

RCS ANALYSIS OF PEC HALF PLANE BURIED IN LOSSY MEDIUM

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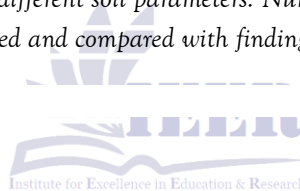
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Corresponding Author: ***Saeed Ahmed****Abstract**

This article examines the scattering width of a Perfect Electric Conductor (PEC) half-plane situated within various soil layers. An analytical solution is presented, providing a closed-form expression for the problem. The study explores the amplitude of the Radar Cross Section (RCS) for a range of electric Permittivity and corresponding conductivities to illustrate the scattering width behavior of the PEC half-plane. Additionally, the impact of soil losses on the RCS is analyzed across different soil parameters. Numerical results from the analytical solution are discussed and compared with findings from existing research.

**INTRODUCTION**

This paper investigates the diffracted field and backscattered echo width of a Perfect Electric Conductor (PEC) half-plane across various soil parameters, including permittivity, conductivity, and permeability. The closed-form solution for the PEC half-plane is available in prior works [2-6]. The solution, which addresses both electric and magnetic polarizations, is presented in terms of Fresnel integrals. This study aims to extend this analysis into a lossy medium to examine the scattering width and diffracted field of a PEC half-plane. The importance of Radar Cross Section (RCS) in radar systems and its applications, as detailed in sources [?], lies in its ability to aid radar in detecting and analyzing an object's shape, range, effective capture area, and size [15]. Ground-probing radar, used for detecting subsurface cavities, exemplifies one of the significant applications of electromagnetics (EM). The radar cross section, denoted $\sigma_{\mu\epsilon}$, is calculated for objects within a lossy medium, requiring careful assessment of losses in the RCS computation for PEC objects.

By measuring the time interval of reflected signals, the range to a target can be calculated, with the half-time interval indicating the target's distance. Radar applications span civilian (e.g., airport surveillance, marine navigation, weather radar), military (e.g., target tracking, fire control, reconnaissance), and scientific fields (e.g., astronomy, remote sensing). This article expands on previous work [2, 3] by analyzing scattering losses for various soil parameters in a lossy medium, drawing on methods established by Kashgind and Vainshteyn [4]. Asymptotic techniques [5-7] are applied to far-field measurements for narrow aperture widths. Understanding soil's response to EM waves and the scattering from buried targets further underscores the significance of ground-probing radar in subsurface detection. Investigate the response of the soil for a short pulse, and illustrate the role of the complex dielectric permittivity of the various soil models in determining radar range resolution. The strength of response produced by an object depends

on its depth, shape, size and on its electric properties. This leads to a concept of an optimum frequency and bandwidth for imaging in a particular soil. The significance of RCS of buried cavities is evident that the ability of the radar to detect and analyze the shape, range, effective capture area and size of an object is the chief attributes of the Radar Cross Section (RCS). The radar cross section RCS of several canonical objects in lossy media has been investigated by many researchers [15-46] who have worked out. This manuscript addresses electromagnetic issues in lossy media, using estimated values for conductivity and dielectric constants of different materials. The study's goal is to analyze a subsurface cavity, modeled as a PEC slot, within various soil types.

2. Materials and methods

The problem formulated in [2] has been studied in light of lossy medium. This two dimensional geometrical problem in which a plane wave impinges upon a PEC half plane as shown in

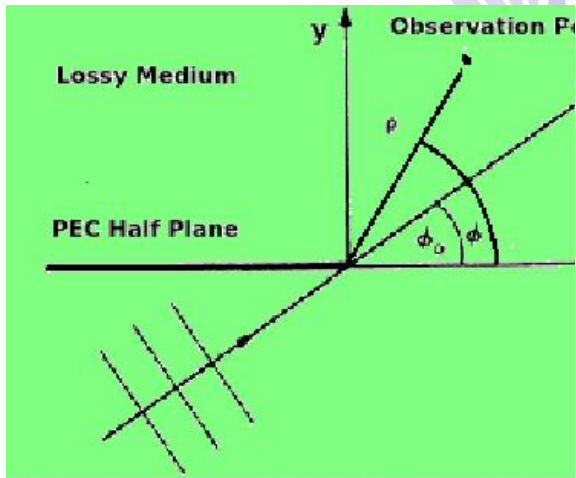


Fig.1. The geometry of the problem

Only the z-component incident field is taken,

$$E^{inc} = e^{-i\gamma\rho\cos(\phi-\phi_0)}$$

where ϕ_0 is the incidence angle and γ is the complex wave number. The coordinates (ρ, ϕ) of the observation point are defined in Fig.1. The time

