# Ultra Wideband Radar Target Recognition Using Multiple Transient Responses

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***Abstract* – In resonance based target recognition, studies have mainly been focus on exploiting the natural resonant modes embedded in an ultra wideband transient signature measured at a specific aspect and polarization state. The information that carries in polarimetric and aspect dependency nature of the scattering phenomena has not been well exploited. The objective of this paper is to investigate the pros and cons for different possible approaches to handle the multiple aspects, full polarimetric, and wideband scattered data, aiming for a more robust target recognition procedures and outcomes.**

***Index Terms* — *Transient electromagentic scattering, Resonance based target recognition, Automated Target Recognition, Ultra Wideband Radar***

## I. Introduction

Recognition of radar targets based on its transient electromagnetic signature has been of significant research interest for years. According to the Singularity Expansion Method (SEM) proposed in the 1970s [1], the late time transient electromagnetic signature of a definitive target under a short pulse illumination can be written as a sum of damped sinusoids. These damped sinusoids correspond to the Natural Resonant Frequencies (NRFs) of the target. Theoretically, these NRFs are purely dependent on physical target attributes (shape and dielectric properties) which allow them to be a unique feature set for target classification.

Most of the theoretical development of transient scattering under the SEM framework took place in the 1970s and a summary can be found in [1]. Automated Target Recognition (ATR) solution (e.g. [4]-[5] ) has been a popular research topic in the 1980s and 1990s. With the advancement in semi-conductor technology in the last two decades, direct generation and measurement of pulses with picosecond width becomes commercially available and research focus has become more application oriented, e.g. subsurface target detection [6]-[9] and non-destructive evaluations[10]-[13].

In most previous studies, the target is illuminated using linear polarized electromagnetic wave and the corresponding co-polarized scattered response is used for post-processing. The de-polarized nature of the electromagnetic scattering, which would provide another degree of information about the target, has not been taken into account in the past. Recent attempts have been made to exploit the polarimetric information embedded in the Ultra Wideband (UWB) full polarmetric transient signatures. In its first attempt, the potential of using the Characteristic Polarization States (CPS) at the resonant frequencies as a feature set for target characterization is investigated [14]-[15]. Ma and Brown [12] demonstrated the potential use of this CPS-NRF feature set to determine the number of eggs inside boxes. In addition, a recent attempt has been made to apply ATR schemes on full-polarimetric target signatures [16]. On the other hand, attempts have been made to exploit information embedded in a number of target signatures measured at different aspects forming a feature set for target classification [17]-[19].

The aim of this study is to investigate different ways to handle the multiple aspects full polarimetric transient scattered data for target characterization. Sarkar et al. [18] introduced a modified matrix pencil method (MPM) that allows us to process multiple transient signatures simultaneously in the NRF extraction process. Lui et al. [16], have looked into ways to process a single full polarimetric transient signature in an effective manner. With the recent interest in microwave imaging in biomedical applications, computation and measurement of multiple aspects scattering data becomes much easier than it used to. In this paper, numerical examples of full polarimetric wideband transient signatures from simple dielectric targets at different aspects will be used to differentiate these different approaches for handling the multi-dimensional data for target classification.

## II. The Singularity Expansion Method

According to the SEM, the late time transient electromagnetic signature can be expressed as a sum of decaying sinusoids, given by

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

where $a_n$ and $ø_n$ are the aspect dependent amplitude and phase shift of the $n^{\text{th}}$ mode and $T_l$ is the onset of the late time period. It is assumed that only $N$ dominant modes are excited by the incident field. This NRF set is given by , where $\sigma_n$ and $\omega_n$ are the damping coefficients and resonant frequencies respectively. These NRFs correspond to the physical attributes of the target and are theoretically independent to aspect and polarization state.

## III. The Scattering Problem

When a short-pulse strikes a target, current is first induced on the leading edge and then propagates through the target. Dominant resonant current modes that related to the target global dimensions are then established. The induced current acts as a secondary source and re-radiate electromagnetic field to free space in all directions spatially with different depolarization degrees. Henceforth, depending on the geometrical and electrical features of the target [21], the scattered field can be in any polarization.

In frequency domain, full polarimetric measurement can be performed by measuring the target's scattered field using any two orthogonal polarization states. The co- and cross-polarized components for each of the two orthogonal components result in four scattered field components forming the 2x2 entries of the Sinclair scattering matrix [21]. In general, the matrix entries are spatially variable, meaning measurement at different radar-target aspects will result in different matrix entries, and hence providing new information about target's shape and orientation. If we only measure the scattered field in a particular polarization at a particular aspect, we have simply discarded an extensive amount of information needed for target classification.

Under UWB illumination, the scattering matrix also varies as a function of excitation frequency. Most studies in resonance based target recognition have focused on developing signal processing algorithms for NRF extraction from a single transient signature. The spatial and polarization nature of scattering has not been well addressed because these NRFs are theoretically aspect and polarization independent [1]. As reported in [22], however, the amplitude $a_n$ and phase $ø_n$ of these NRFs are highly sensitive to aspect and polarization states. Proper attention is required to handle the multi-dimensional data. As a result, we investigate different approaches that incorporate the polarimetric nature of scattering using Sinclair matrix, together with the spatial diversity from multiple aspects measurement data and the MPM signal processing tool to better extract and process the NRF information to achieve better classification performance.

## IV. CONCLUSION

Different approaches for handling the multi-dimensional scattered data from definitive target in the UWB resonance based radar target recognition have been considered. Numerical results will be presented and it turns out that quite different results can occur if care is not taken to address the all the underlying assumptions inherent in the SEM representation.

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