Development of a Radio Propagation Model for an Open Cut Mine

J.J. Aitken
J.J. Aitken & Partners Pty Ltd, Hornsby NSW

A propagation model developed to analyse mobile radio in an open cut mine is described. The model is based on the Geometrical Theory of Diffraction with extensions for dielectric surfaces.

Introduction

In most propagation modelling problems the terrain can be represented with a reasonable degree of accuracy by some combination of three shapes. The shape most commonly used is the simple knife edge which gives surprisingly good estimates when applied to isolated obstacles.

The other shapes generally used are the cylinder for mountains and rolling hills, and the sphere for certain undulating terrain and plains.

The terrain of an open cut mine is, however, quite different from a natural surface. Instead of clear peaks and rolling hills the sides of the mine are cut into benches, giving jagged discontinuities.

Figure 1 Representative terrain types

The mountainous path of Figure 1(a) is an example of a path with an isolated "knife-edge" obstacle. Solutions for this situation are based on the Fresnel-Kirchoff diffraction theory and may be determined using the methods explained in many texts. (E.g., Hall [1]) Tree cover on the top of the mountain will usually improve the diffracting edge, giving path losses typically within 3dB of predictions [2].

The rolling hills of Figure 1(b) are somewhat more difficult to handle. They will normally be treated as a series of cylinders but care must be taken when determining the radius of the cylinders. If the radius is large, the losses may be over-estimated as it may be more appropriate to treat the path as part of a sphere of radius equal to that of the earth. An allowance for the effective roughness of the sphere is then added to the calculated loss.

The work of Wait and Conda [3] treats diffraction by cylinders particularly well, with a detailed analytical solution which is taken up for practical application to irregular terrain by Dougherty and Maloney [4].

The stepped shape of Figure 1(c) is more difficult to solve. The commonly used methods fail and it is necessary to treat the surface as a series of cliffs or wedges. A solution for this case is discussed in this paper.

Diffraction by a Wedge

Several approaches have been taken to the solution of the problem of diffraction by a wedge or cliff. Hufford developed an integral approach to the problem which allows an analytical solution for each terrain type. This method has been used to determine radiated space wave patterns as a function of the launch elevation angle and for determining the optimum positioning of an HF coastal antenna on a sloping beach [5]. It has the drawback however of requiring large amounts of computer time for each analysis point and becomes impractical for a path with many edges.

Furutsu [6,7] proposed a generalised series residue formulation for propagation over irregular and inhomogeneous terrain. The method is capable of taking cliffs and bluffs into account but the amount of calculation involved is large and becomes unwieldy. Vogler [8] has recently published an algorithm based on Furutsu's work, but with the simplification from generalised terrain to multiple knife eges.

The most practical and elegant approach to the solution of diffraction over a wedge is the Geometrical Theory of Diffraction (GTD). This theory was proposed by Keller [9] as an extension of the classical geometric optics and introduces diffracted rays in addition to the usual rays of geometric optics. These rays are produced by rays incident upon edges, corners or vertices of boundary surfaces or grazing surfaces.

The GTD proposed by Keller has a difficulty in that the predicted field produced by a wave incident on an edge is discontinuous near the shadow and reflection boundaries. This is corrected by an extension of the GTD by James and Poulton [10] and subsequently Kouyoumjian and Pathak [11] giving a uniform geometrical theory of diffraction (UTD). The UTD introduces diffraction coefficients based on Fresnel integrals which ensure that the total field is continuous at shadow and reflection boundaries.

The analysis of wedge diffraction for this study has been based on a text by G.L. James, "Geometrical Theory of Diffraction for Electromagnetic Waves" [12]. The reader is referred to this text for a development and explanation of the theory.

A typical wedge diffraction configuration is shown in Figure 2.

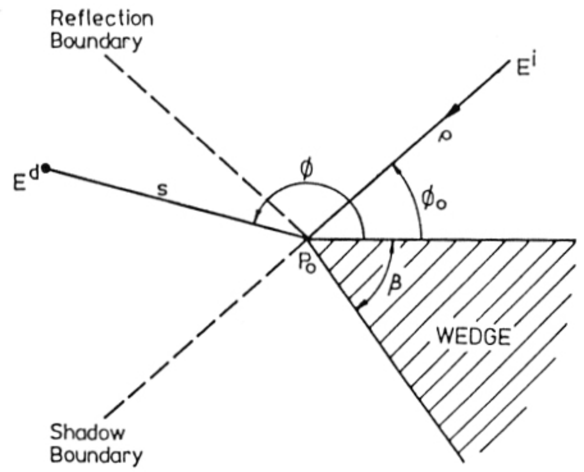

Figure 2 **Wedge Configuration**

Spherical Wave

In mobile radio systems the field will originate from an antenna which behaves as a point source. The wavefront will therefore be spherical, with radius equal to the distance from the source (when in the far field of the antenna).

