Interaction Notes

Note 600

December 2005

Various Linear Combinations of Polarimetric Channels for Suppression of Early-Time-Scattering Signals

Carl E. Baum
University of New Mexico
Department of Electrical and Computer Engineering
Albuquerque New Mexico 87131

Abstract

Continuing the discussion from a previous paper, this paper considers various possibilities for cancelling of early-time scattering signals for better recording of the late-time resonances for target identification. Topics include rotation of the polarization basis (antenna rotation), and including of various gains (filters) in the radar channels. This leads to schematic system designs for one or two dual-pol antennas..

`

This work was sponsored in part by the Air Force Office of Scientific Research.

1. Introduction

A recent paper [1] has considered the possibility of exploiting polarimetric differences between early- and late-time scattering from some target of interest for purposes of target identification/classification. The concept involves suppression of the large early-time scattering signals by combining the scattered signals from different polarizations in a cancellation sense. This cancellation should occur before the transient recorder to reduce the required dynamic range required to record the late-time resonant-scattering signal in the presence of the early-time scattering signal. For this to be effective, there needs to be significant polarization differences (for at least some of the resonances) between the late- and early-time signals.

In the previous paper various canonical scattering shapes were considered to show how this cancellation might work. For polarization-independent early-time scattering the differencing of $V_{h,h}$ and $V_{\mathrm{v,v}}$ is appropriate. For a dominant single-linear-polarization scattering one can rotate the polarization basis to achieve a similar cancellation. The present paper goes into more complicated scattering conditions to generalize the technique.

For present purposes, let us label our polarization basis as

$$
\begin{aligned}
&C_1 : \text{ polarization } \vec{1}_1 \text{ (first quadrant)} \\
&C_2 : \text{ polarization } \vec{1}_2 \text{ (second quadrant)}
\end{aligned}
\tag{1.1}
$$

as indicated in Fig. 1.1. These are rotated from the usual horizontal $\vec{1}_h$ and vertical $\vec{1}_{\mathrm{v}}$ polarization by an angle ψ, giving

$$
\begin{aligned}
\vec{1}_1 &= \vec{1}_h \cos(\psi) + \vec{1}_{\mathrm{v}} \sin(\psi) \\
\vec{1}_2 &= -\vec{1}_h \sin(\psi) + \vec{1}_{\mathrm{v}} \cos(\psi) \\
\vec{1}_h &= \vec{1}_1 \cos(\psi) - \vec{1}_2 \sin(\psi) \\
\vec{1}_{\mathrm{v}} &= \vec{1}_1 \sin(\psi) + \vec{1}_2 \cos(\psi) \\
\vec{1}_h \cdot \vec{1}_{\mathrm{v}} &= 0 \quad , \quad \vec{1}_1 \cdot \vec{1}_2 = 0
\end{aligned}
\tag{1.2}
$$

One of our degrees of freedom will be an appropriate choice of ψ .

Note that it is also arbitrary what we call horizontal $\vec{1}_h$ (and associated vertical $\vec{1}_v$ by implication). We can orient according to some local horizon or choose some orientation of interest on the target. Our antennas will be oriented according to $\vec{1}_1$ (and $\vec{1}_2$ by implication).

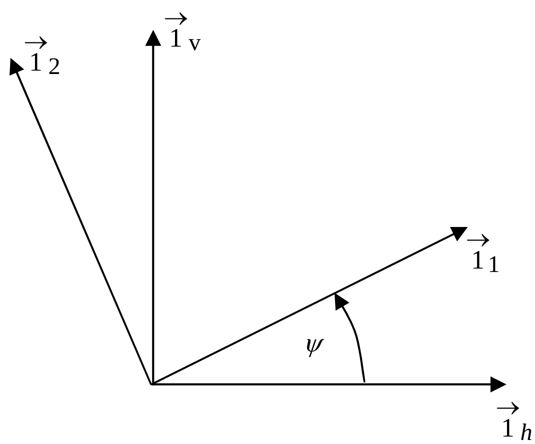

Fig. 1.1 Polarization Rotation.

