RADAR DETECTION OF TARGETS IN A SEA CLUTTER ENVIRONMENT USING E-PULSE TECHNIQUE

P. Ilavarasan*, J. Ross, R. Bebermeyer, E. Rothwell,
K. M. Chen and D. Nyquist
Department of Electrical Engineering
Michigan State University
East Lansing, MI 48824

The radar detection of a target flying just above the ocean surface is difficult because the target response is usually overwhelmed by strong sea clutter. Recently, we have studied the feasibility of using an ultra wide band, pulse-type radar combined with the E-pulse technique to address this problem.

To study the nature of sea clutter, the ocean wave is modeled by a sinusoidal conducting surface and a theoretical analysis conducted to calculate the scattering of a short EM pulse from this ocean wave model. An experiment was also conducted to measure the scattering from a simulated ocean wave model illuminated by a short EM pulse either synthesized by sweeping the 1-7 GHz frequency band using a network analyzer or generated by an EM pulse generator. Theoretical and experimental studies indicate that a short EM pulse is reflected principally from the tops of the ocean wave crests. This results in a sea clutter that is periodic with the period determined by the distance between the ocean wave crests.

To increase the probability of detection of the target it is desirable to minimize the sea clutter return. Generally, the application of post-receive processing methods are less desirable than optimization performed in the transmit portion of the system. Thus, one would like to determine if there is an optimal transmitted pulse waveform that would minimize the clutter return. By examining the damped periodic nature of the sea clutter return, it can be seen that a significant portion of the signal can be approximately represented as a sum of exponentially damped sinusoids. Thus, a finite duration E-pulse may be constructed and transmitted such that when it illuminates the ocean wave the sea clutter is minimized while the target response is enhanced.

This paper will demonstrate the utility of the E-pulse method in sea clutter reduction using both theoretical and measured clutter returns from a simulated ocean wave model of sinusoidal conducting surface. It will also be shown that the E-pulse spectrum can be further modified to increase the target response without losing the clutter reduction capability.

RADAR DETECTION OF TARGETS IN A SEA CLUTTER ENVIRONMENT USING E-PULSE TECHNIQUE

P.Ilavarasan, J. Ross, R. Bebermeyer, E. Rothwell,
K.M. Chen and D. Nyquist

Department of Electrical Engineering
Michigan State University
East Lansing, MI 48824

Goal

Increasing the probability of detecting targets in the ocean environment using short interrogating pulses and revealing target response by reducing the sea clutter

Overview

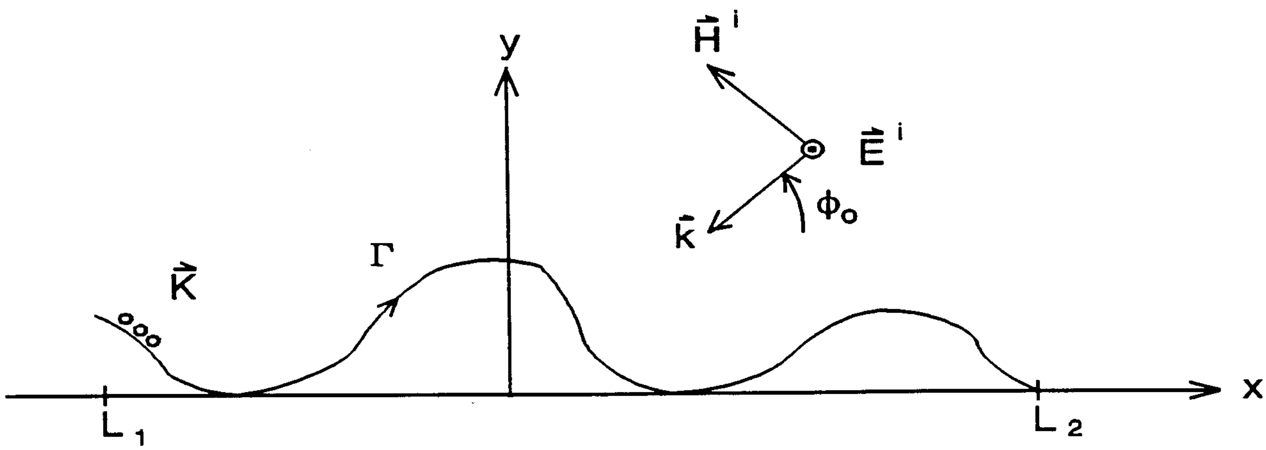
- Theoretical sea clutter response obtained via MoM in frequency domain.
- Experimental sea clutter response measured in frequency domain
- Sea clutter reduction using either frequency-domain E-pulse technique (post-processing) or clutter reducing transmit waveform (CRTW) (pre-processing)

Preliminary

- Sea clutter is modeled as a perfectly conducting periodic sinusoidal surface
- Most of the contribution of the response is due to specular reflections from the wave crests
- Frequency-domain sea clutter response can be represented as a sum of a few exponentials (Frequency domain E-pulse)
- Time-domain sea clutter response can be represented as a sum of a few damped sinusoids (CRTW)
- Complex frequencies or times are extracted using E-pulse technique

Sea Clutter

Theoretical Analysis



- Scattered field of two-dimensional perfectly conducting surface

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

$k = \omega\sqrt{\mu_o\epsilon_o}$ and $\vec{\rho}$ = the position vector in the x-y plane

Γ = contour of the surface

$H_o^{(2)}$ = second kind Hankel function of order zero.

