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Analysis of amplitude and slope diffraction coefficients

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Abstract: The diffraction mechanism is used for field prediction in both light and shadowed regions. Slope and amplitude diffraction coefficients are vital to predict the field strength at the receiver accurately. In this paper, amplitude and slope diffraction coefficients for one of the ray theoretical models, the slope uniform theory of diffraction with convex hull (S-UTD-CH) model, are analyzed. Moreover, diffraction coefficients are given for knife-edge and wedge structures.

Key words: Amplitude diffraction coefficient, slope diffraction coefficient, diffraction mechanism, S-UTD-CH model, slope diffraction, field prediction

1. Introduction

Ray theoretical models are used to predict the field strength at the receiver accurately. Like a direct ray, reflected and diffracted rays are also important to predict the field strength at the receiver accurately. The diffraction mechanism runs not only in light regions, but also in shadowed regions. To calculate the diffracted field, amplitude and slope diffraction coefficients have to be calculated. These diffraction coefficients are directly proportional to the diffracted fields. The diffraction mechanism has maximal effect when the angle between incoming and diffracted rays is 180°. In this paper, one of the ray theoretical models, the slope uniform theory of diffraction with convex hull (S-UTD-CH) model [1,2], is reviewed. Amplitude and slope diffraction coefficients for knife-edge and wedge structures are given. Analysis of the amplitude and slope diffraction coefficients and derivatives of these coefficients is done. Simulation results showing how the diffracting angle changes the diffraction coefficients are given.

2. S-UTD-CH model

According to the UTD formulation in [3], the received field behind an obstacle is given by

$$E = \left[E_i D + \frac{\partial E_i}{\partial n} d_s \right] A\left(s\right) e^{-jks}, \tag{1}$$

where E_i is the incident field, k is the wave number, and D and d_s are amplitude and slope diffraction coefficients and changes with the structure of the obstacle, respectively. Obstacle types can be knife-edge or wedge. A is the spreading factor, n is normal, and s is the distance that the wave travelled.

The amplitude diffraction coefficients in Eq. (1) are given in [4] (for wedge) and [5] (for knife-edge) by

$$D_s = R_{os} R_{ns} D_1 + D_2 + R_{os} D_3 + R_{ns} D_4, \tag{2a}$$

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$$D_h = R_{oh} R_{nh} D_1 + D_2 + R_{oh} D_3 + R_{nh} D_4, \tag{2b}$$

$$D(\alpha) = -\frac{e^{-j\pi/4}}{2\sqrt{2\pi k \cos(\alpha/2)}} F[x], \tag{2c}$$

where R is the reflection coefficient of the imperfectly conducting wedge. The subscripts s and h stand for soft and hard polarization, respectively. The subscripts *0* and n represent zero and n faces of the wedge, as shown in Figure 1.

The formula in Eq. (2c) is used for the knife-edge type of obstacle. $F[x]$ is the transition function and α is the diffracting angle as shown in Figure 2.

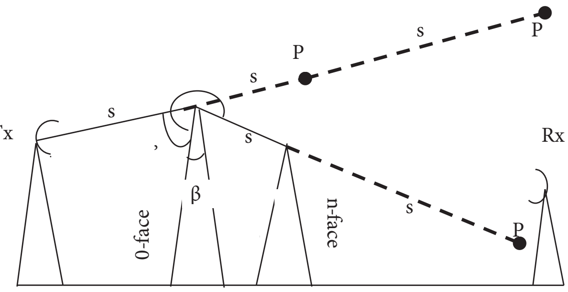

Figure 1. Ray geometry of multiple diffraction for the wedge.

