SCATTERING OF TRANSIENT RADIATION FROM AN IMPERFECTLY-CONDUCTING INFINITE PERIODIC SEA SURFACE

A. Norman*, J.Song, D.P. Nyquist, J. Ross, P. Ilavarsan
M. Seneski, K.M. Chen, and E.J. Rothwell

I. Introduction

The performance of an impulse radar in a sea-surface environment is strongly influenced by the ability to minimize the sea clutter. In this paper, two methods of determining the transient scattering from a sea-surface interface will be investigated. One method will utilize the Rayleigh approximation, and therefore will be valid only for certain parameter regimes, while the other method will use MFIE's and will yield correct results for all regimes. The advantage of the Rayleigh approximated analysis is in the computation time involved. In both methods, frequency-domain results are obtained. A large bandwidth of frequency is needed to properly reconstruct the time-domain transient response; this implies a large number iterations is needed to implement such a bandwidth. The knowledge gained from this analysis will allow for a minimization of sea clutter, thus improving impulse radar detection in a sea environment. The TM polarization is of the greatest interest, because of the Brewster angle phenomenon, therefore only the TM case will be discussed in detail.

II. Theory

It is assumed that the air region (1) is located above the sea-air interface, with permittivity $\epsilon_1 = \epsilon_0$, and the sea-water region is located below the interface with permittivity ϵ_2. Wavenumbers in the two regions are $k_i = \omega\sqrt{\mu_0 \epsilon_i}$ for $i = 1,2$. For this development the problem is considered to be only 2-D (uniform in the y direction), with the sea-air interface characterized by $z(x) = -h\cos(2\pi x/L)$ with h the sea height and L its period.

For a plane incident wave, $H_y^i = A_0 \exp(-j\beta x)\exp(jqz)$, where $\beta = k_1 \sin\theta_i$, $q = k_1\cos\theta_i$ and θ_i is the angle of incidence. $H_y(x,z)$ is the generating field component, which satisfies the 2-D Helmholtz equation in both regions (1) and (2). The resulting boundary conditions are,

$$H_{y2} = H_{y1} \quad , \quad \frac{\partial H_{y2}}{\partial n} = \frac{\epsilon_2}{\epsilon_1}\frac{\partial H_{y1}}{\partial n} \tag{1}$$

II.A Rayleigh approximation method

By Floquet's Theorem, the scattered and transmitted waves can be represented as a summation of Floquet modes with unknown amplitudes. These waves must also obey the scalar helmholtz equation in their respective regions, which when applied yields a second order differential equation with constant coefficients. The solution can be approximated by the Rayleigh hypothesis, which states that the scattered field can be approximated by summing only the space harmonics that are travelling upward away from the air-sea interface, and likewise, the transmitted field can be approximated by summing the space harmonics that are travelling downward away from the air-sea interface. Therefore, by the Rayleigh hypothesis the scattered waves in the two regions ($i=1,2$) can be approximated as,

$$H_i(x,z) = \sum_{n=-\infty}^{\infty} B_{in} e^{-j\beta_n x} e^{\mp j q_{in} z} \tag{2}$$

where, $\beta_n = \beta + 2n\pi/L$, and $q_{in} = \sqrt{k_i^2 - \beta_n^2}$, branch cut such that $Im\{q_{in}\} < 0$. Applying boundary conditions at the air-sea interface, and then using Galerkin's method to form a system of coupled equations, the problem can be reduced to matrix equations for the unknown coefficients B_{1n}, B_{2n}. Eqs. (2) subsequently provide a solution for the scattered field. The coupled matrix equations are

$$\sum_{n=-\infty}^{\infty} (\beta_n I_{1mn}^{(1)} - q_{1n} I_{1mn}^{(2)}) B_{1n} - \frac{\epsilon_1}{\epsilon_2} \sum_{n=-\infty}^{\infty} (\beta_n I_{2mn}^{(1)} + q_{2n} I_{2mn}^{(2)}) B_{2n} = A_o(-\beta I_m^{(3)} - q I_m^{(4)}) \tag{3}$$

$$-\sum_{n=-\infty}^{\infty} I_{1mn}^{(2)} B_{1n} + \sum_{n=-\infty}^{\infty} I_{2mn}^{(2)} B_{2n} = A_o I_m^{(4)} \tag{4}$$

where,

$$I_{imn}^{(1)} = -j\pi h/L[\, j^{\pm|m-n+1|} J_{|m-n+1|}(q_{in}h) - j^{\pm|m-n-1|} J_{|m-n-1|}(q_{in}h)]$$

$$I_{imn}^{(2)} = j^{\pm|m-n|} J_{|m-n|}(q_{in}h)$$

$$I_m^{(3)} = -j\pi h/L[\, j^{-|m+1|} J_{|m+1|}(qh) - j^{-|m-1|} J_{|m-1|}(qh)]$$

$$I_m^{(4)} = j^{-|m|} J_{|m|}(qh)$$

II.B MFIE method

The scattered field is composed of a superposition of cylindrical waves emanating from line sources located on the sea-air interface. Applying the 2-D Green's theorem, and invoking the boundary conditions, it can be shown that the magnetic field and its normal derivative satisfy the following coupled integral equations for all points $\vec{\rho} \in C_p$ on the interface.