The integral equation for ***K(x)***

$$\int_{L_1}^{L_2} K(x')\, H_o^{(2)}\!\left(k\sqrt{(x-x')^2 + [f(x)-f(x')]^2}\right) L(x')\,dx' = \frac{4}{k\eta} E_z^i(x, f(x))$$

$$L_1 \le x \le L_2$$

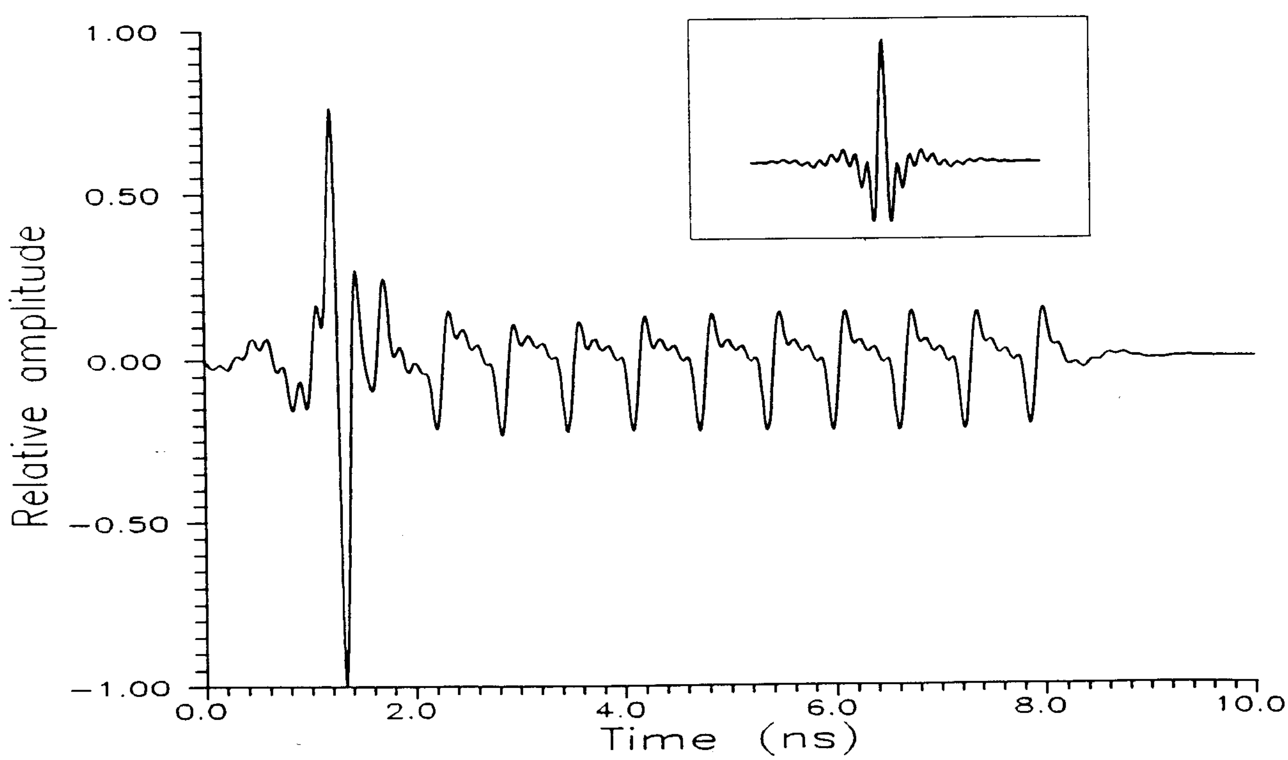
and the function $f(x)$ in our case

$$f(x) = \frac{h}{2}\left[1+\cos\left(\pi\frac{x}{\lambda_w}\right)\right] \qquad -L \le x \le L$$

