Characterization of Radar Targets based on Ultra Wideband Polarimetric Transient Signatures

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Abstract

Resonance based target recognition has been well studied for the last three decades. The purely target dependent natural resonant frequencies are used as a feature set for target classification. Such technique may fail if the targets of interest have similar or almost the same resonant frequencies. In this paper, the idea of using the polarimetric features at the resonant frequencies is investigated and demonstrated via numerical examples.

1. Introduction

Recognition of definitive radar targets based on Ultra Wideband (UWB) transient electromagnetic scattering has been of significant interest throughout the years. Scattering mechanisms, such as scattering centre which corresponds to local phenomena in the early time [1] , or a resonance description that relates to the global resonance phenomena of the entire target [2], have been considered as feature sets for target classification. Compared to the scattering centre description which is highly related to the local scattering phenomena and is usually aspect dependent, the late-time resonant modes provides a better solution for target characterization as these resonant modes are theoretically independent to incident aspect and polarization states. In most studies, the UWB transient target signature is usually measured at one aspect with one linear polarization state as theoretically the same set of resonant modes should be able to excite at any incident aspect and polarization state. However, previous study by Shuley and Longstaff [3] has found that in practice, some resonant modes may not be able to be extracted at some polarization angles (linear). This is due to the fact that the target may not be not well excited at that particular aspect and polarization state. In view of this, one has to excite the target at a number of polarization states hoping that all the dominant resonant modes within the frequency band of interest are excited. However, this involves in a large amount of target signatures to process and to our knowledge there is not any good solution with low computational cost [4]. On the other hand, we can also excite the target at two orthogonal linear polarization states and measured the co- and cross-polarization direction for each excitation, resulting the full polarization matrix (Sinclair matrix). Polarimetric signatures of a target can thus be obtained given the polarization matrix. In this paper, characterization of radar target based on such UWB full polarmetric target signature is considered. In particular, the possibility of using the characteristic polarization states (CPSs) of the Natural Resonant Frequencies (NRFs) as a feature set is investigated.

2. Ultra Wideband Transient Electromagnetic Scattering

Upon excitation of the target in free space using a short electromagnetic pulse, the late time period of the UWB transient target signature can be expressed as [2]

$$r(t) = \sum_{n=1}^{N} a_n e^{\sigma_n t} \cos(\omega_n t + \phi_n), \qquad t > T_l \qquad (1)$$

where a_n and $ø_n$ are the aspect dependent amplitude and phase of the n^{th} mode and T_l is the onset of the late time period. It is assumed that only N modes are excited under band-limited short-pulse excitation. The NRFs are given by $s_n = \sigma_n \pm j\omega_n$, where σ_n and ω_n are the damping coefficients

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

and resonant frequencies respectively. These NRFs correspond purely to the physical properties of the target's geometry, dielectric properties and loss mechanisms and are theoretically independent to incident aspect and polarization states which allow them to be a good feature set for target classification. However, due to the relatively low energy level in the late-time period of the target signature (which is more susceptible to noise), together with the fact that the target is not well excited at some frequencies for that particular incident aspect and polarization states, some NRFs are not able to be extracted from the target signature in practice.

3. Characteristic Polarization States at Resonant Frequencies

Consider the situation which the target is excited under UWB signals at two orthogonal components along the x and y axis, the full polarmetric UWB target signatures in the late time period can be written as

$$[r(t)] = \begin{bmatrix} r_{hh}(t) & r_{hv}(t) \\ r_{vh}(t) & r_{vv}(t) \end{bmatrix} \tag{2}$$

where the component $r_{ab}(t)$ corresponds to case where when the target is illuminated under y polarization and the signature is measured in the x polarization, where a, b corresponds to horizontal (h) or vertical(v). According to (1), the late time period of each target signature can be written as a sum of damped exponentials. If we consider the nth resonant mode, $s_n = \sigma_n \pm j\omega_n$, the corresponding complex Sinclair matrix $[A_n]$ can be given by the corresponding residues of each component [4]

$$[A_n] = \begin{bmatrix} a_{n,hh}e^{j\phi_{n,hh}} & a_{n,hv}e^{j\phi_{n,hv}} \\ a_{n,vh}e^{j\phi_{n,vh}} & a_{n,vv}e^{j\phi_{n,vv}} \end{bmatrix} \tag{3}$$

