POLARIZATION DIVERSITY FOR REDUCTION OF SCATTERING FROM SPATIALLY PERIODIC PERFECTLY CONDUCTING SURFACES

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I. Introduction

Detection of targets airborne above the ocean surface is difficult using conventional radars due to the strong clutter response of the ocean surface. It is thus desirable to find ways to reduce the strength of the scattering from the ocean surface relative to the target. One method for achieving this is to use polarization-diverse ultra-wideband signals, wherein the polarization states of transmitting and receiving antennas are varied to minimize the clutter response.

This paper evaluates the effect of varying the polarization states of the transmitting and receiving antennas on the target and sea clutter responses. The ocean surface is modeled as a spatially periodic conducting surface and the target is a conducting missile with 4 orthogonal stabilizing fins. The response of the surface is calculated using the method-of-moments for both TE (horizontal) and TM (vertical) excitation. The polarimetric response of several realistic targets (aircraft and missiles) are measured and used to evaluate the best polarization state for target detection.

II. Theory

The scattered field response of a finite 2-dimensional conducting sea surface model has been found through both experimental and theoretical means. This section presents the theory for the cases of TE and TM polarization. Consider a general finite sized perfectly conducting surface with a TE (or TM) excitation as shown in Figure 1. The field scattered by the periodic conducting surface can be computed from the surface currents, $K_u(u)$, which are solutions of the electric field integral equation (EFIE)

$$\hat{u}\cdot\vec{E}^i(\vec{\rho}(u)) = \frac{\omega\mu_o}{4}\int_\Gamma \hat{u}\cdot\hat{u}' K_u(u')H_o^{(2)}(k|\vec{\rho}-\vec{\rho}'(u')|)du' + \frac{1}{4\omega\epsilon_o}\frac{\partial}{\partial u}\int_\Gamma \frac{\partial K_u(u')}{\partial u'}H_o^{(2)}(k|\vec{\rho}-\vec{\rho}'(u')|)du' \tag{1}$$

for the TM case, and the TE case EFIE

$$\hat{z}\cdot\vec{E}^i(x,y) = \frac{\omega\mu_o}{4}\int_\Gamma K_z(x',y')H_o^{(2)}(k|\vec{\rho}-\vec{\rho}'(u')|)dl' \tag{2}$$

where $H_o^{(2)}$ is the zeroth order Hankel function of the second kind, k is the wavenumber, ω

is the radian frequency, μ is the permeability, and $\vec{E}^i$ is the incident electric field. For the case of a single-valued surface function, $y(x)$, the EFIE for TM excitation becomes

$$\hat{u}\cdot\vec{E}^i(x,y(x)) = \frac{\omega\mu_o}{4}\int_\Gamma \hat{u}\cdot\hat{u}' K_u(x')H_o^{(2)}(k\sqrt{(x-x')^2+(y(x)-y(x'))^2})L(x')dx' + \frac{1}{4\omega\epsilon_o}\frac{1}{L(x)}\frac{\partial}{\partial x}\int_\Gamma \frac{\partial K_u(x')}{\partial x'}H_o^{(2)}(k\sqrt{(x-x')^2+(y(x)-y(x'))^2})dx' \quad (3)$$

and for TE the EFIE becomes

$$\hat{z}\cdot\vec{E}^i(x,y(x)) = \frac{k\eta}{4}\int_\Gamma K_z(x')H_o^{(2)}(k\sqrt{(x-x')^2+(y(x)-y(x'))^2})L(x')dx' \quad (4)$$

where $L(x)$ is the arc length function of the surface. In solving the EFIE by the MoM, the unknown surface current density is expanded in a series of basis functions $f_n(x)$. The amplitudes of the basis functions a_n are computed using Galerkin's method. Pulse basis functions are used in the TE case, and to avoid difficulties with discontinuities in the current, triangular basis functions are used for the TM case. To handle the source point singularity encountered in the self-term, the small argument approximation for the Hankel function is used, and the integrals are computed analytically. Note that for the TM case, the magnetic field integral equation (MFIE) may prove to be more convenient.