Rectangular basis functions used to expand the current ***K(x)***

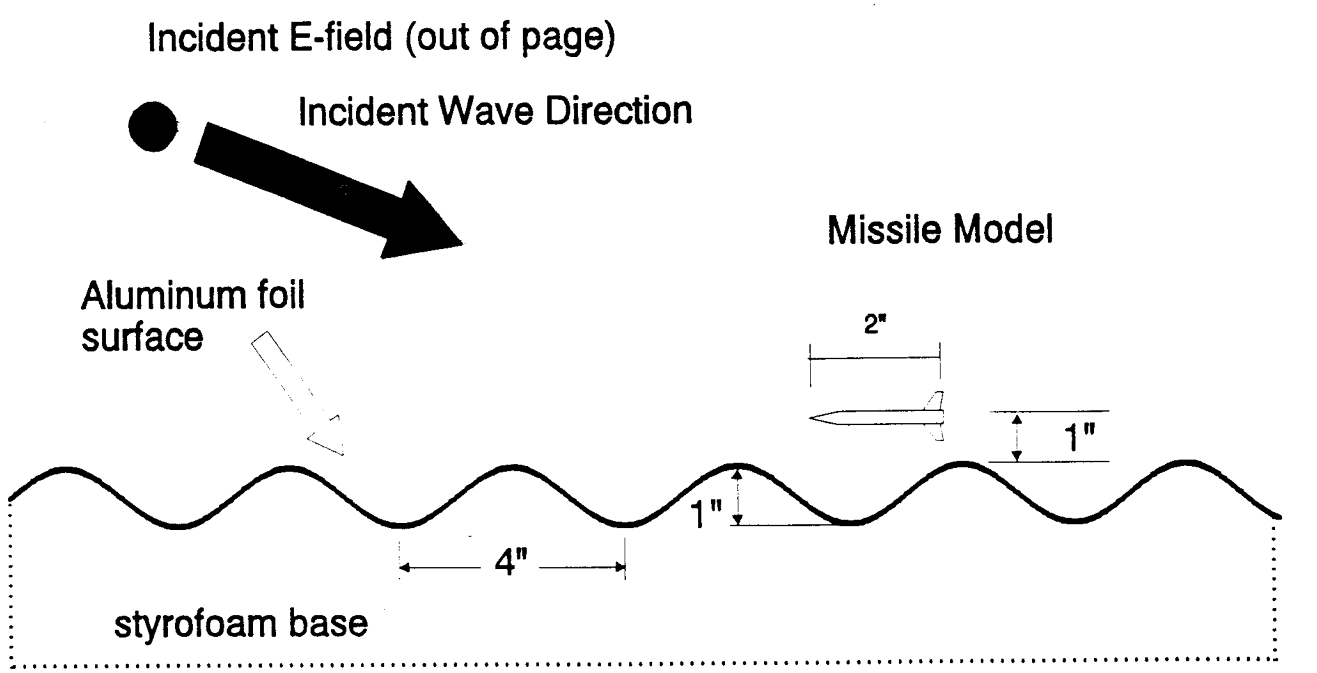
λ_w = water wavelength (wave period width)

- Theoretical time-domain response of sinusoidal sea surface $h=1''$, $L=4''$, $\phi_0=27^0$

