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Wave diffraction by a right-angled interface between resistive half and whole planes

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A B S T R A C T

The interaction phenomenon of electromagnetic plane waves by a right angled interface between whole and half screens with different resistivities is studied. The construction, under examination, is considered in order to model various corner discontinuities between transmissive surfaces for indoor wireless communications. First of all, the initial waves, which occur in the absence of the diffracting edge, are determined. Then the scattered geometrical optics fields are obtained by subtracting the initial waves from the total geometrical optics fields. The diffracted field is constructed directly from the scattered geometrical optics wave by a new method. The resultant field expressions are examined numerically.

1. Introduction

The interaction of electromagnetic waves with the obstacles, on their path of propagation, is an important aspect in the modeling of any radio channel. The propagation of waves in urban area is strictly determined by the locations of the buildings, streets, vehicles, etc. The number of floors, layout of rooms, open or closed doors, corridors and furniture are the main factors that affect the field distribution in indoor propagation. Generally, the path loss is determined experimentally for different propagation scenarios in buildings [1,2]. Martijn and Herben measured the signal strength for four office buildings which are illuminated by a base station antenna at 1800 MHz [3]. A waveguide based model was developed for wave propagation along the corridors of buildings by Yarkoni and Blaunstein [4]. A detailed study on measurement of radio-wave propagation in large buildings was carried out by Young et al. for continuous wave signals [5,6]. A radio channel modeling of indoor propagation was put forth by Gupta and Joshi [7] for a specific building. Han et al. [8] studied on a new indoor propagation model that took into account the angles formed by wave and surfaces of the scatterers. Further studies also are based on obtaining an empirical model by measuring the radio-wave propagation in specific building types [9,10]. An alternative to measurement based empirical modelling of wave propagation in radio channels is the method of ray tracing [11]. This technique is based on the geometrical optics (GO) and geometrical theory of diffraction (GTD) that represent the waves as rays, propagating in energy conserving tubes. The reflection, transmission and refraction processes are defined in the context of GO. GTD extends the GO approach for the diffraction phenomena [12]. Agalet et al. developed a ray-tracing based algorithm for microcellular and indoor environments [13]. They also included the uniform theory of diffraction (UTD) [14] in their algorithm. UTD eliminates the infinite field expressions that occur at the transition boundaries in the GTD formulation of the diffracted waves. A ray-tracing algorithm was proposed by Yang et al. [15] for wave propagation in buildings. However, they did not include the diffraction effects. In improvement for the ray-tracing method was put forth by Remley et al., who included a uniform diffraction field expression for the impedance wedge, which was represented in terms of Fresnel coefficients [16]. A fast three dimensional ray-tracing method was introduced by Ji et al. [17], who used the same UTD diffraction coefficient for an imperfectly conducting wedge. Further examples of ray tracing algorithms can be found in Refs. [18,19].

Although the impedance surfaces are taken into account in the ray tracing algorithms, there is only one study that proposes the usage of resistive boundary conditions in wireless communications. In this paper, Demetrescu et al. [20] suggested the modeling of building corners by resistive wedges. Resistive boundary conditions are defined for a thin dielectric surface on which only the electric currents are supported [21]. The surface resistivity (R_e) is given by the formula $j/[\omega d(\varepsilon - \varepsilon_0)]$ where ω is the angular frequency and d thickness of the dielectric layer. ε and ε_0 are the permittivities of the layer and free space respectively. When an incident wave hits a resistive screen, a portion of it reflects from the surface. The remaining part transmits throughout the layer. The reflection and transmission coefficients of the surface is determined by the angle of incidence and a parameter η, which is defined by the relation $Z_0/2R_e$. Z_0 is the impedance of free space. In ray tracing methods of wireless communications, the resistive boundary

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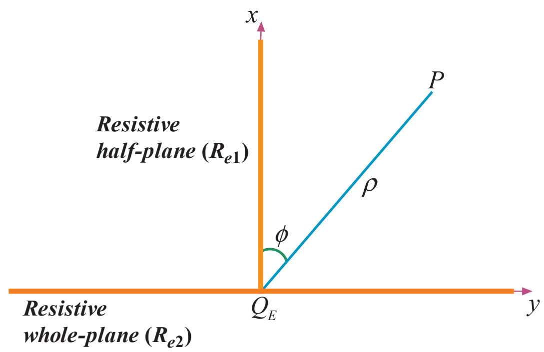

Fig. 1. The geometry of the problem.

conditions are more preferable in modeling the walls, windows or doors than the impedance boundary conditions, since they provide the representation of the transmitted waves besides the reflected fields.

The aim of this paper is to evaluate the diffraction coefficient of a geometry which is formed of a right-angled intersection of resistive half and whole planes. This scenario can model neighboring two rooms or buildings in mobile communications. A plane wave illumination is assumed. First of all, the initial field expressions will be obtained when the part of the geometry that causes diffraction is excluded. The scattered GO waves will be evaluated by subtracting the initial fields from the total GO waves. The diffracted waves will be determined by using a method put forth by the author [22–24]. The uniform expressions of the diffraction waves will be obtained and the total fields will be investigated numerically.

A time factor of $\exp(j\omega t)$ is suppressed throughout the paper.

