Regular paper

RADIOWAVE PROPAGATION FUNDAMENTALS AND ATTENUATION APPROXIMATION

Miloš DŽAJIĆ[1], Mićo GAĆANOVIĆ[2]

Abstract: The theory about radio wave propagation (reflection and diffraction) is described in the first part. The second part considers the use of that theory in mobile communications.

Keywords: Reflection, Diffraction, Attenuation, Approximation model

INTRODUCTION

There are two propagation phenomena:

- Reflection
- Diffraction

General Complex Reflection coefficients [3]

Figure 1 shows the incident, reflected and refracted rays, with the *E* phasors pointing out of the paper and the *H* vector parallel to the paper as required for the direction of power transmission *S* for each ray.

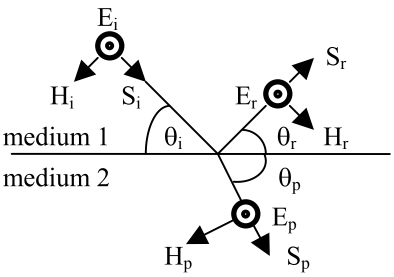

Fig.1 - *Vector relationship in reflection and refraction* [3]

From the continuity of tangential electric fields:

$$E_i + E_r = E_p \qquad (1)$$

From the continuity of tangential magnetic fields and noting that that $\theta_i = \theta_r$:

$$(E_i - E_r)\sin\theta_i / Z_1 = E_p \sin\theta_p / Z_2 \qquad (2)$$

where Z_1 and Z_2 are the impedances of medium 1 and 2 respectively.

Assuming that $\mu_1=\mu_2$, combining (1) and (2) to eliminate E_p and using Snell's law $\frac{\cos\theta_1}{\cos\theta_2} = \sqrt{\frac{\varepsilon_{r2}}{\varepsilon_{r1}}}$ to write θ_p in terms of θ_i:

$$\frac{E_r}{E_i} = \frac{\varepsilon_{r1}\sin\theta_i - \sqrt{\varepsilon_{r2} - \varepsilon_{r1}\cos^2\theta}}{\varepsilon_{r1}\sin\theta_i + \sqrt{\varepsilon_{r2} - \varepsilon_{r1}\cos^2\theta}} \qquad (3)$$

Medium 1 is air or vacuum (ε_{r1}=1) and ε_{r2} can be replaced by complex equivalent $(\varepsilon_{r2}-j\sigma_2/\omega)/\varepsilon_0$. According to that the complex reflection coefficient for perpendicular incidence on a surface is therefore given by:

$$\rho_{perp} = \frac{\sin\theta - \sqrt{(\varepsilon_r - j\chi) - \cos^2\theta}}{\sin\theta + \sqrt{(\varepsilon_r - j\chi) - \cos^2\theta}} \qquad (4)$$

where: $\chi = \frac{\sigma_2}{\omega\varepsilon_0} = \frac{\sigma_2}{2\pi f}\cdot\frac{1}{8.854\cdot 10^{12}} = 18\cdot 10^9\,\frac{\sigma_2}{f}$.

Rezoning similar to that in equation (1) and (5) the complex reflection coefficient for parallel polarisation is given by:

$$\rho_{para} = \frac{(\varepsilon_r - j\chi)\sin\theta - \sqrt{(\varepsilon_r - j\chi) - \cos^2\theta}}{(\varepsilon_r - j\chi)\sin\theta + \sqrt{(\varepsilon_r - j\chi) - \cos^2\theta}} \qquad (5)$$

where:

θ = incidence angle measured between the ray and surface

ε_r = relative permittivity of the reflecting material

σ = the conductivity of the reflecting material in Sm^{-1}

f = frequency in Hz

Figure 2 illustrates the general behaviour of these coefficients for electrical properties typical of good (σ=0.03 Sm^{-1}, ε_r=40) and poor (σ=0.0001 Sm^{-1}, ε_r=3) ground conductivity at 1900 MHz.

For perpendicular polarisation the amplitude of the reflection coefficient falls from unity at grazing incidence to a lower value at normal incidence, depending on frequency and the electrical properties of the ground. The phase angle is always 180°, that is, a phase reversal on reflection.

For parallel polarisation the behaviour of the reflection coefficient is more complicated. At grazing and normal incidence the amplitude is the same as that for perpendicular. This is necessarily so at normal incidence since both polarisations represents the same geometry.

Between the extremes of grazing and normal incidence, however, parallel polarisation falls to a reflection minimum at what is termed the pseudo-Brewster angle. For smaller incidence angles the phase change to parallel polarisation is 180°, as for perpendicular, but above the pseudo-Brewster angle it switches to zero and remains at this value up to normal incidence.

The opposite phase angle between perpendicular and parallel polarisation at normal incidence arises from the

[1] University of Banja Luka, Faculty of Electrical Eng., Patre 5, 78000 Banja Luka, Bosnia and Herzegovina, E-mail: milos.dzajic@gmail.com
[2] University of Banja Luka, Faculty of Electrical Eng., Patre 5, 78000 Banja Luka, Bosnia and Herzegovina, E-mail: bilchy@blic.net

convention used to define polarisation; the geometry of the rays and surface are the same in both cases.