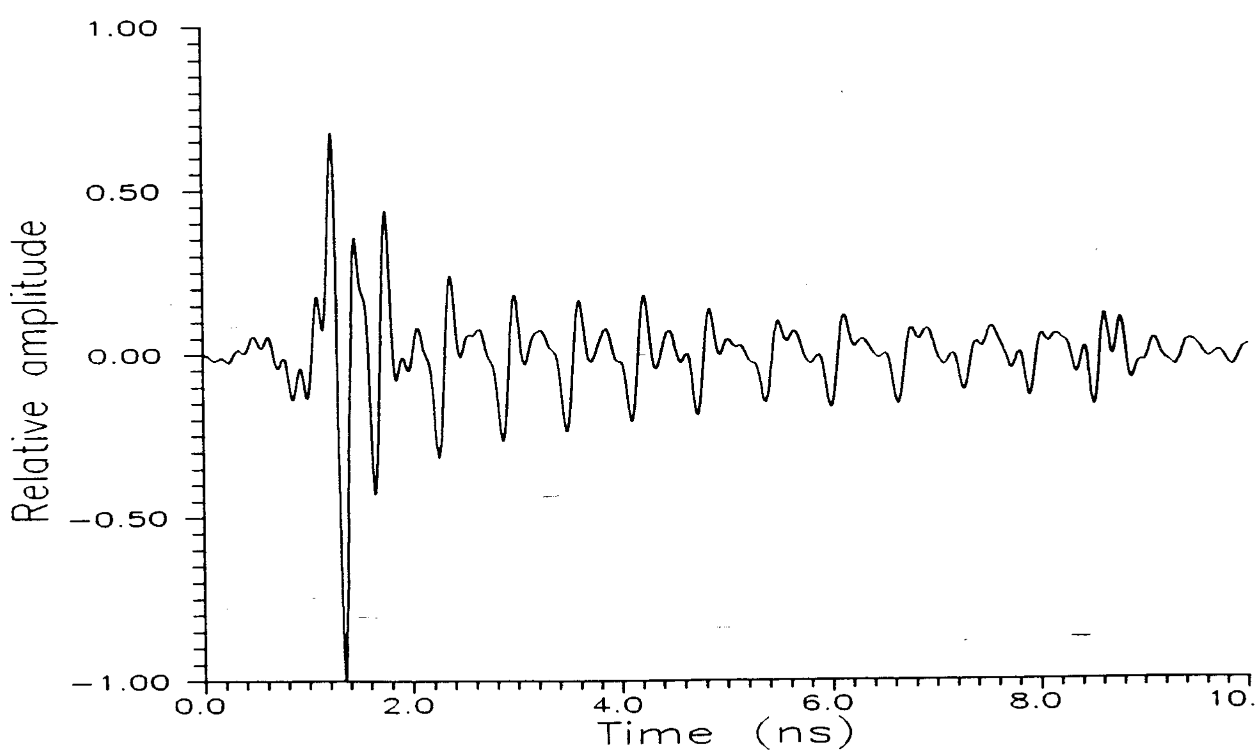


Experimental Analysis

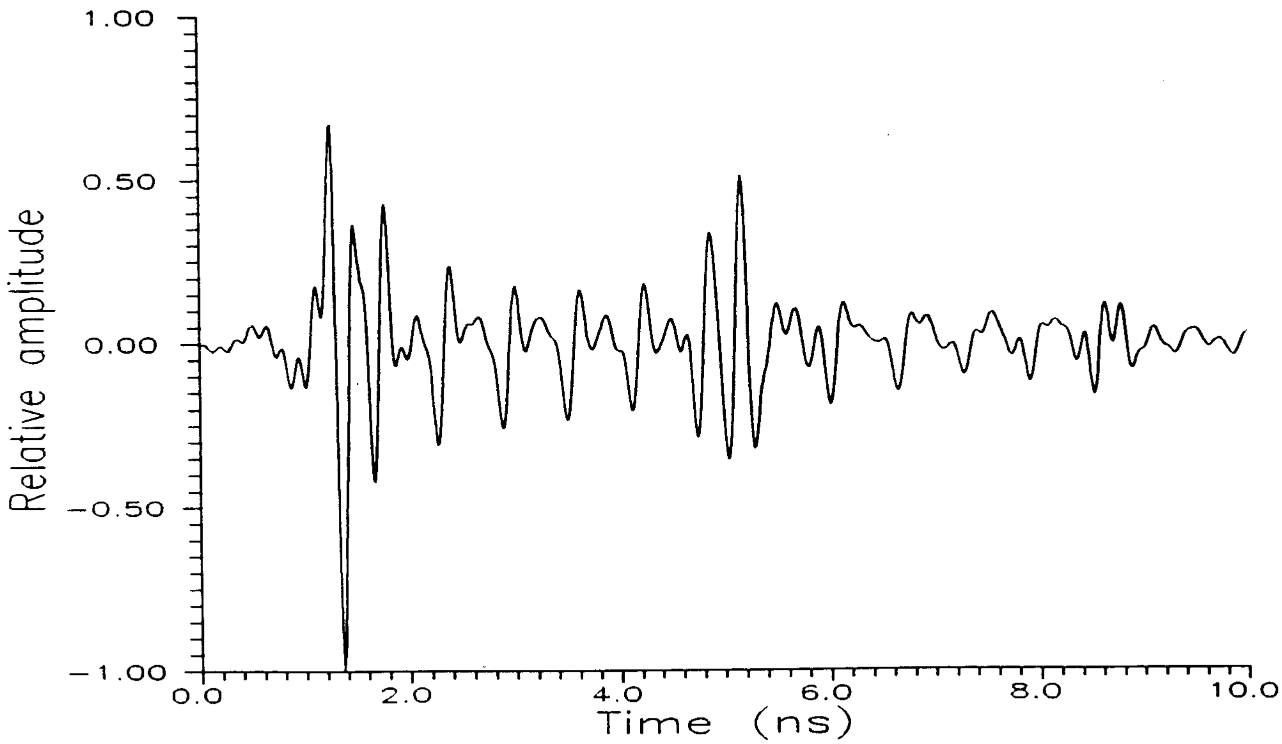
- Simulated sea surface environment



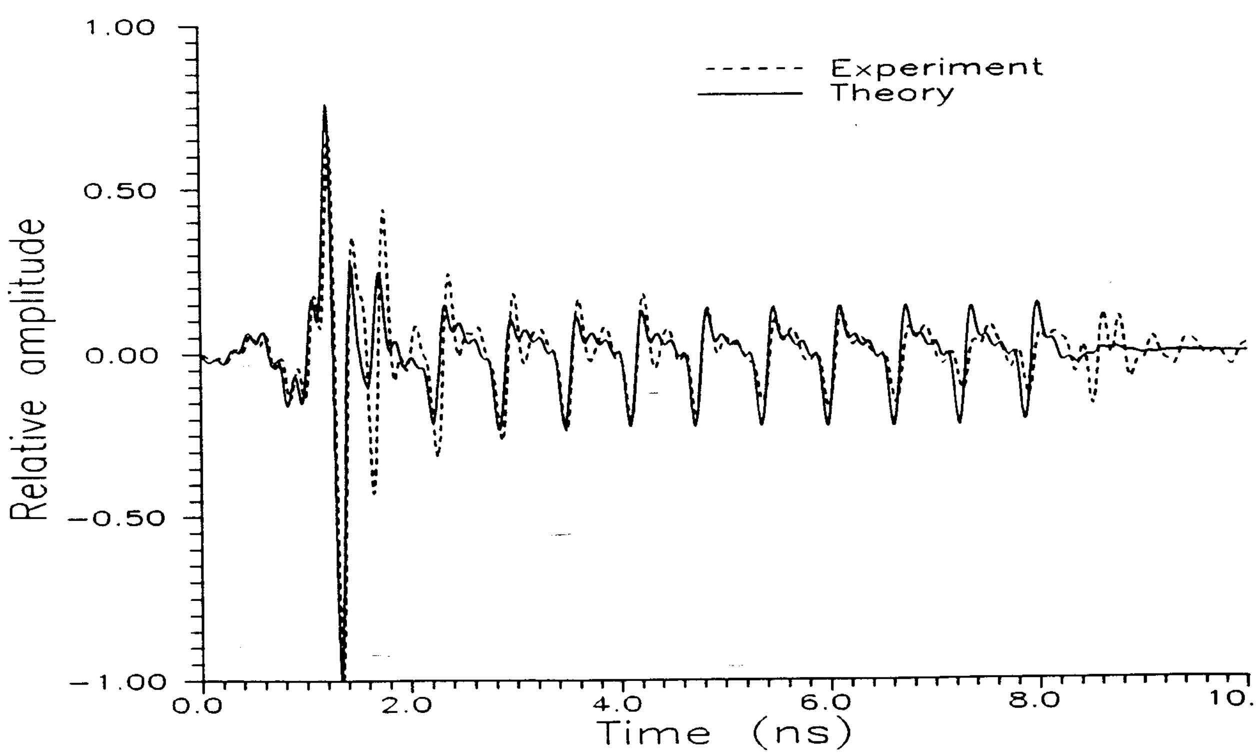
- Measured response of surface (1.0-7.0 GHz)



- Measured response of surface + missile



- Compare the experimental and theoretical sea clutter responses