dependence is $\exp(j\omega t)$. For magnetic polarization, the incident magnetic field is H^{inc} has only a z component given by [3]

$$H^{inc} = e^{-i\gamma\rho\cos(\phi-\phi_0)} \quad (2)$$

Figure 1: Plane wave diffraction by a semi-infinite plane placed in lossy medium

The exact total Electric field E and magnetic field H are given by

$$H = (\pi)^{-\frac{1}{2}} e^{i(\frac{\pi}{4} - \gamma\rho)} (\Psi_1(\rho, \phi) + \Psi_2(\rho, \phi))$$

where $\Psi_1(\rho, \phi) = F \left[(2\gamma\rho)^{1/2} \sin(\frac{\phi-\phi_0}{2}) \right]$ and $\Psi_2(\rho, \phi) = F \left[(2\gamma\rho)^{1/2} \sin(\frac{\phi+\phi_0}{2}) \right]$

$$\sigma_{\mu\epsilon} = \lim_{R \rightarrow \infty} 4\pi R^2 \frac{|e^{Im(\vec{K} \cdot (\vec{R} - \vec{a}))} \vec{E}_s|^2}{|\vec{E}_i e^{Im(\vec{K} \cdot \vec{a})}|^2}$$

$$\sigma_{\mu\epsilon} = \lim_{R \rightarrow \infty} 4\pi R^2 \frac{|e^{Im(K)(R-a)} \vec{E}_s|^2}{|e^{Im(K)a}|^2}$$

where $\vec{\rho}$ is the distance from the coordinate origin to the dominant specular point of the target, $\vec{E}_s$ is the scattered electric field vector and for a monostatic radar, $\vec{R}$ is the range

to the target object from the transmitter. where

$$\gamma = \beta - i\alpha$$

in which real part β is interpreted as the phase constant, and the imaginary part α is the attenuation constant. where

$$\alpha = \omega \sqrt{\epsilon_0 \mu_0} \sqrt{\frac{\epsilon_r}{2}} \left[\sqrt{1 + \left(\frac{18\sigma}{\omega \epsilon_r \epsilon_0} \right)^2} - 1 \right]^{1/2} \quad (1)$$

$$\beta = \omega \sqrt{\epsilon_0 \mu_0} \sqrt{\frac{\epsilon_r}{2} \left[\sqrt{1 + \left(\frac{18\sigma}{\omega \epsilon_r \epsilon_0} \right)^2} + 1 \right]}^{1/2}$$

here σ is the conductivity of soil, ϵ_0 is the permittivity of free space and ϵ_r is the relative permittivity of soil. The Fresnel type integral define as in [3]

$$F(z) = e^{iz^2} \int_z^\infty e^{-it^2} dt \quad (7)$$

For lossy media, γ in equations (1 – 3) is .

When $\gamma\rho \gg 1$ and ϕ is not near $\pm\phi_0$, then the physical interpretation of the diffracted fields in geometrical optics terms from the above equations (3) and (4) can be observed in [3]

$$D_E(\rho, \phi) = E_d \simeq \frac{\cos(\frac{1}{2}\phi)\sin(\frac{1}{2}\phi_0)}{\cos(\phi_0)-\cos(\phi)} \left(\frac{2}{\pi\gamma r}\right)^{\frac{1}{2}} e^{-i(\gamma r + \pi/4)} \quad (8)$$

$$D_H(\rho, \phi) = H_d \simeq \frac{\sin(\frac{1}{2}\phi)\cos(\frac{1}{2}\phi_0)}{\cos(\phi_0)-\cos(\phi)} \left(\frac{2}{\pi\gamma r}\right)^{\frac{1}{2}} e^{-i(\gamma r + \pi/4)} \quad (9)$$