2. Equal Dual-Polarization Transmission and Reception

Consider first the both polarization channels, C_1 and C_2, are identical in the sense that they respond to the same scattering with the same signals. As in Fig. 2.1 let the scatterer have two planes of symmetry with the common axis pointing to the radar. More generally, let the scattered early-time fields be described by two orthogonal polarizations (no cross pol) which can be associated with symmetry planes S_h and S_{v}. For present purposes we then define horizontal and vertical by the target early-time scattering.

Assuming our radar polarizations to be aligned with the target then S_h returns a signal V_h, and S_{v} returns a signal V_{v}. Of course, V_h and V_{v} may have different time/frequency dependencies, but let us ignore this for the moment. Then with the radar rotated an angle ψ we have signals in C_1 (transmit and receive) as V_1, and in C_2 (transmit and receive) as V_2, given by

$$\begin{aligned} V_1 &= V_h \cos^2(\psi) + V_{\mathrm{v}} \sin^2(\psi) \\ V_2 &= V_h \sin^2(\psi) + V_{\mathrm{v}} \cos^2(\psi) \end{aligned} \tag{2.1}$$

Differencing these signals gives

$$V_1 - V_2 = \left[V_h - V_{\mathrm{v}}\right]\left[\cos^2(\psi) - \sin^2(\psi)\right] \tag{2.2}$$

We now find, as in [1 (Section 3)], that a condition for zero difference is

$$V_{\mathrm{v}} = V_h \tag{2.3}$$

i.e., a polarization-independent early-time scattering, independent of ψ. However, we find another condition for zero difference given by

$$\psi = \frac{\pi}{4} \quad \left(= 45^\circ\right) \tag{2.4}$$

independent of the relative size of V_h and V_{v}. *They could even have different waveforms (time histories).*

So this signal differencing of two polarizations may be quite useful. It is suggestive of an experimental procedure involving rotating the radar antenna(s) until a minimum in the early-time difference signal is achieved.

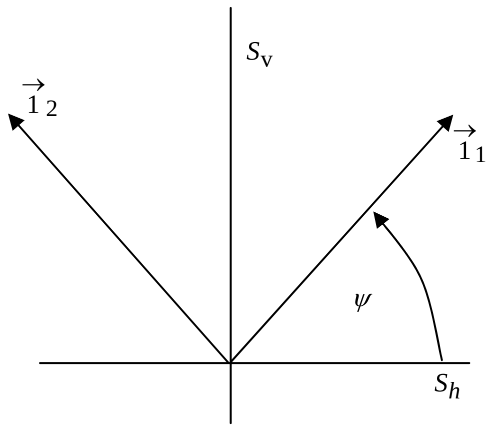

Fig. 2.1 Early-Time Target Symmetry Planes

3. Unequal Dual-Polarization Transmission and Reception

As another degree of freedom, let us include two different filters $\tilde{F}_1(s)$ and $\tilde{F}_2(s)$ in the C_1 and C_2 channels. This can potentially make unequal early-time signals from two orthogonal polarizations more equal (i.e., closer to equality). We then have two signals

$$
\begin{aligned}
& F_1(t) \circ V_1(t) \text{ and } F_2(t) \circ V_2(t) \\
& \circ \equiv \text{convolution with respect to time } t \\
& s \equiv \Omega + j\omega \equiv \text{ Laplace-transform variable or complex frequency}
\end{aligned}
\tag{3.1}
$$

Our objective is to make

$$F_1(t) \circ V_1(t) \simeq F_2(t) \circ V_2(t) \tag{3.2}$$

If our radar polarization were aligned to the target, i.e., $\psi = 0$, then we would need

$$F_1(t) \circ V_h(t) \simeq F_2(t) \circ V_{\mathrm{v}}(t) \tag{3.3}$$

as one possibility.