Sea clutter reduction

Frequency-domain E-pulse

- sea clutter approximately represented as a sum of specular reflections. Altes proposed a simple model

$$r_{sc}(t) = \sum_{m=1}^{M} p(t) * h_m(t - T_m)$$

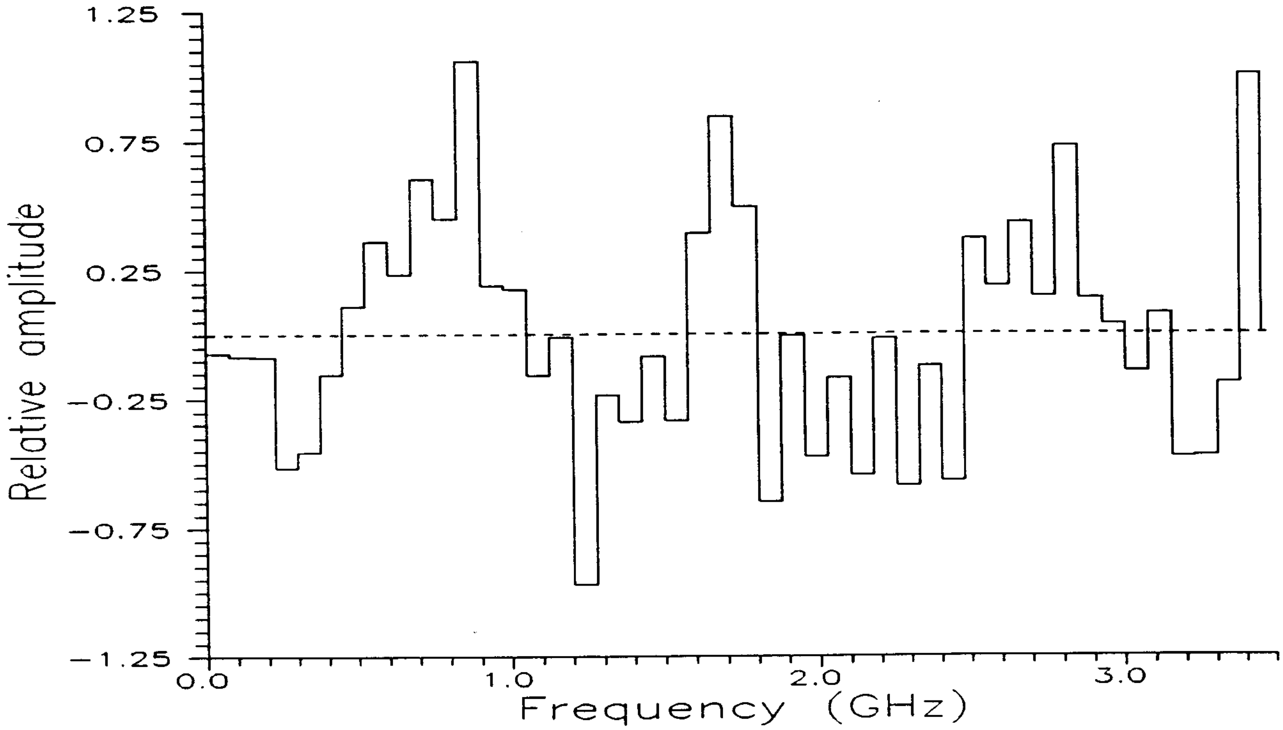
p(t) = incident pulse
$h_m(t)$ = localized impulse response at m^{th} scattering center at time T_m

