Techniques and Methods for Adaptive Single Antenna Radar System Polarization Optimization for Anti Jam and Anti Clutter Applications

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Abstract — Antenna polarization refers to the electric field orientation of a radio wave with respect to the earth’s surface. It is advantageous for a radar system to be able to alter its antenna polarization due to the varying nature of target geometries, clutter, and unwanted jamming. This novel approach offers a system in which antenna polarization is adapted to match an optimal state determined from the changing electromagnetic environment.

Keywords—Antenna; Polarization; Adaptive; Radar; Clutter; Jamming; Anti Jam; Radar Cross Section

I. INTRODUCTION

Radar systems are used in commercial and military applications to remotely sense objects using electromagnetic energy. Radars transmit energy and sense its return after the energy is reflected by objects within the radar antenna’s field of view to determine the object’s location, speed, size, and other descriptive traits. The radar senses the desired return (reflected electromagnetic energy) from the objects the radar is intending to detect as well as undesired returns from clutter (returns from land, sea, buildings, and other unwanted objects) and jammers (systems which intentionally or unintentionally radiate energy that degrades the radar’s performance). There are many processing techniques and coding schemes which exist to combat jamming and clutter. However, to the knowledge of the authors, there are no current techniques which can adaptively combat clutter and jammers by optimizing antenna polarization in real time.

Polarization refers to the electric field orientation of a radio wave with respect to the earth’s surface. Polarization types include vertical, horizontal, slant 45, right hand circular, left hand circular, and elliptical. For example, a vertically polarized radio wave has an electric field that oscillates along a vertical line (relative to the surface of the earth) over time. Antenna polarization is characterized by the polarization of the wave it emits. Slant 45 polarizations refer to polarizations which are oriented on a 45 degree slant relative to the earth’s surface between vertical and horizontal. Circular and elliptical polarizations have an electric field vector which rotates over time (the electric field vector traces out an ellipse or circle over time).

Antennas most efficiently receive the same polarization that they transmit. A vertically oriented antenna transmits vertical polarization and most efficiently receives vertical polarization. If a vertically polarized antenna is used to receive horizontally polarized waves, it could introduce approximately 20dB or more loss into your receiver system because the antenna is not oriented in the same direction as the wave you are trying to receive (i.e. the antenna sees very little of the wave) [1]. This is the guiding principle behind this novel system, which controls changes in an antenna’s polarization to find the minimum impact from polarized clutter or polarized jamming. Essentially the radar antenna and receiver are used to detect the polarization of the clutter or jamming, and then the radar’s antenna polarization is rotated or altered in response. With the resulting antenna polarization misaligned to the polarization of the unwanted energy, the effects of clutter or jamming interference is reduced or eliminated.

II. ADAPTIVE POLARIZATION SYSTEM DESCRIPTION

This unique system which reduces the impact of clutter or jamming is shown as a block diagram in Fig. 1. The radar system consists of the typical pieces of a generic radar transceiver: the antenna, transmitter/receiver, and the rest of the generic radar system which provides signal processing. Details of the radar system are not discussed in this paper as this radar system could take many forms with various front ends and processing capabilities. The generic radar system has three new blocks.

![Figure 1. Block Diagram of Polarization Optimization for Anti-Jam and Anti-Clutter Radar](image)

The first block of the new system is the Jam/Clutter Detection block. This block consists of any analog or digital method that determines that jamming or clutter is present in the return. The jam/clutter detection could take on many approaches. Jamming
could be detected by using an analog or digital approach to detect a higher than expected receiver noise floor and/or any unusual targets which possess unrealistic dynamics, unexpected or changing radar cross section (RCS), unexpected or changing locations, and other abnormalities. Clutter could be detected by determining the location of returns and correlating them to where natural obstructions should be located.

When jamming or clutter is detected, the power level of the unwanted return is stored in memory. The polarization of the radar antenna(s) is then altered either electrically or mechanically to yield a new radar polarization by the Polarization Control block. The new receive levels from jamming or clutter are determined by the Jam/Clutter Detection block and fed to the Memory block. If the new jamming or clutter received power levels are smaller (have been diminished by the new radar polarization orientation), then this polarization orientation is stored as being an improvement over the old orientation and will be used as the optimal polarization orientation unless a repeat of this process yields a new optimal orientation.