We also need to consider the effects of such filters on the late-time resonances. For our late-time identification let us consider a range of frequencies $f = \omega/(2\pi)$ given by

$$
\begin{aligned}
& f_\ell \le f \le f_u \\
& f_\ell \equiv \text{ lower frequency} \\
& f_u \equiv \text{ upper frequency}
\end{aligned}
\tag{3.4}
$$

Ideally our filters do not attenuate or disperse in this range. For $f > f_u$ we can have different attenuations in each channel to achieve near equality for the early-time signals in the sense of (3.2). The constraints on the frequency characteristics between early- and late-time signals may make early-time equality difficult to achieve, but one may still bring the two polarization signals closer together than without the filters.

4. Dual Transmit and Receive Systems

Recall the discussion in [1(Section 4)] concerning temporal separation of the signals in the two radar channels so that the signals may be subtracted in an analog manner before reaching the recorder. Figure 4.1 shows how this may be accomplished with two dual-polarization antennas, one transmit antenna and one receive antenna. Figure 4.2 accomplishes the same in a single dual-polarization antenna, with the addition of two directional couplers to separate the transmit and receive signals.

Again, the delay t_{del} is there to make the C_2 channel radiate and receive (at the antenna(s)) at a time after the late-time signal from the C_1 channel has died away. The two signals are brought back into temporal coincidence by the insertion of an equal delay in the C_1 channel for the received signal. Note also the inverter and filters. In addition to this one may insert limiter(s) (nonlinear) before pulses reach the recorder.