- Hurst and Mittra suggest that frequency domain response of $r_{sc}(t)$ be represented as an exponential function of frequency (assuming $P(\omega) = \mathscr{F}\{p(t)\}$ slowly varying)

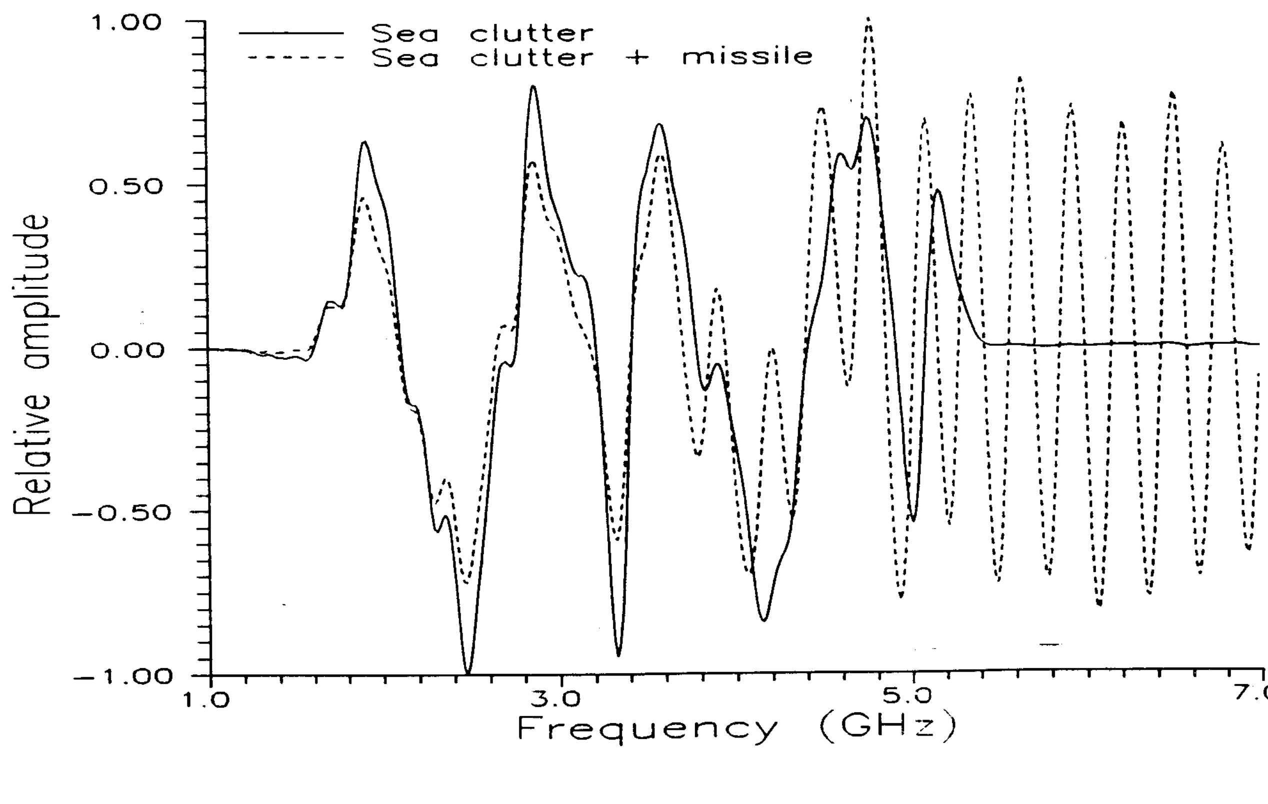
$$R_{sc}(\omega) = \mathscr{F}\{r_{sc}(t)\} = \sum_{m=1}^{M} P(\omega) H_m(\omega) e^{-j\omega T_m} = \sum_{m=1}^{M} B_m e^{\tau_m \omega}$$

$H_m(\omega)$ = transfer function of the m scattering center
$\tau_m = \alpha_m - jT_m$ = complex times associated with scattering center impulse responses