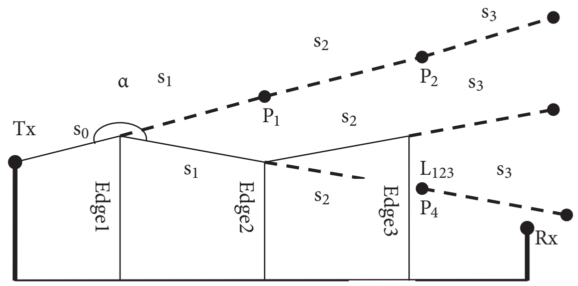

Figure 2. Ray geometry of multiple diffraction for the knife-edge obstacle.

The slope diffraction coefficient for the wedge case is given in [5] (for knife-edge) and in [6] for (wedge) by

$$d_s(\alpha) = -\frac{e^{-j\pi/4}}{\sqrt{2\pi k}} L_s \sin(\alpha/2)\left(1 - F(x)\right)), \tag{3a}$$

$$ds_s = \frac{\partial R_{0s}}{\partial \varphi'} R_{ns} D_1 + R_{os} R_{ns} \frac{\partial D_1}{\partial \varphi'} + \frac{\partial D_2}{\partial \varphi'} + \frac{\partial R_{0s}}{\partial \varphi'} D_3 + R_{os} \frac{\partial D_3}{\partial \varphi'} + R_{ns} \frac{\partial D_4}{\partial \varphi'}, \tag{3b}$$

$$ds_h = \frac{\partial R_{0h}}{\partial \varphi'} R_{nh} D_1 + R_{oh} R_{nh} \frac{\partial D_1}{\partial \varphi'} + \frac{\partial D_2}{\partial \varphi'} + \frac{\partial R_{0h}}{\partial \varphi'} D_3 + R_{0h} \frac{\partial D_3}{\partial \varphi'} + R_{nh} \frac{\partial D_4}{\partial \varphi'}, \tag{3c}$$

where ds_s and ds_h are the slope diffraction coefficients for soft and hard polarizations, respectively.

If there are 2 or more obstacles in the scenario, the derivative of the slope diffraction coefficient is required to calculate the field strength at the receiver. The derivatives of the slope diffraction coefficient for knife-edge and wedge types are given in [1,2].

In the field strength prediction, not only diffracted fields but also reflected fields from the wedge faces have to be taken into account. To calculate the reflected field, the reflection coefficients for *0* and n faces for soft and hard polarizations are given in [7].

3. Analysis of diffraction coefficient

The S-UTD model has the most contribution to UTD in the transition region. If the obstacle in the scenario is in the transition region of the previous obstacle, UTD fails to predict the relative path loss accurately. If the obstacles' heights are close to each other, the diffracting angle goes to 180°. In this case, the amplitude and slope diffraction contribution is maximal. Relative path loss at the receiver is directly proportional to the amplitude and slope diffraction coefficient, as can be seen Eq. (1). If the obstacles' heights are very different from each other, the diffraction contribution goes to zero. For given parameters, the way in which the diffracting angle affects the amplitude diffraction coefficient is shown in Figure 3. Operational frequency is 100 MHz, the distance parameter for the amplitude diffraction coefficient is 2500, and the diffracting angle changes between $\pi/2$ and $3\pi/2$.

As can be seen from Figure 3, the diffraction mechanism has the most effect in the condition that the diffraction angle is π. It can also be concluded here that if the source, diffracting, and observation points are in the same line, the diffraction contribution is maximal. Moreover, when the diffracting angle is far from the plane angle, the diffraction contribution can be ignored.

There are 3 cases for slope diffraction. The first is the contribution of the derivative of the amplitude diffraction coefficient. The second is the contribution of the slope diffraction coefficient, and the third is the contribution of the derivative of the slope diffraction coefficient.

First, to see the contribution of the slope diffracted field, the derivative of the amplitude diffraction coefficient can be observed. The contribution of the derivative of the amplitude diffraction coefficient is given in Figure 4. Operational frequency is 100 MHz, the distance parameter for the amplitude diffraction coefficient is 2500, and the diffracting angle changes between $\pi/2$ and $3\pi/2$. The distance between the obstacles is 1000 m.