2. Definition of the problem

The geometry, in Fig. 1, is taken into account. The problem is symmetric according to the coordinate z. The Cartesian and cylindrical coordinates are given by (x, y, z) and (ρ, ϕ, z) respectively. Q_E is the diffraction point. The resistivities of the half and whole planes are given by R_{e1} and R_{e2} respectively. P is the observation point.

The incident wave is given by

$$\overrightarrow{E_i} = \overrightarrow{e_z} E_0 e^{jk\rho\cos(\phi-\phi_0)} \tag{1}$$

for E_0 is the complex amplitude. E represents the electric field. k is the wavenumber and ϕ_0 angle of incidence. The aim is to determine the diffracted wave and total field.

3. The method of solution

The method, introduced in [22–24], will be considered as the solution technique of the problem. First of all, the general definitions, related with the excited waves in the scattering phenomenon, shall be given. The total field is defined by the equation

$$u_T = u_{in} + u_S \tag{3}$$

where u is a component of the electromagnetic field [22–24]. u_{in} is the initial wave, which is composed of only GO waves. This field component can be obtained by removing the scatterer that causes the diffraction process from the geometry of the problem. u_S is the scattered wave and represents the effect of the scattering structure on the initial field. The diffraction field only exists in the scattered wave, since the initial field is composed of the GO wave(s). Thus Eq. (3) can be rewritten as

$$u_{TGO} + u_{Td} = u_{in} + u_{SGO} + u_{Sd} \tag{4}$$

for the subscript d represents "diffracted". Eq. (4) leads to the relations

$$u_{TGO} = u_{in} + u_{SGO} \tag{5}$$

and

$$u_{Td} = u_{Sd}. \tag{6}$$

Eq. (6) shows that the diffraction component of the scattered wave directly gives the total diffracted field. If there are only two transition boundaries in the problem, the high frequency asymptotic expression of the diffracted wave will be given by

$$u_d = \frac{e^{j\frac{\pi}{4}}}{\sqrt{2\pi}} \frac{f(\phi,\alpha,\theta)}{\cos\phi + \cos\alpha} \frac{e^{-jk\rho}}{\sqrt{k\rho}} \tag{7}$$

according to GTD. The parameter θ is equal to $\arcsin(\eta)$. α represents the angle of incidence. f is a function to be determined.

The procedure of finding the function f can be introduced as follows;

(1) determine u_{in} by excluding the diffracting part from the geometry of the problem,
(2) write u_{TGO} from the geometry of the problem,
(3) evaluate u_{SGO} from Eq. (5),
(4) determine the transition boundaries from the discontinuities of u_{SGO},
(5) if there are two transition boundaries, determine f by using the relations

$$f(\pi \mp \alpha,\alpha,\theta) = -\sin\alpha A(u_{SGO}) \tag{8}$$

and

$$K_+(\alpha,\theta)K_+(\pi \mp \alpha,\theta) = \frac{\sin\alpha\sin\theta}{\sin\alpha + \sin\theta} \tag{9}$$

where $A(u_{SGO})$ shows amplitude of the scattered GO field which has a discontinuity at the related transition boundary. K_+ is the split function that occurs in the Wiener-Hopf factorization of the diffraction problem of waves by a resistive half-plane [25]. It can be defined by the equation

$$K_+(\alpha,\theta) = \frac{4\sqrt{\eta}\sin(\alpha/2)}{\left[1 + \sqrt{2}\cos\frac{(\pi/2)-\alpha+\theta}{2}\right]\left[1 + \sqrt{2}\cos\frac{(3\pi/2)-\alpha-\theta}{2}\right]} \times \left\{\frac{\psi_\pi\left(\frac{\pi}{2}-\alpha+\theta\right)\psi_\pi\left(\frac{3\pi}{2}-\alpha-\theta\right)}{\left[\psi_\pi\left(\frac{\pi}{2}\right)\right]^2}\right\}^2 \tag{10}$$

where ψ_π is the Maliuzhinets function [25] and can be expressed as

$$\psi_\pi(x) = \exp\left[-\frac{1}{8\pi}\int_0^x \frac{\pi\sin v - 2\sqrt{2}\pi\sin(v/2) + 2v}{\cos v}dv\right]. \tag{11}$$

4. The solution of the problem

In this section, the diffracted field by the discontinuity at Q_E, in Fig. 1, will be evaluated. The strategy of solution was given in Section 3. The uniform diffraction wave will be obtained by the method of uniform theory of diffraction [14,26].

First of all, the initial fields must be determined according to the procedure, given in Section 3. The diffraction at Q_E occurs because of the existence of half-screen at $\phi = 0$. For this reason, the half-screen must be removed from the geometry in order to obtain the initial waves. Thus only the resistive whole screen remains in the geometry. The initial waves can be written as

$$\overrightarrow{E_{in}} = (\overrightarrow{E_i} + \Gamma_2\overrightarrow{E_{r2}})U(\pi-\phi) + T_2\overrightarrow{E_i}U(\phi-\pi) \tag{12}$$

in this case. $\overrightarrow{E_{r2}}$ is reflected wave from the whole plane and reads

$$\overrightarrow{E_{r2}} = \overrightarrow{e_z} E_0 e^{-jk\rho\cos(\phi+\phi_0)}. \tag{13}$$

Γ_2 and T_2 are the reflection and transmission coefficients of the resistive whole plane, which can be represented by