It is worth mentioning that all real desired radar targets will also have a radar cross section (RCS) that varies with polarization and, therefore, varying returns levels for various radar polarizations [1]. If the system detects a greatly reduced return from desired targets for various polarization orientations this should be incorporated into the decision for the “optimal” polarization orientation of this radar system at that instance in time. Essentially the “optimal” polarization orientation should be a joint decision between having larger return levels from desired realistic targets and having diminished return levels from jamming and clutter.

III. ADAPTIVE POLARIZATION SYSTEM EXAMPLES

To show how this system is useful, a possible radar scenario with unwanted clutter is shown in Fig. 2. The radar transceiver transmits a vertically polarized wave. This wave hits the intended target, which in this example is an airplane being tracked for commercial or military purposes. The wave also hits an unintended target such as a vertically oriented building, group of trees, mountain, radio tower, etc. The radar return is shown in the graph at the top right and shows that there are sufficiently strong returns from the intended target, but even stronger returns from the unwanted clutter. This example shows the object causing clutter is vertically large and relatively smaller in the horizontal direction. This indicates that it will return a larger signal for a vertically polarized radar and a smaller signal for a horizontally polarized radar.

Fig. 3 shows what would happen if the radar transceiver rotated its polarization to horizontal. The return from the clutter rotated is decreased as its size in the horizontal direction is smaller than that of the vertical direction. Also, the return from the intended target increases as the airplane is larger in the horizontal direction than it is in the vertical direction. The unwanted return is decreased by altering the antenna’s polarization. This same example scenario is also applicable for a scenario where the unwanted energy is from a jamming transmission. This scenario shows how altering the radar transceiver’s polarization can reduce the impact of clutter or jamming.

The advantages of having a radar system that can dynamically change its polarization become even more apparent with a jammer example. For a monostatic radar system, the received power from a given target return can be found using (1) [3,4].

\[ P_{Rx} = \frac{P_{Tx}}{G_{ant}} \sigma \lambda^2 R \]

\( P_{Rx} \) is the radar’s transmit amplifier output power, \( G_{ant} \) is the radar’s antenna gain, \( \sigma \) is the RCS of the reflecting object, \( \lambda \) is the wavelength of the radiated wave, and \( R \) is the distance.
between the radar and the reflecting object. This equation does not account for atmospheric losses, but is sufficient for this example.

\[ S(dBW) = 10 \log_{10}(P_{rx}) = 10 \log_{10}\left( \frac{P_{tx}\sigma \lambda^2}{(4\pi)^2 R^2} \right) \]  

(1)

Equation (1) indicates the power received from objects reflecting the radar transmission. However, the radar may also receive unwanted energy from a jamming source that is transmitting energy which interferes with the radar’s ability to receive. The amount of power that the radar receives from an unwanted jammer is found in (2) [3,4]. \( P_{tx-jam} \) is the jammer’s transmit amplifier output power, \( G_{ant} \) is the gain of the radar’s antenna, \( G_{jam} \) is the gain of the jammer’s antenna, \( \lambda \) is the wavelength of the radiated wave, \( R \) is the distance between the jammer and the radar.

\[ J(dBW) = 10 \log_{10}(P_{rx-jam}) = 10 \log_{10}\left( \frac{P_{tx-jam}G_{ant}G_{jam}\lambda^2}{(4\pi)^2 R_j^2} \right) \]  

(2)

Equations (1) and (2) do not take into account any polarization mismatch loss which this proposed radar architecture takes advantage of. Equation (1) does not need a polarization mismatch term since the radar is using the same antenna for transmit and receive (i.e. the antenna cannot be oriented differently than itself). Equation (2) requires polarization mismatch to be incorporated as a loss into the equation which accounts for any disorientation between the radar antenna and the jammer antenna. This polarization mismatch term indicates a loss in the power received from the jammer due to the jammer antenna and radar antenna possibly having different polarization orientations (e.g. horizontal and vertical). Equation (3) is the resulting jammer power equation with the new antenna polarization mismatch loss term \( L_{ap} \). Equation (4) shows how antenna polarization mismatch loss is calculated for linearly polarized antennas where \( \theta \) is the mismatch angle between the radar and jammer antennas [5].