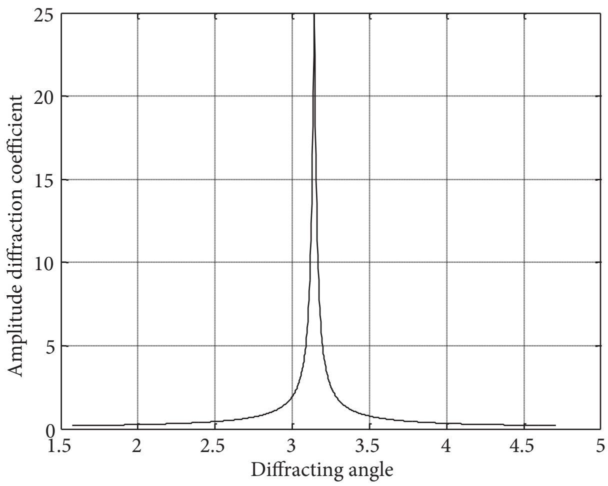

Figure 3. Amplitude diffraction coefficient analysis.

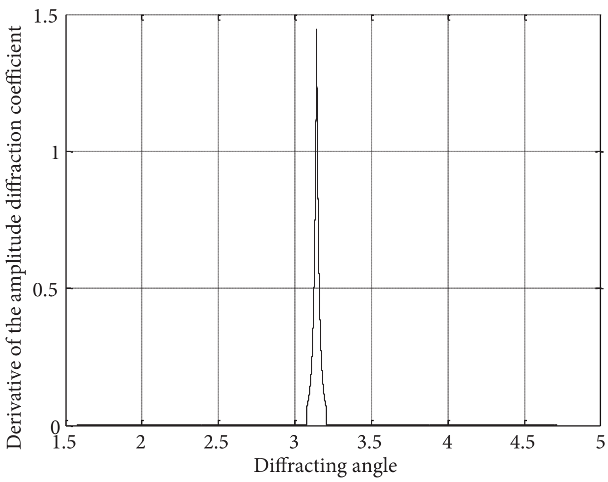

Figure 4. Derivative of amplitude diffraction coefficient analysis.

As illustrated in Figure 4, the diffraction effect is maximal in the condition of plane angle diffraction. In this figure, the transmitting, diffracting, and observation points are at the same height.

Second, to see the contribution of the slope diffracted field, the slope diffraction coefficient can be analyzed. The way in which the slope diffraction coefficient changes with respect to the diffracting angle is shown in Figure 5. Operational frequency is 100 MHz, the distance parameter for the slope diffraction coefficient is 2500, and the diffracting angle changes between $\pi/2$ and $3\pi/2$.

As can be seen from Figure 5, the diffraction mechanism has the most effect in the condition of plane angle diffraction. It can be concluded that when the diffracting angle is far from the plane angle, the slope diffraction contribution can be ignored.

Third, to see the contribution of the slope diffracted field, the derivative of the slope diffraction coefficient can be observed. The way in which the derivative of the slope diffraction coefficient changes with respect to the diffracting angle is shown in Figure 6. Operational frequency is 1000 MHz, the distance parameter for the slope diffraction coefficient is 2500, and the diffracting angle changes between $\pi/2$ and $3\pi/2$. The distance between the obstacles is 1000 m.

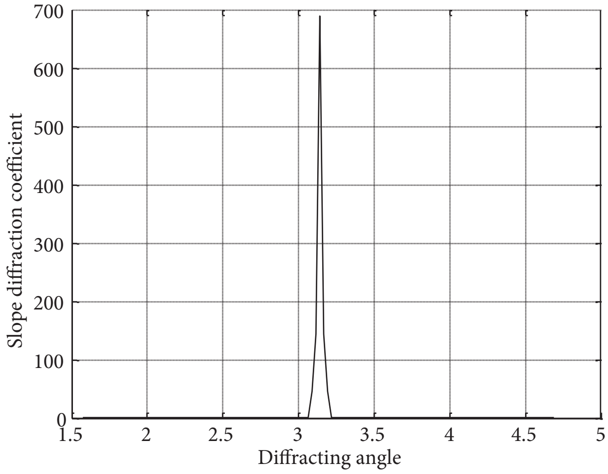

Figure 5. Slope diffraction coefficient analysis.

