SCATTERING BY A PLANAR JUNCTION BETWEEN TWO LOSSY SLABS IN RADIOPROPAGATION ENVIRONMENTS

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Abstract
A method is here proposed for predicting the field scattered by a planar junction between two penetrable lossy slabs having different features. The Geometrical Optics response is attained by extending the approach developed by Burnside and Burgener for lossless slabs. The diffraction contribution is evaluated by using a Physical Optics approximation of the equivalent surface currents densities induced by an incident plane wave and by performing a uniform asymptotic evaluation of the resulting radiation integral. Several numerical simulations are presented to demonstrate the validity of the proposed technique.

INTRODUCTION
As well-known, ray tracing is considered as the preferred approach for the coverage prediction of both micro- and picocellular networks. Unlike existing macrocellular prediction tools, those based on ray tracing require a much more detailed description of the urban environment for properly taking into account the reflection, transmission and diffraction properties of building structures. In particular, high frequency wave propagation through building walls is a complex process affected by several parameters such as the electrical properties of the wall material (brick, concrete, block masonry, etc.), the incident angle, and the presence of windows, which can be treated as a sequence of two planar junctions (see [1] for reference). In order to efficiently solve this propagation phenomenon, it is very important to understand the scattering related to the canonical problem of one planar junction between two lossy dielectric slabs. Obviously, a solution for this last problem can be applied also in other radio propagation environments, as the automotive one.

The aim of this work is to propose a solution for the above canonical problem in the case of a linearly polarized plane wave normally incident on the structure (see Fig. 1). It is based on the extension of the Burnside and Burgener’s method [2] to determine the Geometrical Optics (GO) response of the junction, and on the development of the corresponding Uniform Asymptotic Physical Optics (UAPO) solution for predicting the diffraction contribution. Its resulting analytical expression is given in terms of the Uniform Geometrical Theory of Diffraction (UTD) transition function [3] and is easy to handle and to implement as subroutine also in complex computer codes.

Fig. 1: Geometry of the problem
GO FIELD PREDICTION MODEL

A planar junction of two penetrable nonmagnetic lossy slabs having different geometric and electric characteristics is here considered. A linearly polarized plane wave is assumed to be orthogonally incident on the junction from a direction $\phi_0$. Since the scattering problem does not depend on the $z$ coordinate, the resulting two-dimensional problem is considered in the plane $z = 0$ from this point on. The observation point $P$ is identified by the polar coordinates $\rho, \phi$. The space surrounding the junction is divided in four regions by the reflection ($\text{RSB}$, $\phi = \pi - \phi_0$) and transmission ($\text{TSB}$, $\phi = \pi + \phi_0$) shadow boundaries. Accordingly, the GO field $E_{GO} = E_{GO}^\hat{z}$ is so determined:

$$E_{GO} = \begin{cases} E^i + E^{r1} & 0 < \phi < \pi - \phi_0 \\ E^i + E^{r2} & \pi - \phi_0 < \phi < \pi \\ E^{t1} & \pi < \phi < \pi + \phi_0 \\ E^{t2} & \pi + \phi_0 < \phi < 2\pi \end{cases}$$ (1)

where

$$E^i = E_0 \exp\left(jk_0 \rho \cos(\phi - \phi_0)\right)$$ (2)

is the incident field,

$$E^{r1} = R_1 E_0 \exp\left(jk_0 \rho \cos(\phi + \phi_0)\right); \quad E^{r2} = R_2 E_0 \exp\left(jk_0 \rho \cos(\phi + \phi_0)\right)$$ (3)

are the fields reflected by slab 1 and 2, respectively, and

$$E^{t1} = T_1 E_0 \exp\left(jk_0 \rho \cos(\phi - \phi_0)\right); \quad E^{t2} = T_2 E_0 \exp\left(jk_0 \rho \cos(\phi - \phi_0)\right)$$ (4)

are the fields transmitted through slab 1 and 2, respectively. In the above expressions, $k_0$ is the free-space wavenumber, $E_0$ denotes the electric field at the origin, $R_i$ ($R_s$) and $T_i$ ($T_s$) are the reflection and transmission coefficients related to slab 1(2), respectively. An extension of the Burnside and Burgener’s method [2] to lossy slabs is here adopted for evaluating such coefficients. Since each slab is a lossy material, it must be taken into account that the transmitted field in the slab attenuates in the direction perpendicular to the incident face, whereas the phase propagates in a direction depending on the incident angle and the constitutive parameters of the slab [4]. The presence of the other face originates multiple reflection and transmission contributions. Accordingly, it results:

$$R = R_0 \frac{1 - (P_{da}P_{att})^2 P_a}{1 - (P_{da}P_{att})^2 P_a R_0^2}; \quad T = \frac{(1 - R_0^2)P_{da}P_{att}P_t}{1 - (P_{da}P_{att})^2 P_a R_0^2}$$ (5)

wherein the reflection coefficient $R_0$ related to the incident face is:

$$R_0 = \frac{\cos \theta^i - \sqrt{\epsilon_r - \sin^2 \theta^i}}{\cos \theta^i + \sqrt{\epsilon_r - \sin^2 \theta^i}}$$ (6)