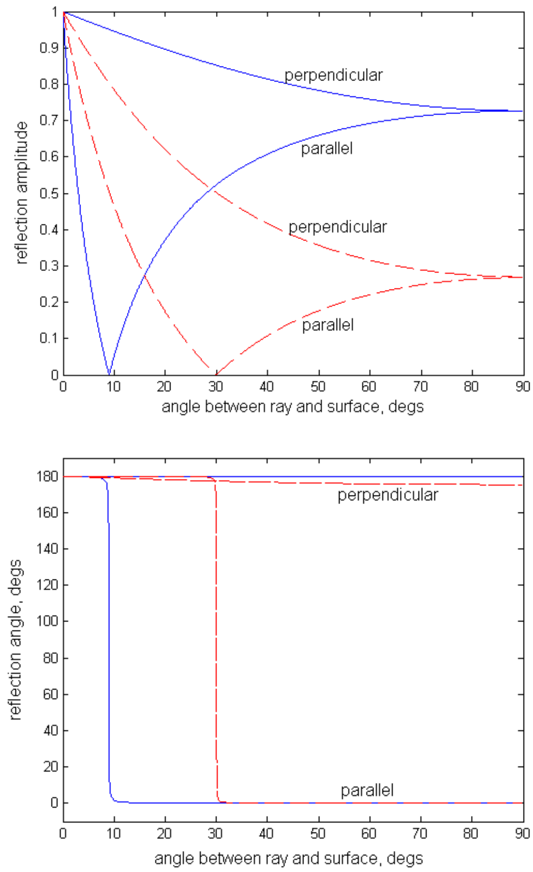

Fig.2 - *Reflection coefficient amplitude and phase at 1900 MHz for: well conducting ground (solid blue curves) and poorly conducting ground (red dashed curves).* [3]

Diffraction by a single knife edge [2]

Figure 3 represents the diffraction by a single knife edge. Let d be distance between the transmitter and receiver, d_1 and d_2 be the respective distances from the edge to the transmitter and the receiver, h is the algebraic height of the edge above the straight line joining the transmitter to the receiver, α be the incidence angle and θ be the diffraction angle.

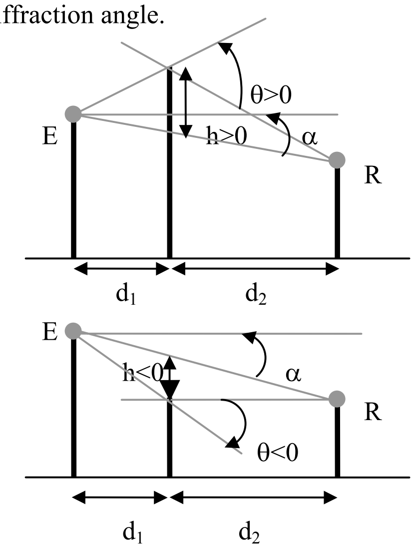

Fig.3 - *Diffraction by a single knife edge* [2]

Let us now introduce a parameter ν defined by the following equation:

$$\nu = h\cos\alpha\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} = \theta\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} \qquad (6)$$

where θ is as defined by the equation:

$$\theta = h\frac{d_1+d_2}{d_1 d_2} \qquad (7)$$

The field strength at the reception point is given by the following equation:

$$\left|\frac{E}{E_0}\right| = \left|\frac{1}{1+j}\int_{\nu}^{\infty} e^{j\pi\frac{t^2}{2}}dt\right| = \frac{\sqrt{2}}{2}\left[\left(\frac{1}{2}-\xi(\nu)\right)^2+\left(\frac{1}{2}-\eta(\nu)\right)^2\right] \qquad (8)$$

where E_0 is the field strength that would exist at the same distance in the free space, i.e in the absence of the edge, while $\xi(\nu)$ and $\eta(\nu)$ are defined by the Fresnel integrals:

$$\xi(\nu) = \int_0^{\nu}\cos\frac{\pi t^2}{2}dt$$
$$\eta(\nu) = \int_0^{\nu}\sin\frac{\pi t^2}{2}dt \qquad (9)$$

where η is the dimensionless parameter of the Fresnel-Kirchhoff diffraction formula, which expresses the obstruction by the obstacle of the direct path between the transmitter and receiver.