$$\frac{H_y(\vec{\rho})}{2} - PV\int_{C_p} \left[H_y(\vec{\rho}\,') \frac{\partial G_1(\vec{\rho}\,|\,\vec{\rho}\,')}{\partial n'} - \frac{\partial H_y(\vec{\rho}\,')}{\partial n'} G_1(\vec{\rho}\,|\,\vec{\rho}\,') \right] dl' = H_y^i(\vec{\rho}) \tag{5}$$

$$\frac{H_y(\vec{\rho})}{2} - PV\int_{C_p}\left[H_y(\vec{\rho}')\frac{\partial G_2(\vec{\rho}\,|\,\vec{\rho}')}{\partial n'} - \frac{\epsilon_2}{\epsilon_1}\frac{\partial H_y(\vec{\rho}')}{\partial n'}G_2(\vec{\rho}\,|\,\vec{\rho}')\right]dl' = 0 \qquad (6)$$

where PV implies principal-value integration, and C_p is the first period of the sea surface. The periodic Green's-function kernels represented by Floquet-mode series are,

$$G_i(\vec{\rho}\,|\,\vec{\rho}') = -\frac{j}{2L}\sum_{n=-\infty}^{\infty}\frac{e^{-j\beta_n(x-x')}e^{-jq_{in}|z-z'|}}{q_{in}} \qquad i=1,2 \qquad (7)$$

The integral equations can be solved numerically by the Method of Moments technique. With the solution for the magnetic field and its normal derivative on the surface, the scattered fields can be determined for an arbitrary field point. The MFIE method is valid for any simply shaped air-sea interface, as long as that interface is extended to be periodic.

III Results

The Rayleigh approximated results provide a good check for the MFIE results, when the sea height is in the valid regime ($2\pi h/L<.448$), see Figures 1-5. Note, however, if the sea height is extended beyond the valid regime the Rayleigh approximated results still agree with those of the MFIE for points well off the surface. The surface fields are influenced greatly when the sea height exceeds the valid region, see Figure 1.

For a mode to propagate in region (1) q_{1n} must be a real number, and this implies $|\beta_n|<k_1$. This introduces a cut-off frequency phenomena to the scattering problem, see Figures 2 and 3. By taking an IFT of the frequency domain spectra, the time-domain characteristics can be examined, see figures 4 and 5.

Information about the Brewster angle phenomenon can be extracted by varying the incidence angle and observing the forward scattered amplitudes. For the lossy case, there is no true Brewster angle where the reflected wave vanishes, but there is a well defined minimum, see figures 6 and 7.

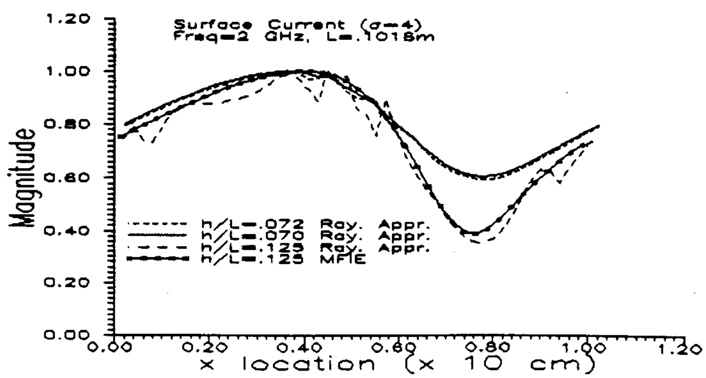

Figure 1 MFIE results are smooth up to h/L=.125, indicating the Rayleigh approximated results break down between h/L=.07 and .072.

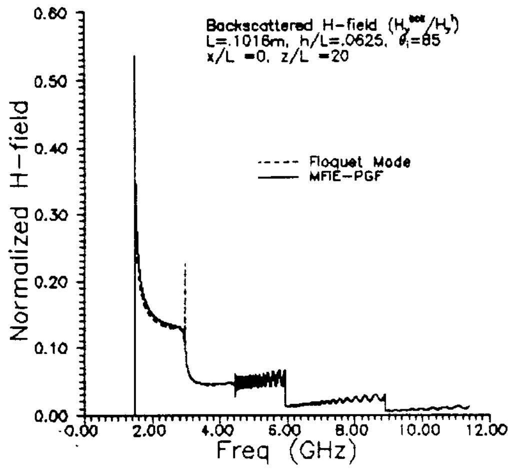

Figure 2 Spectral magnitudes for backscattered fields.