Further, a similar solution can be obtained for the case $\eta = 0$ from [7]. The backscatter echo width of a PEC half plane for the both *E – polarization* and *H – polarization* can be written as

$$\sigma_E = 2\pi |D_E(\rho, \phi)|^2 \quad (10)$$

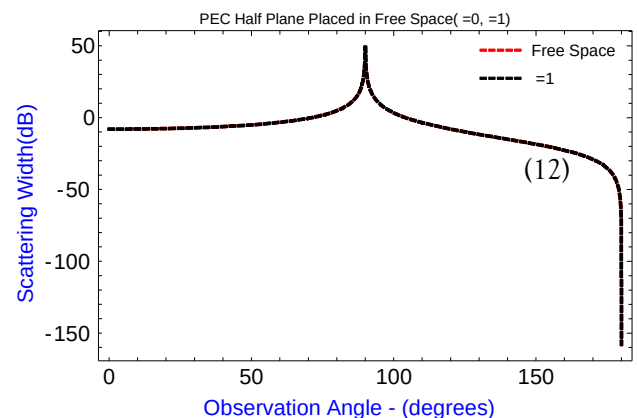
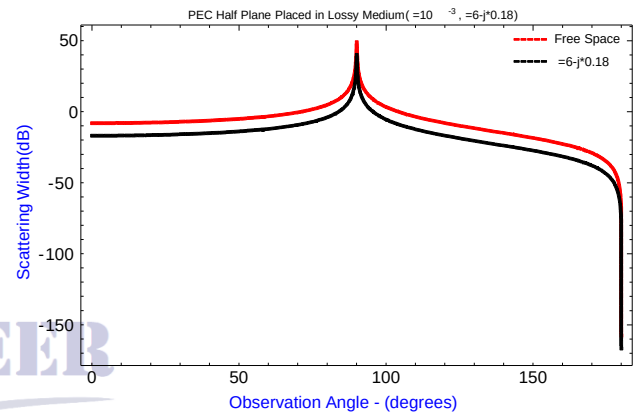
$$\sigma_H = 2\pi |D_H(\rho, \phi)|^2 \quad (11)$$

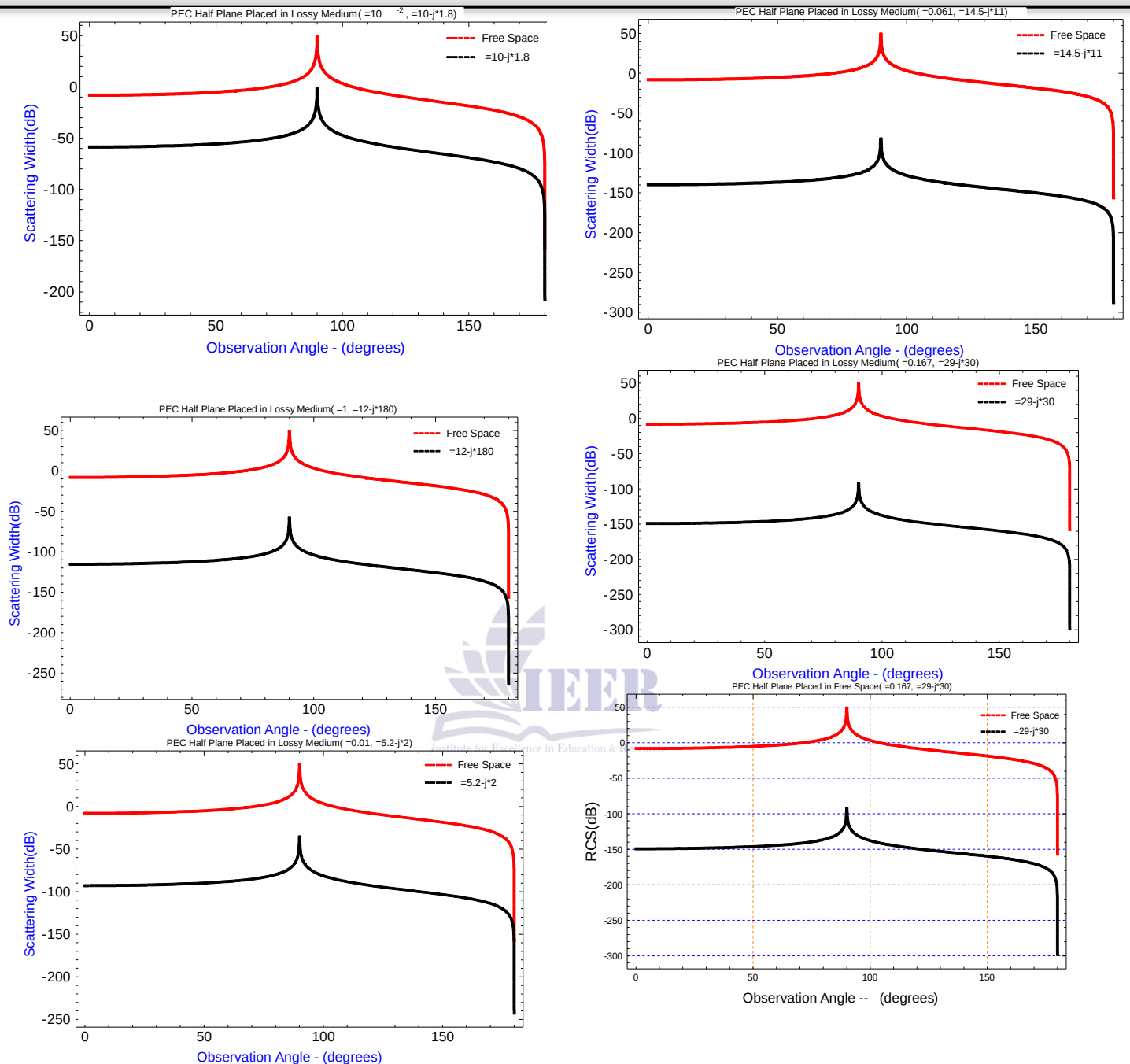
$$D_E(\rho, \phi) = D_H(\rho, \phi) = -\frac{e^{-i\frac{\pi}{4}}}{\sqrt{2\pi}} \frac{\sin\phi \sin\phi_0}{\cos\phi + \cos\phi_0} \times \frac{1}{\sqrt{1-\cos\phi}\sqrt{1-\cos\phi_0}} \frac{e^{i\gamma\rho}}{\sqrt{\gamma\rho}}$$

