Resonance Behavior of a Conducting Wire Object Above a Halfspace

Siyuan Li(1), Chad Hargrave (2), and Hoi-Shun Lui(1)
(1) Global Big Data Technologies Centre, School of Electrical and Data Engineering, University of Technology Sydney, Ultimo, New South Wales 2007, Australia (hoishunantony.lui@uts.edu.au)
(2) Sustainable Mining Research Program, Commonwealth Scientific and Industrial Research Organisation, Pullenvale, Queensland 4069, Australia

***Abstract*— Successful extraction of the resonant modes embedded in the transient target signature is vital to resonance-based radar target recognition. For targets in free space, although these resonant modes are theoretically aspect independent, the corresponding residues are known to be aspect dependent. When the target is located above a halfspace, the interface will electromagnetically interact with the target and alter the residue. Within the context of resonance-based target recognition, the influence from an interface to the residues, to the best of our knowledge, has not been well studied. In this paper, we study this problem through a wire target. Our results show that the residues of the mode follow a similar behavior as the dielectric properties of the halfspace vary.**

I. INTRODUCTION

Detection and recognition of radar targets based on their scattered electric field has been of significant interest over the years [1]-[4]. In the frequency domain, when the wavelength of the excitation wave is comparable to the target's dimension, the natural resonant frequency (NRF) can be excited. Using a short-pulse excitation, we extend the frequencies over a wide bandwidth such that the scattered response consists of several NRFs. The resonant scattering phenomena under wideband excitation can be described by the Singularity Expansion Method (SEM) [2]-[4]. Assumed that only M modes are excited under band-limited excitation, the late-time period ($t > T_L$) of the transient target response can be given by

$$r(t) = \sum_{n=1}^{M} \left(A_n e^{s_n(t)} + A_n^* e^{s_n^*(t)} \right), t > T_L. \qquad (1)$$

The superscript * denotes the complex conjugate operation. The damped exponentials ($s_n = \sigma_n + j\omega_n$) are the target's NRFs. $\sigma_n (< 0)$ and ω_n are known as the damping factor and resonant frequency, respectively. These NRFs are purely dependent on the target attributes such as dimension, geometry, and material properties, which allows them to be used as a feature set for target recognition. A_n is the residue that indicates the strength of the n^{th} mode. In general, A_n is dependent on the aspect and polarisation [5]-[13].

Most studies focus on the scenario where the target is isolated in free space such that the target signature and NRFs are solely target-dependent [2]-[13]. In practice, the target is usually located above a surface (e.g., ground, water surface, wall). Reflections from the interface and multiple interactions between the target and the interface need to be accounted for. More importantly, the existence of the dielectric interface perturbates the NRFs. Previous studies of a wire [14]-[15] and an annular ring target [16]-[17] demonstrate that the NRF varies as a function of the target height above the interface. In [18], a mathematical solution is derived to predict the perturbations of the NRFs.

The aspect dependency of the residue is of practical interest. For target above or below an interface, the residue A_n is affected by the surrounding environment. A_n can be small at specific transmit-receive aspects such that the corresponding NRF cannot be retrieved from $r(t)$. To the best of our knowledge, the impact of the halfspace on the residues has not been well studied. In this paper, we consider a wire target above a halfspace and we study the impact of the halfspace on the residues. In a companion paper [19], we study the aspect dependency of the residues for target below a halfspace.

II. RESULTS AND DISCUSSIONS

Numerical examples of a *L*=30cm wire parallel-oriented at 10cm above dielectric halfspaces with relative permittivity (ε_{r2}) of 6 and 81, as well as conductivity (σ_2) of 0S/m and 0.05S/m, are presented. As illustrated in Fig. 1, the wire is illuminated under parallel-polarized plane-wave excitation with $\theta_i = 15°, 30°, 45°, 60°$ and $75°$. The electromagnetic problems are solved in the frequency domain using the full-wave moment method solver FEKO [20] from 4.88MHz to 10GHz with 2048 samples. The corresponding time-domain responses are obtained using an inverse Fourier Transform [21] and the NRFs are extracted using the matrix pencil method (MPM) [3], [6], [9], [22]. The same wire object in free space and above a perfectly electric conductor (PEC) halfspace are also included.