For monostatic configuration [5], the CPSs in terms of the antenna polarization ratios, P_i, where $i = 1,2,3,4$ can be determined given the Sinclair matrix. The maximum backscattered power P_1 and P_2 can be given by

$$P_i = \frac{-\left|A_{n,xx}\right|^2 + \left|A_{n,xy}\right|^2 - \left|\gamma_i\right|^2}{A_{n,xx}A_{n,xy} + A^*_{n,xy}A_{n,yy}}, \quad i = 1,2\,,\ \left|\gamma_1\right|^2, \left|\gamma_2\right|^2 = \frac{B}{2} \pm \frac{\sqrt{B^2 - 4C}}{2} \tag{4}$$

where $B = \left|A_{n,xx}\right|^2 + 2\left|A_{n,xy}\right|^2 + \left|A_{n,yy}\right|$, $C = \left|A_{n,xx}A_{n,yy}\right|^2 + \left|A_{n,xy}\right|^4 - 2\,\mathrm{Re}\left(A_{n,xx}A^{*2}_{n,yy}A_{n,yy}\right)$. The minimum backscattered power P_3 and P_4 are given by

$$P_3, P_4 = \pm \frac{\left(\sqrt{A^2_{n,xy} - A_{n,xx}A_{n,yy}}\right) \mp A_{n,xy}}{A_{n,yy}} \tag{5}$$

The strokes parameters of each optimal backscattered power can then be obtained and the ellipticity ε and tilt angle τ of each polarization ratio as well as the characteristic angle β can be given by

$$\varepsilon = \frac{1}{2}\sin^{-1}\left(\frac{g_3}{\left(g_1^2 + g_2^2 + g_3^2\right)}\right), \tau = \frac{1}{2}\tan^{-1}\left(\frac{g_2}{g_1}\right),\ \tan^2\beta = \frac{|\gamma_2|}{|\gamma_1|}. \quad (6)$$

where $g = [g_0 \quad g_1 \quad g_2 \quad g_3]$ corresponds to the strokes parameters of each polarization ratio [5].

4. Numerical Examples

Numerical examples of two L-shaped targets shown in Fig. 1 are considered. The length segments of the L-shape Targets 1 and 2 are d1=0.7m, d2= 0.3m and d1=0.6m, d2=0.4m. The target signature is calculated in the frequency domain using commercial moment method solver FEKO [6] from 1.9MHz to 1GHz with 512 equally spaced samples. The target is excited from the positive z direction and two orthogonal components that are in parallel to the x and y axes are considered. The co- and cross- polarized target signatures are thus obtained which resulted in 4 target signatures for each target. The frequency samples are then windowed via a Gaussian window with a delay of 10ns. The late time commences on 12ns and samples from 12ns onwards are imported to the modified matrix pencil method (MPM) [7] for resonant extractions. Compared to the original MPM, the modified MPM is able to handle all 4 target signatures at the same time such that only one set of NRFs and 4 sets of residues will be resulted, which gets rids of the troubles about NRF selection [4]. The resonant modes are tabulated in Table 1 and found that they are almost the same, which implies that traditional resonance based target recognition scheme such as E-Pulse [8] would fail to distinguish the targets. With the use of Sinclair matrix for each NRF given in (3), the ellipticity, tilt angle and the characteristic angles are computed as described above and the results for resonant modes 4 and 5 are tabulated in Table 2. The results showed that these three parameters are quite different at the two resonant frequencies. Such findings demonstrate that utilizing the CPSs at NRFs could potentially be another feature sets for target classification.

5. Conclusions

The possibility of characterization of radar target based on UWB polarimetric transient signatures is presented. In particular, the CPSs of the radar target at the resonant frequencies are considered. The results demonstrate that even though some targets do have very similar NRFs due to the similarities of their structures, the CPS of the NRFs are different which open up a possibility to be used as a feature set for target classification.

6. References

[1] K. T. Kim, H. T. Kim, "One Dimensional Scattering Centre Extraction for Efficient Radar Target Extraction", *IEE Proc. Radar, Sonar Navigation*., Vol. 146, No 3, pp 147-158, Jun. 1999.

