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Polarimetric Suppression of Early-Time Scattering for Late-Time Target Identification

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Abstract

One can suppress the strong signal amplitude of the early-time scattering, relative to the late-time signal containing the natural resonances (for target identification) using various techniques. This paper discusses the use of polarization for the early-time suppression.

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1. Introduction

For target identification/classification, an important technique uses the singularity expansion method (SEM) [10]. The backscattering delta-function response is characterized by the scattering dyadic

$$\tilde{\overleftrightarrow{\Lambda}}_b(\overrightarrow{1}_i;s) = \sum_{\alpha} \overrightarrow{c}_\alpha(\overrightarrow{1}_i)\overrightarrow{c}_\alpha(\overrightarrow{1}_i)e^{s_\alpha t}u(t-t_0)$$

$$+ \quad \text{emtire function (temporal form)} \qquad (1.1)$$

$$\overrightarrow{c}_\alpha(\overrightarrow{1}_i) \bullet \overrightarrow{1}_i = 0 \quad , \quad \text{direction of incidence}$$

As discussed in [4], the scattering problem in general must have an entire function (not describable by complex resonances) to characterize the early-time scattering. Note that the scattering dyadic multiplies the incident field to give (with a delay and $[4\pi r]^{-1}$) the scattered field.

To recognize the target by its complex natural frequencies s_α, one sometimes encounters a problem with a large early-time transient signal in the presence of a low-level late-time resonant signature. This introduces a dynamic-range problem in the transient-signal recording devices (such as digitizers). One would then like to avoid the early-time signal in the recording to accurately measure the late-time waveform.

One can approach the problem of early-time suppression in various ways. One can use limiters [9] to chop off the early-time peak(s). This raises practical questions concerning the response time of the limiter (early-time feed through) and the recovery time (hopefully before the beginning of the late-time signal). Another possibility would have linear (passive and/or active) analog filters. If the early-time signal is sufficiently narrow in time, then special low-pass filters (i.e., integrators [8]) can reduce the early-time amplitude relative to the late-time amplitude. One can also use an incident (interrogating) wave which is designed by its frequency content to maximize the return of the late-time resonances.

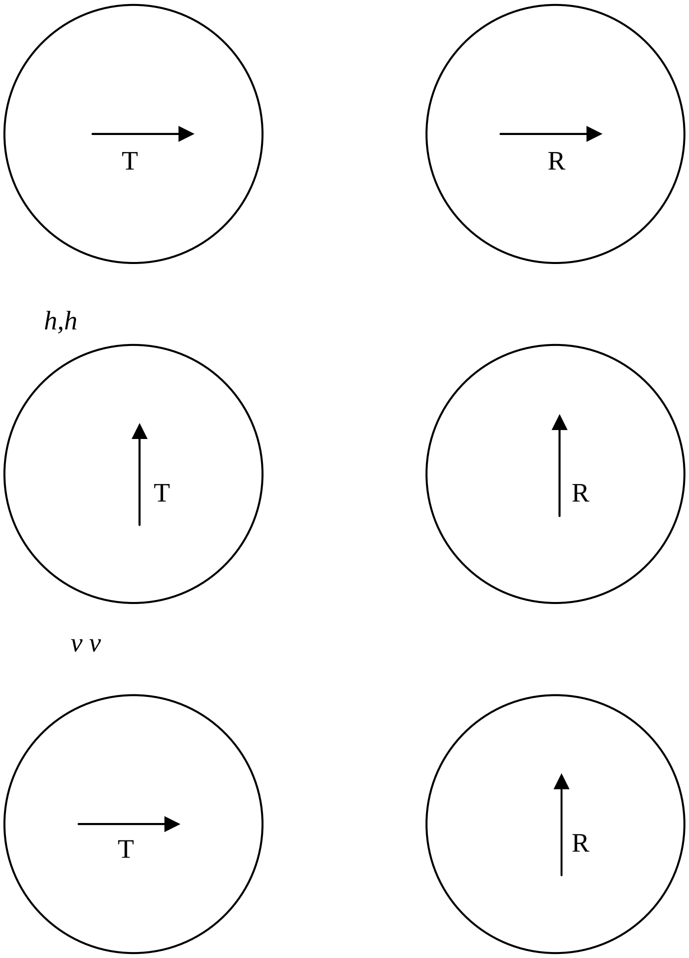
The present paper considers the use of the polarization properties of the scattering. If the early-time polarization is sufficiently different from the late-time polarization [6], then one can in effect “cross polarize” (in a general sense) the radar to the early-time scattering, while letting the late-time scattering (or useful portions of this) through to the recorder.

