Underground Object Detection Using Antiresonant Antennas

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Abstract

Given a horizontal dipole over ground, the variation in the antenna input impedance attributable to a nearby underground anomaly (tunnel) is investigated via finite difference time-domain (FDTD) simulation. The dipole is driven with a broadband source to locate the dominant resonant and antiresonant frequencies and to compute the impedance effects associated with the tunnel over the entire frequency band. The characteristics of the total fields and the fields scattered by the tunnel are analyzed at the resonant and antiresonant frequencies. The effectiveness of the antiresonant dipole as a near-field probe for buried object detection is demonstrated.

1. Introduction

The concept of a near-field probe for buried object detection is investigated using the dominant resonance and antiresonance modes of a simple dipole over ground. An electric field source (dipole) is chosen for the antenna in order to exploit the scattering characteristics of a tunnel (an air-filled void) in a nonmagnetic soil. The near-field of the antenna governs specific components of the antenna input impedance ($Z_A = R_A + jX_A$) where $R_A$ is the antenna resistance and $X_A$ is the antenna reactance [1]. The antenna resistance is the sum of the loss resistance ($R_{loss}$) and the radiation resistance ($R_{rad}$). $R_{loss}$ is related to the amount of power lost in the form of heat while $R_{rad}$ is related to the amount of real power radiated by the antenna. The antenna reactance is related to the net reactive (imaginary) power stored in the near-field of the antenna.

2. Computational Model

An FDTD analysis is performed on a horizontal dipole antenna located above a homogenous soil containing an air-filled tunnel as shown in Figure 1. The dipole of length $l = 1.1$ m is located at a height of $h = 0.2$ m above the soil surface. The electrical properties of the soil are assumed to be $\mu_{soil} = \mu_0$, $\epsilon_{soil} = 10\epsilon_0$, and $\sigma_{soil} = 0.01$ S/m. The tunnel width and height are 1.5 m and the apex of the tunnel is located 2 m below the soil surface. A conformal FDTD solver is utilized in the solution [2]. Negative padding is used in the generation of the grid to ensure that the computational boundaries truncate the model, and the material properties (soil/air) are continuous across the respective boundaries. The overall computational domain measures approximately 6.4 m x 6.4 m x 5.4 m with absorbing boundaries on all six sides of the domain.

3. Input Impedance Characteristics of the Dipole Over Soil – With and Without the Tunnel

The dipole is driven with a broadband voltage source in order to determine the impedance characteristics of the antenna over ground (no tunnel) verses frequency. The spectrum of the broadband voltage source spans the frequency range of 50 to 250 MHz. The computational grid for the broadband analysis is 258 x 277 x 199 = 14.22 Mcells. The resulting impedance of the dipole over a homogeneous soil with no tunnel is shown in Figure 2. The dipole over soil has two resonances in the given frequency range which occur at approximately 125 MHz and 215 MHz. The lower resonant frequency at 125 MHz represents the dominant resonance where the dipole impedance is approximately $(58+j0)\,\Omega$. The second resonance at 215 MHz represents the dominant antiresonance where the dipole impedance is approximately $(1283+j0)\,\Omega$. Note that both the antenna resistance and reactance vary more rapidly in the vicinity of the dominant antiresonance than in the vicinity of the dominant resonance.
The impedance of the dipole is then computed over the range of 50 to 250 MHz for the dipole over soil with the tunnel present. The difference in the dipole impedance found for the two soil environments (with and without the tunnel) is shown in Figure 3. The simulations for the dipole over soil with and without the tunnel are carried out using identical models (identical grids where only the material properties in the tunnel region are changed). The magnitude of the impedance difference is in the range of fractions of an ohm (< 0.5 Ω) at low frequencies below the first dipole resonance at 125 MHz. The dipole impedance magnitude difference increases above the first resonance and peaks at approximately 6.4 Ω in the vicinity of the second resonance (approximately 218 MHz).

The impact of the tunnel on the fields within the soil can be illustrated by comparing the magnitude of the total vector electric field over the x = 0 plane with and without the tunnel present. These plots are shown in Figure 4 at the dominant resonance (125 MHz) and in Figure 5 near the dominant antiresonance (218 MHz). As expected, the field penetration into the soil is more significant for the lower (resonant) frequency, but the tunnel produces significant deformation of the fields at both the resonant and antiresonant frequencies.
Figure 4. $|E_{_{\text{total}}}|$ at resonance ($f=125$ MHz, dB normalized to 1V/m) over the $x=0$ plane (a.) no tunnel and (b.) tunnel present.

Figure 5. $|E_{_{\text{total}}}|$ near antiresonance ($f=218$ MHz, dB normalized to 1V/m) over the $x=0$ plane (a.) no tunnel and (b.) tunnel present.
The fields scattered by the tunnel can be determined by subtracting the vector fields with the tunnel present from the vector fields with no tunnel. The resulting scattered electric field magnitudes at the resonant and antiresonant frequencies are shown in Figure 6. The magnitude of the scattered field at the antiresonant frequency is clearly smaller than that at the resonant frequency. Also, the magnitude of the scattered field interacting with the dipole is significantly smaller in the antiresonance case when compared to the resonance case. However, as shown in Figure 3, the dipole is more sensitive to the presence of the tunnel at antiresonance than at resonance. The higher sensitivity at antiresonance can be explained by noting that the antenna feedpoint current is much smaller (approximately 1/20th) at the antiresonance frequency when compared to that of the resonant frequency.

![Figure 6](image)

Figure 6. $|E_{\text{rms}}|^{\text{scat}}$ (dB normalized to 1V/m) over the $x=0$ plane at (a.) 125 MHz and (b.) 218 MHz.

4. Conclusion

The effectiveness of an antiresonant dipole as a near-field probe for buried object detection has been demonstrated based on its large input impedance (small feedpoint current) combined with resistive/reactive components that vary rapidly in the vicinity of the antiresonant frequency. The small feedpoint current makes the antiresonant dipole more sensitive to the interaction of the scattered field with the antenna. A significantly higher feedpoint current for the dipole at the lower (dominant) resonant frequency yields a lower sensitivity to changes in the environment.

5. References