[2] C. E. Baum, E. J. Rothwell, K. M. Chen, D. P. Nyquist, "The Singularity Expansion Method and Its Application to Target Identification", *Proc. IEEE*, Vol. 79, No.10, pp 1481-1491, Oct. 1991.

[3] N. Shuley, D. Longstaff, "Role of Polarisation in Automatic Target Recognition using Resonance Descriptions", *Electronic Letters*, Vol. 40, No.4, pp 268-270, Feb. 2004.

[4] H. S. Lui, N. Shuley, "Resonance Based Radar Target Identification with Multiple Polarizations," *Proceedings of IEEE Antennas Propag. Society International Symposium 2006*, pp. 3259- 3262, Albuquerque, New Mexico, 9-14 July 2006.

[5] H. Mott, *Remote Sensing with Polarmetric Radar*, Wiley, 2007

[6] FEKO EM Software & Systems S.A., (Pty) Ltd, 32 Techno Lane, Technopark, Stellenbosch, 7600, South Africa

[7] T. K. Sarkar, S. Park, J. Koh, S.M. Rao, "Application of the Matrix Pencil Method for Estimating the SEM (Singularity Expansion Method) Poles of Source-Free transient

Responses from Multiple look Directions", *IEEE Trans. Antennas Propag.,* Vol. 48, No.4, pp. 612-618, Apr., 2000.
[8] H. S. Lui, N. V. Z. Shuley, "Radar Target Identification using a Banded E-Pulse technique", *IEEE Trans. on Antennas Propag.,* Vol. 54, No. 12, pp 3874-3881, Dec., 2006.

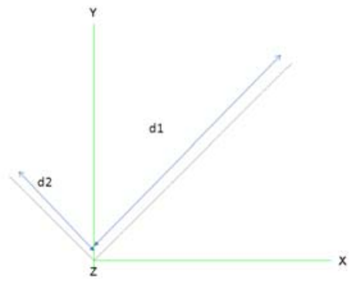

Fig. 1 Two L-shape Targets in FEKO environment. The length of the wire target is 1m. The wire segments of L-shape Target 1 are d1=0.7m, d2=0.3m, and those of L-shape Target 2 are d1=0.6m d2=0.3m respectively

Frequency $f_n = \frac{\omega_n}{2\pi}$	L-shape 1 $\frac{s_n}{c} = \frac{\sigma_n \pm j\omega_n}{c}$	L-shape 2 $\frac{s_n}{c} = \frac{\sigma_n \pm j\omega_n}{c}$
$148HMz$	$-0.07 \pm j3.10$	$-0.07 \pm j3.11$
$300MHz$	$-0.13 \pm j6.28$	$-0.18 \pm j6.29$
$451MHz$	$-0.24 \pm j9.45$	$-0.25 \pm j9.44$
$602MHz$	$-0.29 \pm j12.60$	$-0.33 \pm j12.60$
$759MHz$	$-0.36 \pm j15.90$	$-0.44 \pm j15.78$

Table 1 Extracted NRFs for the two L-shape Targets using MPM

Frequency		L-shape 1		L-shape 2	
		(τ, ε)	β	(τ, ε)	β
$602MHz$	P_1	(89.63°, -2.39°)	0.14°	(87.09°, -7.61°)	2.33°
	P_2	(-0.37°, 2.39°)		(-2.91°, 7.61°)	
	P_3	(-1.47°, -0.23°)		(-3.49°, -3.79°)	
	P_4	(0.76°, 5.01°)		(-2.16°, 19.01°)	
$759MHz$	P_1	(-0.50°, 4.29°)	6.52°	(48.70°, -1.14°)	2.73°
	P_2	(-89.50°, -4.29°)		(-41.29°, -1.14°)	
	P_3	(89.69°, -22.96°)		(-37.72°, -10.69°)	
	P_4	(-88.86°, 14.38°)		(-44.99°, 12.95°)	

Table 2. The tilt angle, ellipticity and characteristic angle of the fourth and fifth resonant modes of the L-Shape Target 1 and L-shape Target 2