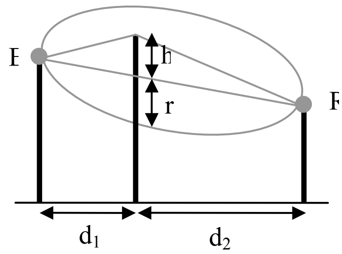

Fig.4 – *Radius of the Fresnel ellipsoid* [2]

In practise it is more common to use parameters of Fresnel ellipsoid shown in figure 4:

$$\frac{h}{r} = \frac{\nu}{\sqrt{2}} = h\sqrt{\frac{(d_1+d_2)}{\lambda d_1 d_2}} \qquad (10)$$

RADIO PROPAGATION APPROXIMATION MODEL

Small cell model [2]

Situation in urban environment is shown in figure 5:

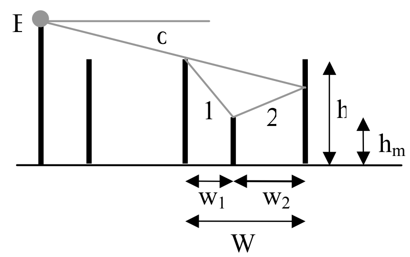

Fig.5 – *Representation of a profile between the emitter and receiver* [2]

The resulting total losses (L) are decomposed into four main terms:

$$L = L_0 + L_{msd} + L_{rts} + L_{\deg} \quad (11)$$

Losses associated with the Distance between the Transmitter and the Receiver (*L_0*)

A_0 is the attenuation due to free-space propagation between two antennas separated by a distance d:

$$A_0 = \left(\frac{\lambda}{4\pi d}\right)^2 \quad (12)$$

Hence,

$$L_0 = -10\log(A_0) \quad (13)$$

Losses due to Multiple edge diffraction

According to France Telecom R&D Model **t**he following equation is used:

$$Q = \left[\frac{\alpha}{0.03}\left(\frac{b}{\lambda}\right)^{1/2}\right]^{0.9} \quad (14)$$

$$L_{msd} = -20\log Q \quad (15)$$

Losses due to the Last Diffraction and Reflection at Buildings and behind the Mobile (L_{rts})

At the level of the mobile, the field can be seen as resulting from the superposition of the wave diffracted by the last building before the mobile (path 1) and the wave reflected by the building after the mobile (path 2). All other paths can be neglected. Let E_1 be the field associated with path 2. The resulting Field E is thus expressed by the following equation:

$$E = \sqrt{E_1^2 + E_2^2} \quad (16)$$

We are thus presented with the two following equations expressing E_1 and E_2 respectively in the form of functions of the free space attenuation E_0:

$$E_1 = \left(\frac{0.225}{\sqrt{2}}\right) E_0 \frac{\sqrt{\lambda w_1}}{\Delta Hm}$$
$$E_1 = \left(\frac{0.225}{\sqrt{2}}\right) E_0 \frac{\sqrt{\lambda(2W - w_1)}}{L_r \Delta Hm} \quad (17)$$

Where ΔHm is the difference between the height of the mobile and the height of the last building, while the parameter L_r represents the inverse of the reflection coefficient for path 2. Assuming that $L_r = 2$ the total value of the field strength as well as the value, expressed in dB, of the losses L_{rts} can be deducted from these two equations:

$$E_1 = \left(\frac{0.225}{\sqrt{2}}\right) E_0 \frac{\sqrt{\lambda\left(w_1 + \frac{2W - w_1}{L_r^2}\right)}}{\Delta Hm} \quad (18)$$

and

$$L_{rst} = -20\log\left(\frac{E}{E_0}\right) \quad (19)$$

Losses due to the Diffraction by a main edge ($L_{\deg}$)

In case of a single edge represented in equation (10), figure 3 and 4, the attenuation due to diffraction is:

$$L_{\deg} = 0 \quad \text{if} \quad \frac{h}{r} < -0.5 \quad (20)$$

$$L_{\deg} = 6 + \frac{12h}{r} \quad \text{if } -0.5 < \frac{h}{r} \le 0.5 \quad (21)$$

$$L_{\deg} = 8 + \frac{8h}{r} \quad \text{if } 0.5 < \frac{h}{r} \le 1 \quad (22)$$

$$L_{\deg} = 16 + 20\log\left(\frac{h}{r}\right) \quad \text{if } \frac{h}{r} > 1 \quad (23)$$

The parameters extracted from this profile are either geometrical variables, like the average with of the streets, the with of the street where the mobile is located, the everage hight of the buildings or the orientation of the street where the mobile is located, or qualitative variables characterizing the environment, for instance.

CONCLUSION

In most cases, the problems that have been solved in practise have geometries much more complicated than those leading to rigorous analytical solutions. Approximate solutions and models must then be used, because they require less numerical calculations.

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Miloš B. Džajić was born in 1981. He is a postgraduate student at the Faculty of Electrical Engineering, University of Banja Luka.

During summer 2005 he worked on his diploma thesis at the Technical University Ilmenau, Germany, where he was studying problems of the theory about electromagnetic waves propagation, phenomena which appears during the propagation and the use of that theory for cell size calculations in mobile communications.

Dr. Mićo Gaćanović was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production.

He received many prestigious world-known awards and certificates for his creative work. Hence, he is included in the work of world groups of creativity, research and new technology in Brussels, Moscow, Pittsburgh and other world cities. He is also involved in research projects from the field of theoretical electrical engineering in Germany, Belgium and Russia.