Note that we are here concentrating on physical (analog) processes so as to avoid differencing of large numbers (digital processing) from digitized waveforms.

2. Antenna Polarization

Figure 2.1 shows the various combinations of transmit and receive polarizations. While this is shown for two nearby antennas for clarity, these combinations are also possible in a single antenna (such as a reflector impulse radiating antenna (IRA)) [1-3].

As will become useful, we do not need to fix $\vec{1}_h$ as horizontal (parallel to local earth). We can rotate the antenna(s) by some angle ψ_h (positive or counterclockwise as seen from the front). There are, of course, electrical ways to combine the signals with appropriate weights (e.g., attenuators) to achieve the same effect.



h,h

v v

h, v (= v,h)

T ≡ transmit

R ≡ receive

Figure 2.1 Antenna Polarization

3. Nulling Some Early-Time Responses by Polarimetry

Consider now some typical early-time scattering examples [5, 12]. This leads to polarimetric ways to suppress such signals in the radar.

3.1. Flat plate, broadside

This produces a strong specular reflection with a waveform proportional to the time-derivative of the incident field. Most importantly, the scattering is polarization independent, i.e., the scattered field has the same polarization as the incident field (with a minus sign). Denoting by V the various voltage signals in the radar, then form

$$\begin{aligned} V &= V_{h,h} - V_{\mathrm{v,v}} \\ &= 0 \end{aligned} \tag{3.1}$$

for this type of scattering. This holds for any rotation of the radar through the angle ψ_h.

If one has such a polarization-independent scattering, another approach considers *h,v* (= *v,h*) scattering (crosspol). In this case one can use only one linear polarization for incidence and rely on the zero crosspol for such early-time scattering. Then one looks at $V_{h,\mathrm{v}}$ for the late-time scattering. One may wish to rotate the antenna, since then only one transmit polarization is needed. One can also combine *h,h* and *v v* transmission to give a linear polarization at any desired angle ψ. The object is to maximize the late-time crosspol scattering.

3.2. Curved surface: convex

In this case we have the Gaussian curvature r_0^{-1} related to the two radii of curvature at the specular point as

$$r_0 = \left[r_1 \, r_2 \right]^{1/2} \tag{3.2}$$

The early-time scattering is a replica (delta function convolution) of the incident waveform [11 (Section 1.4.3), 5 (Section 5)]. The scattering is polarization independent, so the results of Section 3.1 apply.

3.3. Long wedge, normal incidence

Letting the edge be normal to the direction of incidence, we have a strong scattering with polarization $\vec{1}_e$ parallel to the edge. The frequency dependence is such that a delta function gives a scattering proportional to $t^{-1/2}u(t)$ [12]. Clearly we need to look in the polarization perpendicular to this. This can be acomplished by rotating the antenna by an angle ψ with

$$\begin{aligned} \cos(\psi) &= \vec{1}_e \bullet \vec{1}_h \\ \vec{1}_e &= \pm\left[\vec{1}_h \cos(\psi) + \vec{1}_{\mathrm{v}} \sin(\psi)\right] \end{aligned} \tag{3.3}$$

Alternately, we can form

$$V = \sin(\psi) V_{h,h} - \cos(\psi) \ V_{\mathrm{v,v}} = 0 \tag{3.4}$$

3.4. Short wedge, normal incidence

With a finite-length edge at normal incidence we have an early-time signal which replicates the incident waveform [12]. The results of Section 3.3 still apply.

3.5. Cone

In this case, with the first scattering coming from the cone tip, the scattered field is proportional to the time integral of the incident field [12]. While one can null this, the amplitude of the scattered field is small (stealth) compared to the previously discussed cases.