When a spherical wave is incident on a perfectly conducting edge, as shown in Figure 2, the incident field at P_o is

$$E^i(P_o) = (1/\rho)\exp(-jk\rho) \tag{1}$$

The resultant diffracted field may be written about the edge point P_o as

$$E^d(s^d) = D\,E^i(P_o)\,[\rho/(s(\rho+s))]^{\frac{1}{2}}\exp(-jks) \tag{2}$$

The term in square brackets in equation (2) is a sealing term for distance, while the exponential term represents the phase of the diffracted field.

The diffraction coefficient D is defined here for Electric (e) polarisation and for Magnetic (m) polarisation as

$$D^{e,m} = \{h(\Phi^i)_{n=0} + h(-\Phi^i)_{n=0}\} \mp \{h(\Phi^r)_{n=-1} + h(-\Phi^r)_{n=0}\} \tag{3}$$

The diffraction term $h(\Phi^{i,r})$ is a modified Fresnel integral evaluated for

$$\Phi^{i,r} = \varphi \pm \varphi_o \tag{4}$$

Included in the function $h(\Phi^{i,r})$ are terms which give a smooth transition through the shadow and reflection boundaries where

$$|\Phi^{i,r} + 2n\pi N| = \pi \tag{5}$$

N is defined as

$$N = (2\pi - \beta)/\pi \tag{6}$$

Impedance Wedge

The solution described above is strictly applicable only to a perfect conductor, although it holds for slightly lossy materials. The author is not aware of an analytical solution for the general case of a dielectric wedge. (A method for calculating the diffraction by solving a dual series equation solution for a dielectric wedge of arbitrary angle has been published [13].)

Maliuzhinets [14] has provided a solution for the less difficult case of a wedge with given face impedances, deriving functions which incorporate the Brewster angles of the faces. This work has been extended by James [15] by the application of UTD to give uniform diffraction coefficients for an impedance wedge.

In view of the difficulty of solving the functions of [14] for arbitrary angles, we have followed the approach of [15] and assumed a wedge angle of 90 degrees. This is not an unreasonable approximation in an open cut mine where the bench faces are steep and in many cases are 90 degrees for a depth of one wavelength.

The configuration for this case is illustrated in Figure 3.

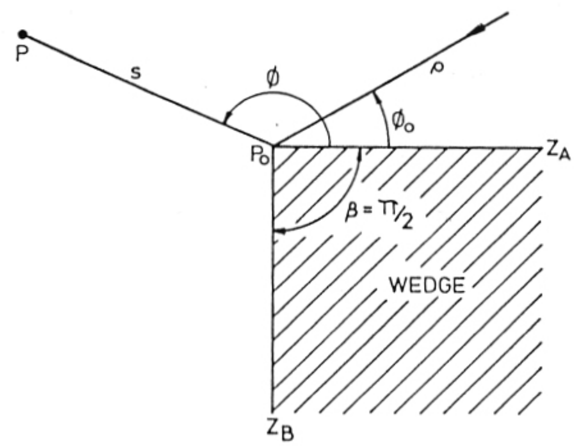

Figure 3 **Diffraction at right angled impedance wedge**

For a spherical wave normally incident on a wedge with faces which have impedances Z_A and Z_B, we have from [15] the diffraction coefficient.

$$D^{e,m} = [\Omega^{e,m}(\varphi_o)]^{-1}\{\Omega^{e,m}(\varphi+\pi)[h(\Phi^i)_{n=0} - h(\Phi^r)_{n=-1}] + \Omega^{e,m}(\varphi-\pi)[h(-\Phi^i)_{n=0} - h(-\Phi^r)_{n=0}]\} \tag{7}$$

which can be seen to be similar in form to equation (3). The function $\Omega^{e,m}(x)$ is defined in [14] as

$$\Omega^{e,m}(x) = \omega(x+\pi/2 - \Psi_b^{e,m})\,\omega(x-\pi/2 + \Psi_b^{e,m}) \times \omega(x-N\pi-\pi/2 + \Psi_a^{e,m})\,\omega(x-N\pi+\pi/2 - \Psi_a^{e,m}) \tag{8}$$

where

$$\omega(x) = \frac{\cos((x-\pi)/6)\,\cos((x+\pi)/6)}{\cos^2(\pi/6)\,\cos(x/6)} \tag{9}$$

for $\beta = 90^o$.

The complex Brewster angles for the wedge faces are given in terms of the surface impedances as

$$\Psi^{e}_{A,B} = \sin^{-1} (Z_o/Z_{A,B})$$

$$\Psi^{m}_{A,B} = \sin^{-1} (Z_{A,B}/Z_o) \qquad (10)$$

The quantity Z_o is the impedance of the medium surrounding the wedge.

Model Implementation

The theory of the preceding sections has been used as the basis of a computer model which determines field strengths within an open cut mine.

The model calculates the field strength at any location by determining for that location the: direct field, reflected fields, singly diffracted fields and multiply diffracted fields and then summing the field contributions.

Extensive field measurements were conducted at VHF and UHF at the Mt Newman open cut iron ore mine to test the validity of this propagation model. The tests were made along specific radials and at random points spread throughout the mine to determine the sensivity of the model to terrain variations. The accuracy of the model was found to be within the accuracy of the field strength measurements, giving predictions generally within ±6 dB of the measured values.

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