While not presented here, the first five NRFs of the wire in different environments are compared. We find that the NRFs do not vary significantly as the dielectric properties of the halfspace change, which aligns with the observations from previous studies [14]-[18]. As the perturbation is small, we include the NRFs of the wire target in free space in Table 1 as reference. These modes are matched with the results in [7]-[9].

The corresponding residues of these five modes are shown in Fig. 2. Mode 1, 2 and 5 are successfully extracted for all the six cases. When the environment changes, we find that the residues follow a similar pattern. Compared with the wire in free space (case (i), red), the amplitude of the residues increases as we increase the permittivity of the halfspace ε_{r2} from 6 (case (iii) and (iv)) to 81 (case (v) and (iv)), and finally to PEC (case (ii)). Mode 4 is not retrieved at $\theta_i = 30°$. At $\theta_i =$

Table 1. Normalized NRF ($s_n L/c$) for the wire target in free space (NB: f is in GHz, $c = 3\times10^8 m/s$, $\theta_i = 45^\circ$ in this case)

n	f	$s_n L/c$	n	f	$s_n L/c$
1	0.476	-0.177 ± j2.989	4	1.964	-0.332 ± j12.343
2	0.970	-0.248 ± j6.097	5	2.462	-0.374 ± j15.467
3	1.467	-0.297 ± j9.216			

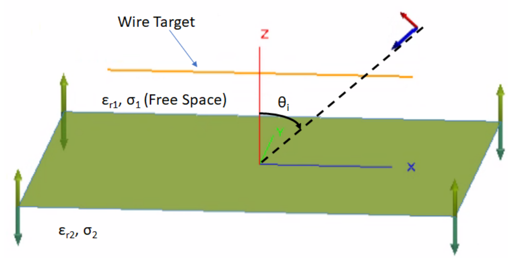

Fig 1. Wire target above a dielectric halfspace with ($\varepsilon_{r2}, \sigma_2$)

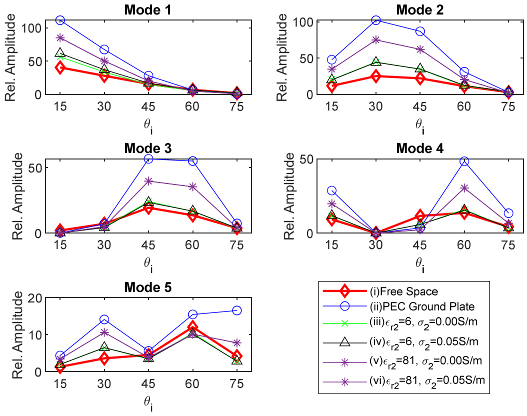

Fig. 2. Residues of the first five modes of the wire target (i) in free Space, (ii) above PEC ground plane, (iii)-(vi) above dielectric halfspace with (iii) $\varepsilon_{r2} = 6, \sigma_2 = 0S/m$, (iv) $\varepsilon_{r2} = 6, \sigma_2 = 0.05S/m$, (v) $\varepsilon_{r2} = 81, \sigma_2 = 0S/m$ and (vi) $\varepsilon_{r2} = 81, \sigma_2 = 0.05S/m$, respectively

15°, mode 3 is only found with a small residue when the wire is in free space (case (i)). It is not retrieved when the wire is above any of the considered halfspace (case (ii) to (v)). This indicates that mode 3 is weakly excited in general.

III. CONCLUSIONS

The aspect dependency of the residues for a wire target above halfspace is studied. Our findings indicate that the existence of a halfspace increases the amplitude of the residue, providing that the mode is well excited when the wire is in free space. For modes that are weakly or not excited when it is in free space, placing the wire above a halfspace is not likely to enhance the strength of the residues. The above findings are limited a specific case. Further studies of wire and other targets with different orientations are required.

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