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Diffraction by material half-planes for grazing incidence

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ABSTRACT

It is shown that the actual solutions of the diffraction problem of waves by material half-planes do not reduce to the correct diffracted field expressions for grazing incidence. The correct expressions are obtained for the diffracted waves by resistive and conductive half-screens. The case for the impedance half-plane directly emerges in terms of the diffracted fields by the previous two semi-screens. The behaviors of the geometric optics and diffraction waves are investigated numerically.

1. Introduction

The exact solution of the diffraction problem of waves by soft (total field is zero on the surface) and hard (normal derivative of the total field is zero on the surface) half-plane was first obtained by Sommerfeld in 1896 [1]. He also gave the expressions of the diffracted waves in the high-frequency approximation [2]. Later this work formed the basis of the geometrical theory of diffraction [3] and its' uniform version [4]. However the solution of Sommerfeld yields interesting field expressions when the angle of incidence is equal to 0°. The amplitude of the diffracted wave doubles for a hard half-plane and becomes zero for a soft half-screen. In literature, this situation was issued by dividing the amplitude of the diffracted field by two in the case of hard half-plane and for a soft half-screen, the non-existence of the diffraction wave is accepted as the correct solution [4–6]. It is important to realize that the actual solution directly leads to zero fields for grazing incidence [7]. In a recent study, we showed that the acceptance of the zero diffraction fields was physically incorrect and proposed an alternative analysis for the problem [8].

The aim of this paper is to extend the new approach to half-screens with different boundary conditions, since the same defect exists also for these problems. The term "material" includes three kinds of surfaces that are non-perfectly conducting [9]. The first one is the impedance surface, which reflects a portion of the incident wave and absorbs the remaining part. Dielectric coated perfectly conducting sheet is an example of this surface. The second kind of material surface satisfies the resistive boundary conditions and reflects some portion of the incident radiation, transmitting the remaining part. The third kind is the conductive surface, which is the electromagnetic dual of a resistive sheet. The diffraction properties of wave by material half-screens were extensively studied by Senior [10,11]. First of all, we will outline the behaviors of the diffracted waves by material half-planes for grazing incidence and investigate the interpretation of this solution in a physical basis. Then new expressions that lead to non-zero diffracted waves will be derived when the angle of incidence is 0°. The uniform representations of the diffracted fields will be obtained and their interactions with the geometric optics (GO) waves will be investigated numerically.

A time factor of $\exp(j\omega t)$ is assumed and suppressed throughout the paper. ω is the angular frequency.

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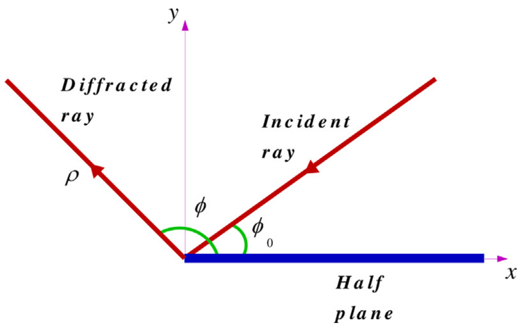

Fig. 1. The diffraction geometry of the material half-screen.

2. Definition of the problem

A material half-screen is located at $x \in [0,\infty)$, $y = 0$ and $z \in (-\infty,\infty)$. It is illuminated by the plane wave

$$u_i = u_0 e^{jk\rho\cos(\phi-\phi_0)} \tag{1}$$

where u_0 is the complex amplitude. The cylindrical coordinates are shown by (ρ,ϕ,z). ϕ_0 is the angle of incidence. The geometry is given in Fig. 1. P is the observation point.

The total field can be expressed by

$$u_T = u_{TGO} + u_d \tag{2}$$

for u_{TGO} and u_d are the total GO and diffracted waves. The total GO field can be introduced as

$$u_{TGO} = u_i U\left(-\xi_-\right) + \Gamma u_r U\left(-\xi_+\right), \tag{3}$$

$$u_{TGO} = u_i U\left(-\xi_-\right) + R_R u_r U\left(-\xi_+\right) + T_R u_i U\left(\xi_-\right) \tag{4}$$

and

$$u_{TGO} = u_i U\left(-\xi_-\right) + R_C u_r U\left(-\xi_+\right) + T_C u_i U\left(\xi_-\right) \tag{5}$$

for impedance, resistive and conductive half-planes respectively [12]. u_r has the expression of

$$u_r = u_0 e^{jk\rho\cos(\phi+\phi_0)} \tag{6}$$

and shows the reflected wave from the surface of the half-plane. The parameter $\xi_\pm$ can be defined by

$$\xi_\pm = -\sqrt{2k\rho}\cos\frac{\phi\pm\phi_0}{2}. \tag{7}$$

$U(x)$ is the unit step function, which is equal to one for $x > 0$ and zero otherwise. Γ, R_R, T_R, R_C and T_C are the reflection and transmission coefficients that can be introduced as

$$\Gamma = \frac{\sin\phi_0 - \sin\theta}{\sin\phi_0 + \sin\theta}, \tag{8}$$

$$R_R = -\frac{\sin\theta}{\sin\phi_0 + \sin\theta}, \tag{9}$$

$$T_R = \frac{\sin\phi_0}{\sin\phi_0 + \sin\theta}, \tag{10}$$

$$R_C = \frac{\sin\phi_0}{\sin\phi_0 + \sin\theta}, \tag{11}$$

and

$$T_C = \frac{\sin\theta}{\sin\phi_0 + \sin\theta} \tag{12}$$

where $\sin\theta$ is equal to Z_0/Z, $Z_0/(2R_e)$ and $2R_m Z_0$ in terms of the surface impedance (Z), surface resistivity (R_e) and surface conductivity (R_m) [12]. Z_0 is the impedance of free space. The diffracted fields can be written as

$$u_d = \frac{e^{-j\frac{\pi}{4}}}{\sqrt{2\pi}} \frac{K_+\left(\phi,\theta\right) K_+\left(\phi_0,\theta\right)}{\cos\phi + \cos\phi_0} \frac{e^{-jk\rho}}{\sqrt{k\rho}}, \tag{13}$$