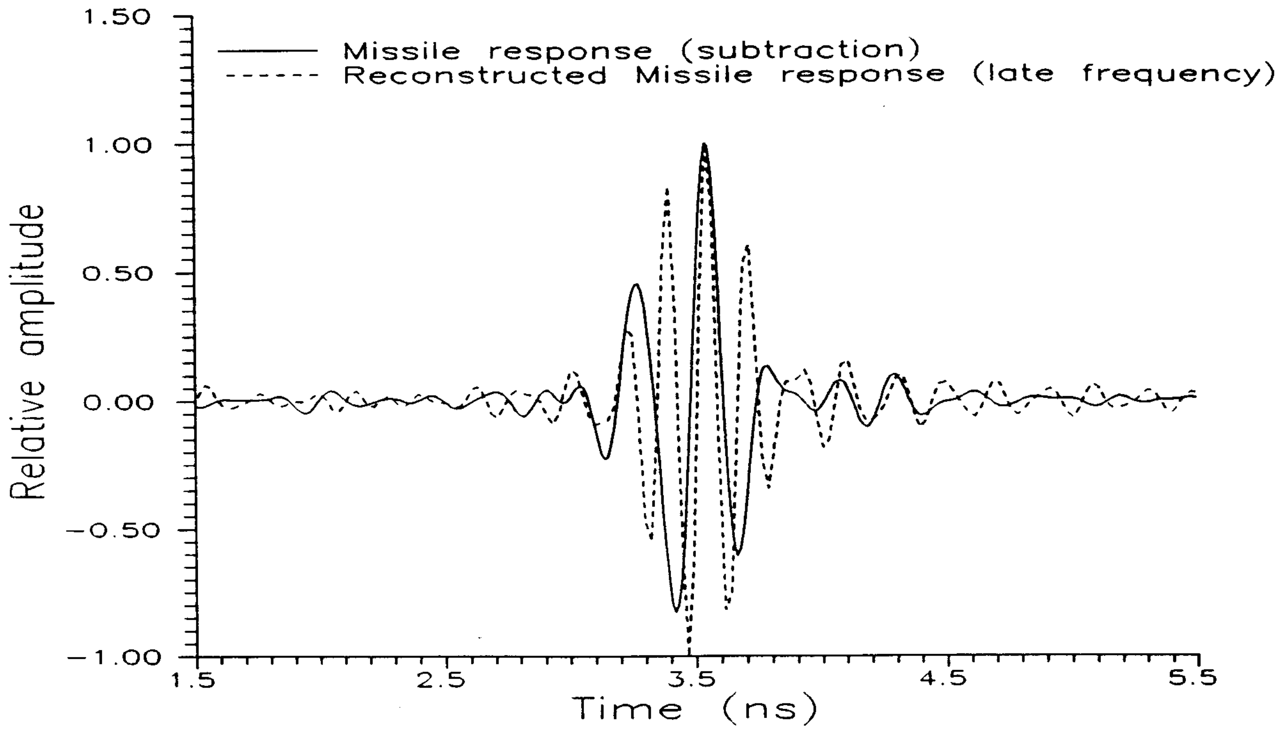
- Frequency domain sea clutter E-pulse is created for measured response



- Convolution of frequency-domain E-pulse of sea clutter with frequency-domain sea clutter response w/ and w/o 2 " missile