which is a diffracted field from a PEC half plane.

$$D_E^s(\rho, \phi) \simeq \frac{\cos(\frac{1}{2}\phi)\sin(\frac{1}{2}\phi_0)}{\cos(\phi_0)-\cos(\phi)} \left(\frac{2}{\pi\gamma r}\right)^{\frac{1}{2}} e^{-i(\gamma\rho + \pi/4)} \quad (13) \text{ and the Scatter}$$

$$\sigma_E = 2\pi |D_E^s(\rho, \phi)|^2 \quad (14)$$





3. Results and discussions

Mathematica software was used to compute numerical results and visualize the behavior and loss effects across various soil layers, shown through plots. These plots are then compared with results from the diffracted field and the scattered Radar Cross Section (RCS) of a PEC half plane placed in free space. Soil parameters for different layers—

including free space with $\epsilon_r = 1$ and $\sigma = 0$, dry sand with $\epsilon_r = 6 - j0.18$ and $\sigma = 10^{-3}$, water saturated sand with $\epsilon_r = 30 - j1.8$ and $\sigma = 10^{-2}$, water saturated silt with $\epsilon_r = 10 - j1.8$ and $\sigma = 10^{-2}$, water saturated clay with $\epsilon_r = 12 - j1.8$ and $\sigma = 1$, 5% water saturated San Antonio Clay with $\epsilon_r = 5.2 - j2$ and $\sigma = 0.01$, 10% water saturated San Antonio Clay with $\epsilon_r = 14.5 - j11$ and $\sigma = 0.061$, and 20% water saturated San Antonio Clay with $\epsilon_r = 29 - j30$ and $\sigma = 0.167$, are taken from Table 1, "Soil Electromagnetic Properties" [34].

The effect of losses on the amplitude of the scattering width for a PEC half-plane embedded in different soil types is examined, and the scattering width is plotted against the observation angle for different permittivity

values (ϵ_r) and corresponding conductivities (σ) and throughout permeability has been taken equal to 1. Figure (a) depicts RCS amplitude variation in free space; Figure (b) in dry sand; Figure (c) in water-saturated sand; Figure (d) in water-saturated silt; Figure (e) in San Antonio Clay Loam with 5% water; Figure (f) in San Antonio Clay Loam with 10% water; and Figure (g) in San Antonio Clay Loam with 20% water. Comparing the RCS of the PEC half-plane in free space and in a lossy medium reveals that as conductivity increases, the scattering behavior shifts, indicating a clear impact of soil composition on RCS amplitude of soil increases the RCS of the buried half plane decreases.

4. Conclusions

In this article, a plane wave scattered by a perfect electromagnetic conductor (PEC) half plane has been investigated. The knowledge of RCS characteristics of some simple targets is very important in RCS measurement and analysis of complex targets. Complex targets such as missiles, ships, aircrafts etc. can be described as collections of relatively simple shapes like spheres, flat plates, cylinders, slot, cones and corner reflectors. The amplitude of RCS of the target decreases as loss of the soil layers increases. The analysis of the lossy medium for target detecting

by the characteristics of the soil is very useful in Radar System and applicable for modeling GPR performance..

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