III. Calibration of measurement system

To accurately measure the polarimetric scattering parameters of an object, the scattering range must be properly calibrated. For the usual case of linearly polarized receive and transmit antennas, a metal conducting sphere is almost universally used as a calibrator since its response is well known theoretically, is inherently independent of orientation, and has a relatively uniform backscattering spectral response for frequencies above resonance. In the case of cross-polarized antennas (i.e. hv, vh) a different calibrator must be used since the sphere does not depolarize the incident wave. Unfortunately, there is no universally used cross-polarization standard.

A thin wire, inclined at a 45 degree angle with respect to the incident electric field vector (h or v), gives a strong response but is too aspect dependent. A circular thin wire loop however exhibits the same depolarization properties as the thin wire without the aspect sensitivity problem, provided the loop axis is oriented normal to the incident wave vector. Further, the circular thin wire loop antenna has been extensively studied and has a well known theoretical model.

Unfortunately, the circular wire loop is an inherently resonant structure and hence responds strongly for some frequencies and minimally for other frequencies. This characteristic makes the loop somewhat less than ideal as a calibration target since for frequencies where the loop response is minimal the calibration tends to be less reliable due to the reduced signal-to-noise ratio in the measurement. To circumvent this problem, two different sized loops are used to perform the calibration.

IV. Results

A comparison of the calculated and measured TE responses of a spatially periodic surface is shown in Figure 2. A sinusoidal surface with 11 peaks, a wave height of 1", and a wave length of 4" was measured in the frequency band 1-7 GHz and inverse Fourier transformed into the time domain. The theoretical predictions are seen to agree well with the measured results. Figure 3 shows the measured TE backscattered response of a conducting missile model situated over the surface. Note that the missile response is clearly visible over the surface response. Results for the TM case are similar, except that the amplitude of the field scattered by the sea surface is greater in magnitude than the TE case by a factor of 2. In Figure 4 it is seen that the backscattered responses of the 2 inch missile is equal in magnitude for both the TE and TM cases, due to the symmetry of the four orthogonal stabilizing fins.

Using thin wire loops to calibrate the measurement system, it is possible to measure the conducting missile in cross polarization. It is not possible to accurately measure the missile in conjunction with the surface, due to the finite size of the surface. A comparison of the cross-polarized backscattered response of the missile is shown in Figure 5 for different fin orientations. It is seen that the orientation of the stabilizing fins has a large effect on the cross-polarized response.

For like polarization, it is concluded that TE is a much better orientation since the magnitude of the scattered field response from the surface is much less than that from the TM case. This would make it easier to detect a target situated directly over the surface, since the magnitude of the field scattered from the missile is nearly identical for both the TE and TM cases. The cross-polarized response of the missile is on the order of 10 times smaller than the like-polarized responses. However, the cross-polarized response of an infinite 2-dimensional is theoretically zero. This might allow for a greater ratio of the magnitudes of target to surface scattered fields, for actual sea surfaces.

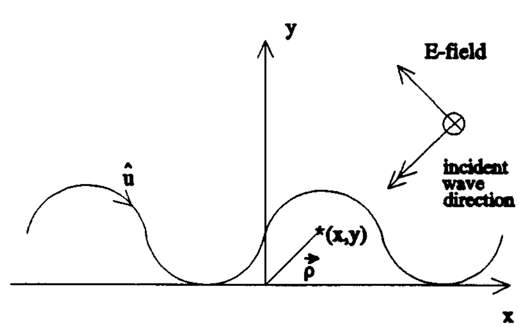

Figure 1. Geometry for finite sized 2-dimensional conducting surface.