It depends on the standard incidence angle $\theta^i$, and the complex permittivity $\epsilon_r$ of the considered slab. Moreover,

$$P_{da}P_{att} = \exp(-j \beta_{eq} l) \exp(-\alpha_{eq} d)$$ (7)
where $\beta_{eq}$ and $\alpha_{eq}$ are the equivalent phase and attenuation factors, respectively, related to the propagation through the slab [4], and $l = d \cos \theta^t$, $d$ being the thickness of the considered slab and $\theta^t$ being the angle between the propagation and attenuation directions. In addition,

$$P_a = \exp\left(j2k_o l \sin \theta^t \sin \theta^t\right); \quad P_t = \exp\left(-j k_o l \cos(\theta^t - \theta^t)\right)$$

in which $P_a$ represents the phase delay factor associated with the shift in the exit location after a double internal reflection, and $P_t$ is a phase factor to refer the transmitted field phase to the front face of the slab.

**UAPO Diffracted Field**

UAPO solutions have been recently developed for efficiently solving many diffraction problems. They have been obtained by using a PO approximation of the equivalent surface current densities induced by an incident field on the illuminated faces of the structure and by accomplishing a uniform asymptotic evaluation of the corresponding radiation integral. Every time such solutions have been applied, they are resulted to be simple to implement in an efficient computer code and accurate when compared with numerical and measured data available in literature.

For the considered canonical problem, the field diffracted by the planar junction is evaluated by summing the diffraction contributions (see [5] as reference for the method of evaluation) due to the edges of the slabs 1 and 2, thus obtaining:

$$E^d = \left(E^d_1 + E^d_2\right) z$$

$$E^d_1 = E_0 \left[\left(1 - T_1 - R_1\right) \sin \phi_0 - \left(1 - T_1 + R_1\right) \sin \phi\right] \cdot F_1 \left(2k_o \rho \cos^2 \left(\left(\phi \pm \phi_0\right)/2\right)\right) \exp\left(-j \left(\pi/4 + k_o \rho\right)\right) \left(2\sqrt{2\pi k_o \rho} \left(\cos \phi + \cos \phi_0\right)\right)$$

$$E^d_2 = E_0 \left[\left(1 - T_2 - R_2\right) \sin \left(\pi - \phi_0\right) - \left(1 - T_2 + R_2\right) \sin \left(\pi - \phi\right)\right] \cdot F_1 \left(2k_o \rho \cos^2 \left(\left(\pi - \phi \mp (\pi - \phi_0)\right)/2\right)\right) \cdot \exp\left(-j \left(\pi/4 + k_o \rho\right)\right) \left(2\sqrt{2\pi k_o \rho} \left(\cos \left(\pi - \phi\right) + \cos \left(\pi - \phi_0\right)\right)\right)$$

where $+ (-)$ sign applies if $0 < \phi < \pi$ ($\pi < \phi < 2\pi$).

**Numerical Examples**

The reported results refer to a junction formed by brick wall (slab 1 with $d = 0.3$ m and $\varepsilon_r = 4 - j0.23$) and glass (slab 2 with $d = 0.01$ m and $\varepsilon_r = 5 - j10^{-11}$). In all the reported figures, the field is computed on the circular path having the radius equal to five times the wavelength at $f = 1800$ MHz. Figure 2 refers to $\phi_0 = \pi/3$. In particular, the GO response and the UAPO diffracted field are independently plotted in Fig. 2a). As can be seen, the diffraction term amplitude presents peaks in correspondence of the GO field discontinuities and this, as expected, allows one to compensate such discontinuities, as shown in Fig. 2b). Therefore, the total field amplitude is continuous throughout, including across the transmission and reflection shadow boundaries. Same considerations can be made about the results in Fig. 3, which are relevant to $\phi_0 = 5\pi/6$. 

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REFERENCES


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This work was supported in part by MIUR COFIN 2005099984_002 (PRIN-2005)