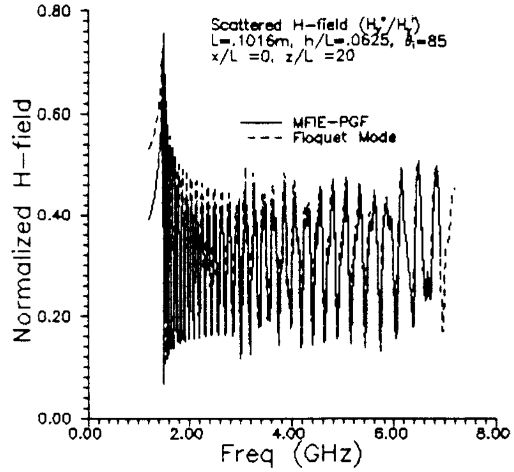

Figure 3 Spectral magnitudes for total total scattered H-field.

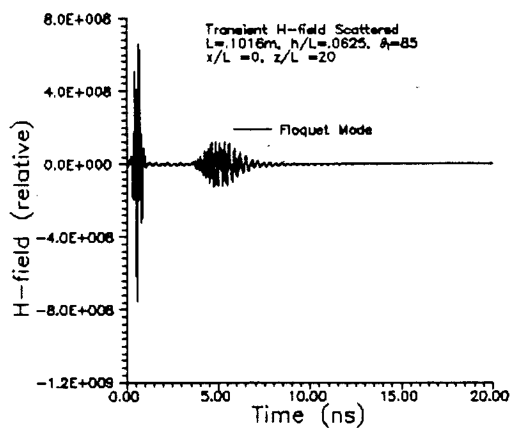

Figure 4 Time-domain response for total scattered H-field.

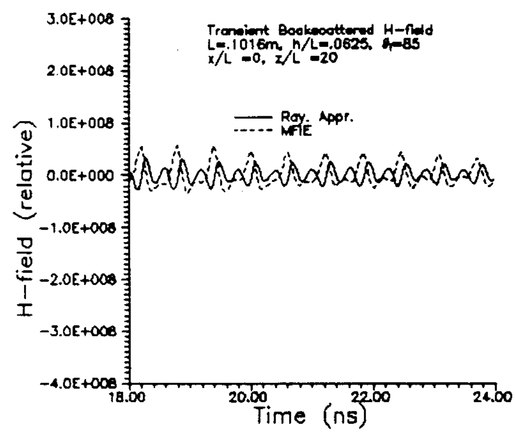

Figure 5 Time-domain response for back-scattered H-field.

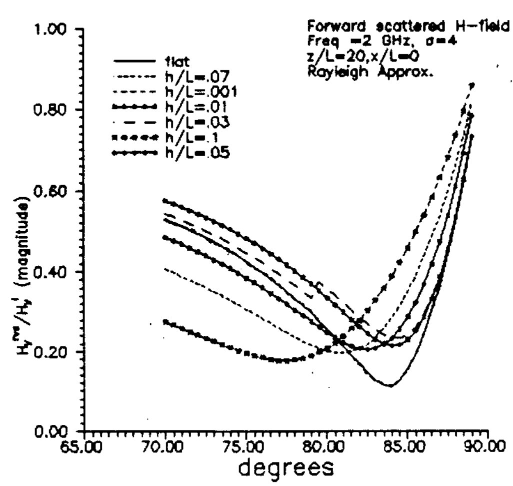

Figure 6 Identification of a Brewster angle for various h/L.

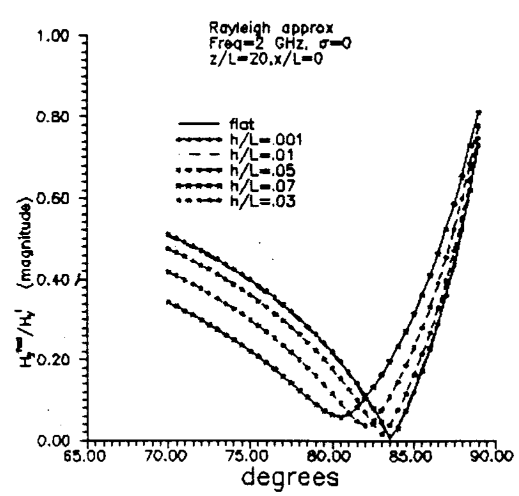

Figure 7 Brewster's angle identification for lossless case (perm = 80).