\[ J(dBW) = 10 \log_{10}(P_{rx-jam}) = 10 \log_{10}\left( \frac{P_{tx-jam}G_{ant}G_{jam}\lambda^2}{L_{ap}(4\pi)^2 R_j^2} \right) \]  

(3)

\[ L_{ap} = \frac{1}{\cos(\theta)} \]  

(4)

Fig. 4 indicates the principle of polarization mismatch loss. In Fig. 4A the transmit antenna is vertically polarized and transmits a vertically polarized wave. The receive antenna is also vertically polarized and receives the signal with no polarization loss. In Fig. 4B the transmit antenna is again vertically polarized transmitting a vertically polarized wave. However, the receive antenna in Fig. 4B is now oriented as slant 45 and therefore has a much smaller effective antenna size (height) along the orientation of the wave. Although the receive antenna in Fig. 4B is the same size as the receive antenna in Fig. 4A, its receive gain is reduced by \( \cos(\theta) \) because its effective height in the vertical plane is smaller by a factor of \( \cos(\theta) \).

The extreme case is shown in Fig. 5 where the receive antenna is orthogonal (perpendicular) to the transmit antenna. This orientation results in the receive antenna theoretically receiving none of the transmitted wave since it is orthogonal to the transmitting antenna.

\[ \frac{J}{S}(dB) = 10 \log_{10}\left( \frac{P_{rx-jam}}{P_{rx}} \right) \]  

(5)
\[
J/S (dB) = 10 \log_{10} \left( \frac{P_{tx,jam} G_{ant} G_{jam} R^2}{L_{AP} (4\pi)^2 R^2} \right)
\]

This new system takes advantage of the \(L_{AP}\) term in (5). The radar system can alter its polarization to purposefully find the polarization mismatch angle between the radar and jammer antennas (or clutter) that minimizes the power received from the clutter or jammer (J) by maximizing the polarization mismatch loss (\(L_{AP}\)). Fig. 6 shows values of J and S for various polarization mismatch angles (\(\theta\)). The solid line shows the received power from the desired object which for this example remains relatively constant. The dashed line shows the received power from the jammer which is greatly reduced for certain angles (\(\theta\)). The plot in Fig. 6 results from an example scenario where the values in (1) and (3) are \(P_{tx-jam} = 10\)Watts, \(G_{jam} = 10\)dBi, \(\lambda = 0.15m\), \(R = 10\)nmi, \(L_{AP}\) varies with \(\theta\) according to (3), \(P_{tx} = 1,000\)Watts, \(G_{ant} = 40\)dBi, \(\sigma = 16\)dBsm, and \(R_j = 100\)nmi.

Figure 6. Jammer and Signal Power Levels for Various Polarization Mismatch Angles

Real antennas have a limited polarization loss when orthogonal to the wave polarization. The orthogonal polarization mismatch loss is known as co-pol to cross-pol ratio (co/x-pol) and is usually at most 15-20dB for linearly polarized antennas. Fig. 6 represents a system with an ideal (infinite) co/x-pol ratio. Fig. 7 shows the resulting J/S ratios for the jamming and target return signal levels from Fig. 6 as well as two more realistic polarization mismatch loss models which cut-off at 15dB and 20dB co/x-pol ratios respectively.

IV. CONCLUSION AND FUTURE WORK

This work presents a novel radar antenna system which dynamically changes polarization in the presence of clutter and jamming. The methods described use a sense, observe, decide, and react decision process to optimize the antenna polarization state. The optimal antenna polarization state is one that minimizes the received power levels from polarized clutter and jamming signals. Future work could be performed to develop a functional unit which demonstrates the decision process and control of an antenna’s polarization in the presence of polarized clutter or jamming.

REFERENCES