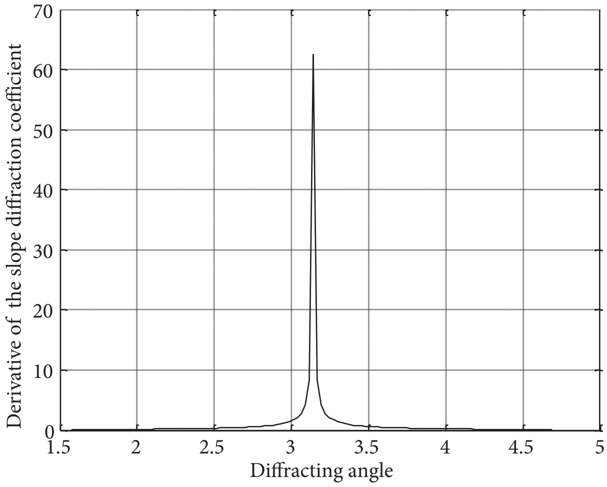

Figure 6. Derivative of slope diffraction coefficient analysis.

As illustrated in Figure 6, the diffraction effect is maximal in the condition of plane angle diffraction. In this figure, the transmitting, diffracting, and observation points are at the same height.

The diffraction mechanism has made most contribution in the case of plane angle diffraction. To prove this, the following test scenario is analyzed. Transmitter height is 0 m; operational frequency is 1800 MHz. There is a knife-edge, whose height is 50 m, 1000 m away from the transmitter. There is a receiver at a distance of 2000 m from the transmitter. There are 4 cases of receiver and, for each case, a simulation is made and the following results are obtained. For receiver heights of 0, 50, 100, and 150 m, the relative path loss obtained is –30.7 dB, –24.7 dB, –6.02 dB, and –0.27 dB, respectively. For the case of a receiver height of 0 m, there is only diffracted wave and a diffraction angle far from 180°. For the case of a receiver height of 50 m, there is only diffracted wave and a diffraction angle close to 180°. For the case of a receiver height of 100 m, there is only diffracted wave and the diffraction angle is 180°. For the case of a receiver height of 150 m, there are direct and diffracted waves and a diffraction angle far from 180°. In the fourth case, the direct wave is dominant, and for that reason, the diffraction mechanism can be ignored. However, in the case of no direct wave, the diffraction mechanism is dominant. Moreover, the diffraction mechanism has the most contribution in the case of plane angle diffraction.

4. Conclusion

In this paper, the formulations of the S-UTD-CH model for knife-edge and wedge structures were given. The total field at the receiver can result from direct, reflected, or diffracted fields. Direct fields have dominant effects at the receiver. If there is no direct field to the receiver, diffracted fields can affect the total field at the receiver. The ways in which the diffraction angle affects the amplitude and slope diffraction coefficients and the derivatives of these were discussed in this study. Amplitude and slope diffraction coefficients are directly related to diffracted fields at the receiver. The magnitude of amplitude and slope diffraction coefficients changes with the diffraction angle, operational frequency, and distance parameters. The diffraction angle changes with the heights of the obstacle in the scenario. The diffraction mechanism has the most effect in the condition of plane angle diffraction. Plane angle diffraction results from the equal height of the transmitter, obstacle, and receiver. Moreover, if the transmitter, obstacle, and receiver are in the same line, plane angle diffraction occurs. Furthermore, when the diffracting angle is far from the plane angle, the diffraction contribution can be ignored with respect to the direct field. As the heights of the obstacles in the scenario are close to each other, the diffraction angle goes to 180° or π, and the diffracted field's contribution is maximal.

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