4. Separation of Polarizations

One difficulty with this approach concerns the obtaining of two separate (*h,h* and *v,v* or appropriate combinations) polarization signals, such as is the case for early-time polarization-independent backscattering. (See Section 3.1 and 3.2.) Of course, one can perform two separate target interogations, one with each of the two orthogonal transmit polarizations. This gives a problem. One can always combine the results in a computer, but this has a dynamic-range problem for recovering the late-time information.

One would like an analog way to perform this combination of the two. One could place one signal, say $V_{h,h}$ in a delay line. By transmitting vertical at a later time to illuminate the target at a time after the late-time scattering from the first pulse, we can have a second signal in the *v* channel. With the delay time in the *h* channel equal to the delay of the *v* channel, the two signals can be differenced in real time in an analog fashion, giving the desired early-time cancellation. A similar technique can be used in transmit by splitting the signal from a pulser into the two channels and inserting a delay line in the *v* channel (same delay as in the h receive line). With two “identical” delay lines, imperfections (attenuation, dispersion) are balanced in the two channels. With ideally no early-time crosspol, there are late-time signals outside the time widow of interest, but one might ignore these. Of course, there may be some early-time crosspol, but this can be small by comparison.

For the case of a dominant signal early-time polarization (Sections 3.3 and 3.4) the situation is somewhat simpler. In this case one transmits and receives a polarization orthogonal to the scatterer early-time polarization. This can be accomplished by antenna rotation using an appropriate linear combination of *h* and *v* channels, now operated simultaneously in time.

5. Analog Signal Combination

The concern here is the required dynamic range of the digital recording devices. By reducing the early-time signal relative to the late-time signal before they reach the recorder, we lessen the dynamic-range problem.

The signal combination then needs to be done in an analog fashion by combining signals in circuits, transmission lines, etc. In some cases an inverter (which can be made with coaxial cables and chokes (ferrite)) is required to reverse the sign of a signal. Signals can also be multiplied by a positive constant by an attenuator (or amplifier). Care is needed so as to have the desired frequency-response characteristics.

6. Late-Time Polarization Differences from Early-Time Polarization

After minimizing the early-time scattering signal, we still need to observe the late-time complex resonances. This requires that the polarization properties of at least some of the late-time damped sinusoids differ significantly from the early-time polarization properties. As discussed in [6] there are a variety of polarizations associated with the various substructures on a target of interest. One then chooses those which are different from the early-time polarization. The cases of linear polarization can be promising for the required differences.

7. Application to Clutter Reduction

The discussion here has been in terms of reducing the early-time scattering signals. However, targets are often in the presence of other scatterers which produce signals which we call *clutter*. We need to reduce these for our target identification. Similar techniques can be applied. For this purpose, the early-time scattering can be regarded as just another source of clutter. The clutter from the additional scatters also has polarization properties. So we can consider “cross polarizing” to this clutter as well. An example, given in [7], considers a periodic array of vertical posts (fence posts, wall studs, etc.). There, the consideration was in terms of removing this clutter by a SAR technique by subtracting this as background when scanning a target behind the post array. Here we can note that the post array will typically scatter more in vertical than in horizontal polarization. Hence, one may preferentially look for the $V_{h,h}$ scattered signal. The polarization of the target early-time signal and the late-time resonances also need to be considered.

8. Concluding Remarks

Now we add another dimension to our attempts to suppress early-time relative to late-time scattering, namely polarization. The examples discussed here show the various forms this might taken, including various combinations of two linear polarization. This will have various requirements for hardware realization. While the discussion here is in terms of backscatter (monostatic), the concepts apply to bistatic (or multistatic) radar, and to synthetic aperture radar (SAR) as well.

Here we have used scattering theory to illustrate various examples of interest. This can be generalized to an experimental technique as well. By measuring the early- and late-time polarization properties of targets of interest one can experimentally optimize the early-time suppression using techniques such as discussed in Sections 3 and 4.

The present technique need not be used alone. It can be combined with others, such as analog filtering, nonlinear limiters, etc.

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