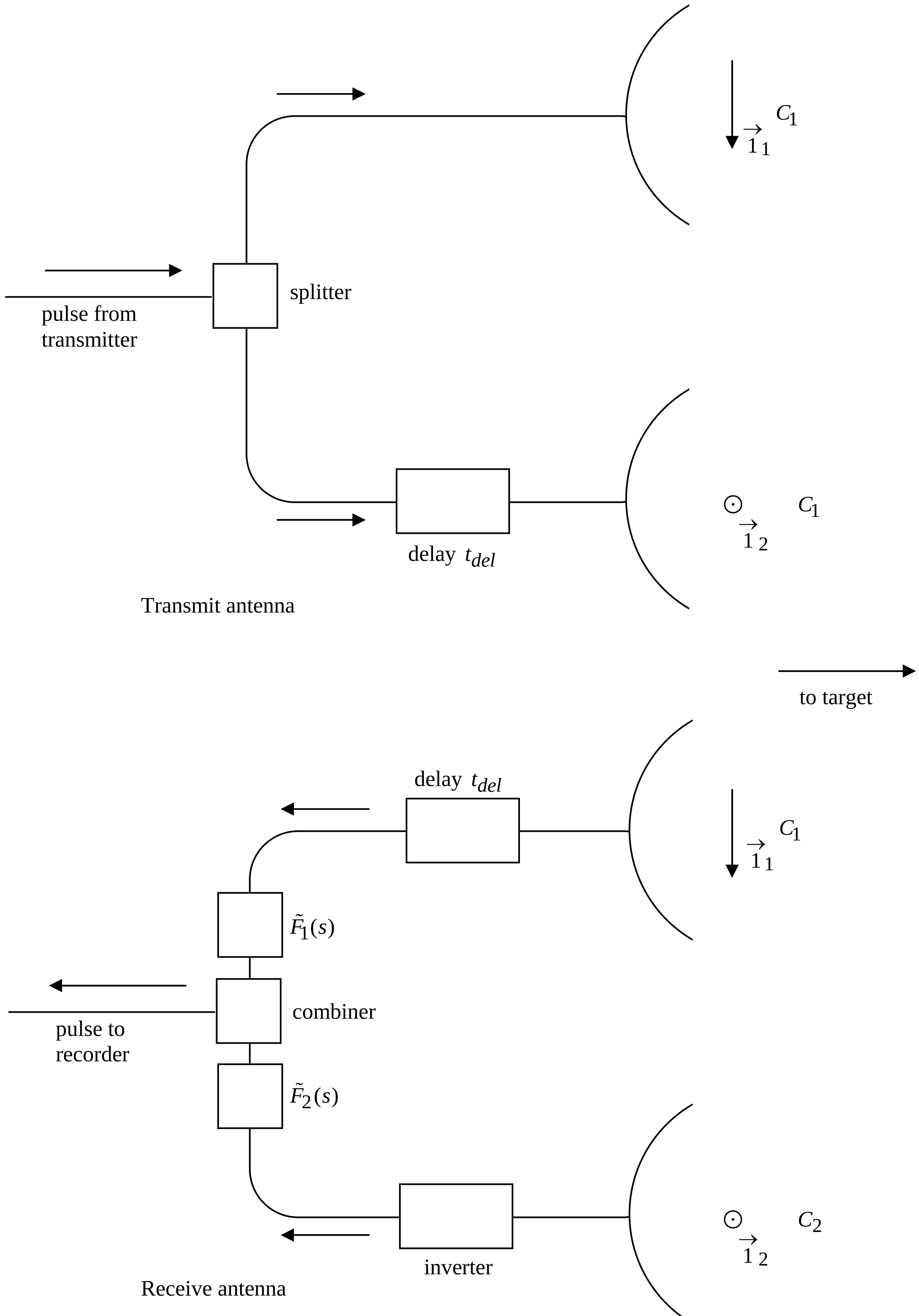

Fig. 4.1 Two Dual-Polarization Antennas

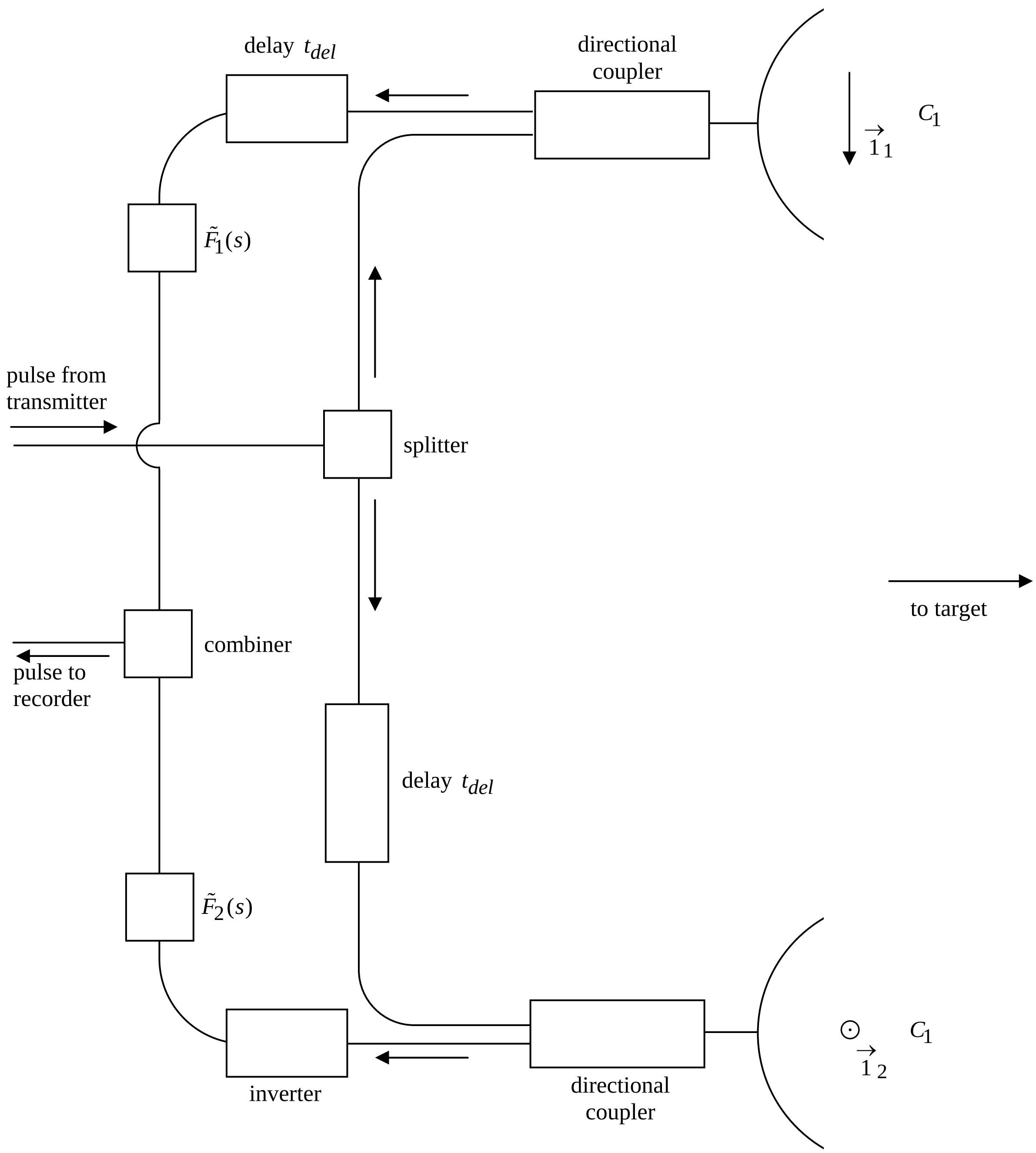

Fig. 4.2 Single Dual-Polarization Antenna with Directional Couplers

5. Single Transmission Polarization with Dual Receive Polarization

One may ask whether one can avoid some of the radar-system complexity by transmitting a single polarization, say $\overrightarrow{1}_1$, while receiving both polarizations $\overrightarrow{1}_1$ and $\overrightarrow{1}_2$. One then considers the copol $V_{1,1}$ and crosspol $V_{2,1}$ signals. We can also include the two filters in the receive channels discussed in Section 3.

Again, with the two scattering orientations as in Fig. 2.1 we can consider the scattering received by the antenna. This gives signals

$$\begin{aligned} V_{1,1}(s) &= \tilde{F}_1(s)\left[\tilde{V}_h(s)\cos^2(\psi) + \tilde{V}_\mathrm{v}(s)\sin^2(\psi)\right] \\ V_{2,1}(s) &= \tilde{F}_2(s)\left[-\tilde{V}_h(s) + \tilde{V}_\mathrm{v}(s)\right]\cos(\psi)\sin(\psi) \end{aligned} \tag{5.1}$$

If we only have a $\tilde{V}_h$, then with equal filters the difference is zero at $\psi = 45^\circ$, but the presence of S_v alters this. With scattering from only S_v the difference is zero for $\psi = -45^\circ$. Various other combinations are possible. One can adjust the gains (filter attenuation) and rotate the antenna for best results. However for equal $\tilde{V}_h$ and $\tilde{V}_\mathrm{v}$ there is no crosspol scattering and differencing the signals will not give a cancellation.

6. Concluding Remarks

The combination (differencing) of two orthogonal copol impulse-radar channels can now be seen to be a potent technique for cancellation of early-time target scattering. The differencing can be weighted by filters for better cancellation. Add to this the rotation of the polarization basis by rotation of the radar antenna(s), and we have yet more flexibility for empirical optimization.

The early-time cancellation must be considered in the context of the late-time resonances for target identification. If some such resonances are linearly polarized, and in a direction not parallel to the polarization(s) of the early-time scattering, this separation of the late-time resonances is possible. Antenna rotation (polarization basis) can also help in this regard.

References

1. C. E. Baum, "Polarimetric Suppression of Early-Time Scattering for Late-Time Target Identification", Interaction Note 499, December 2005.