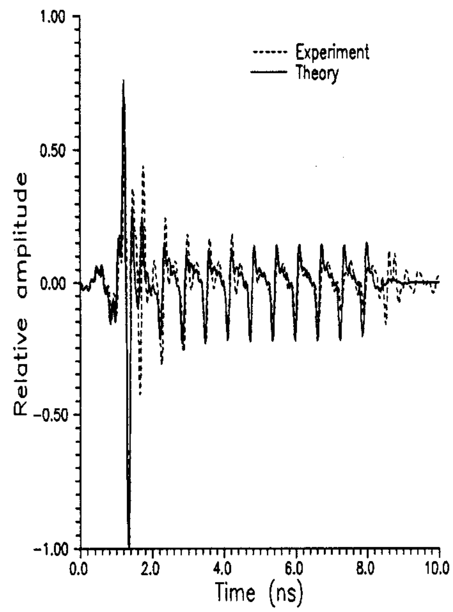

Figure 2. Comparison of scattering from sea surface model for TE polarization.

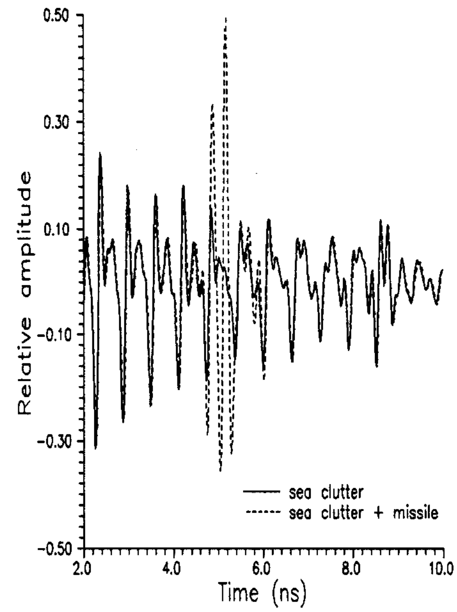

Figure 3. Scattered field response of 2" missile model over sea surface for TE polarization.

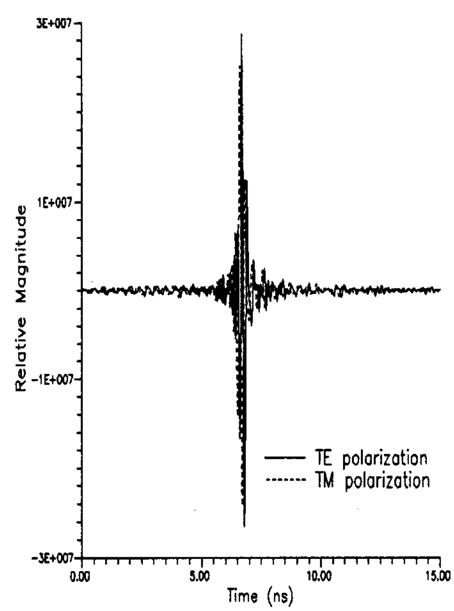

Figure 4. Scattered field response of isolated missile for TE and TM polarization.

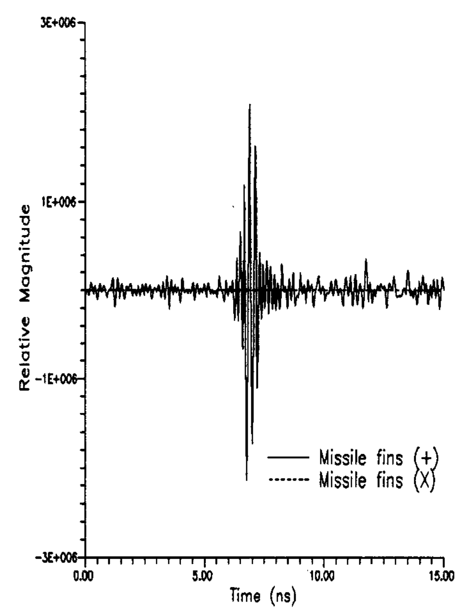

Figure 5. Cross-polarized scattered field response of isolated missile.