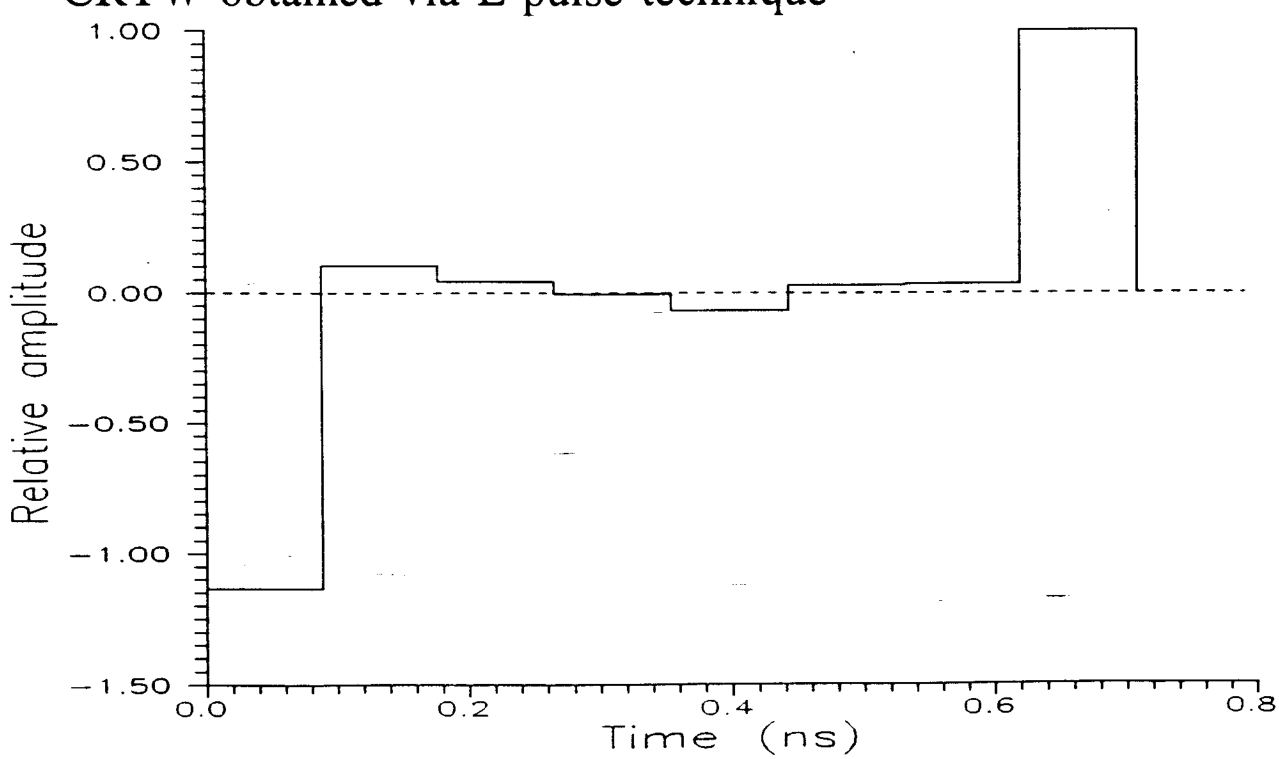


- Missile response and reconstructed missile response from the late frequency convolution

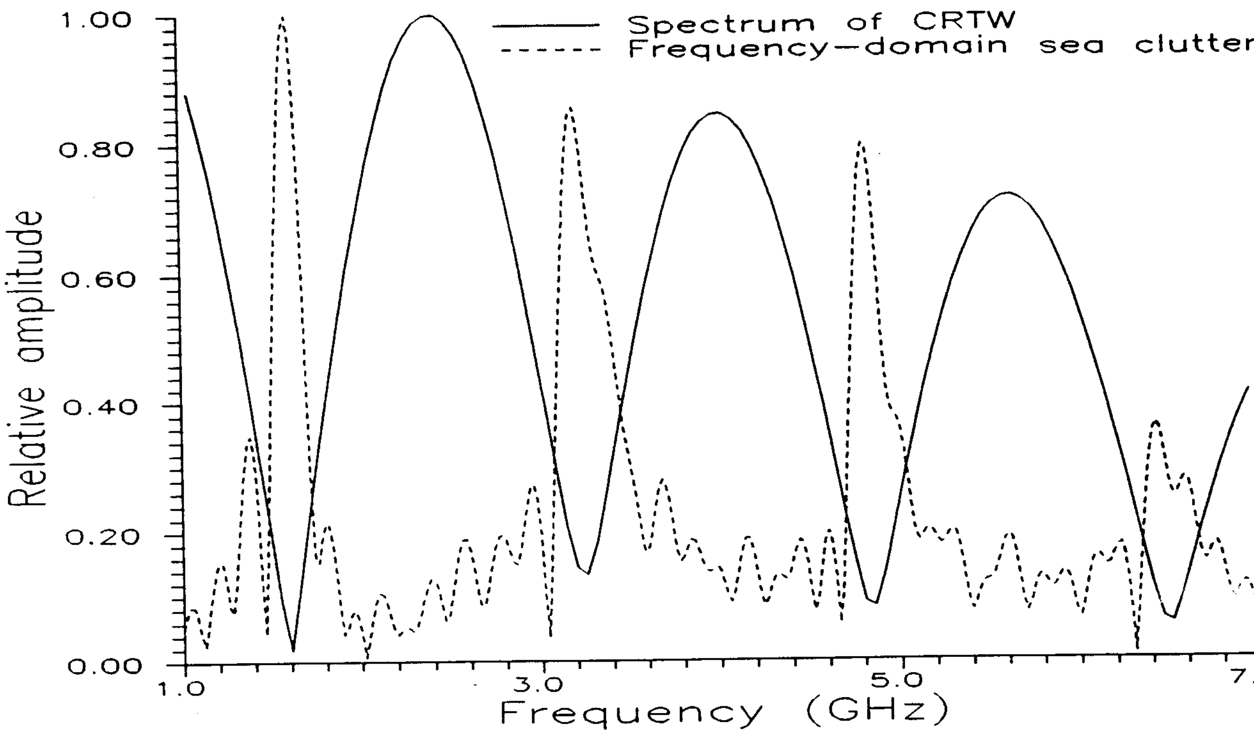


Clutter Reducing Transmit Waveform

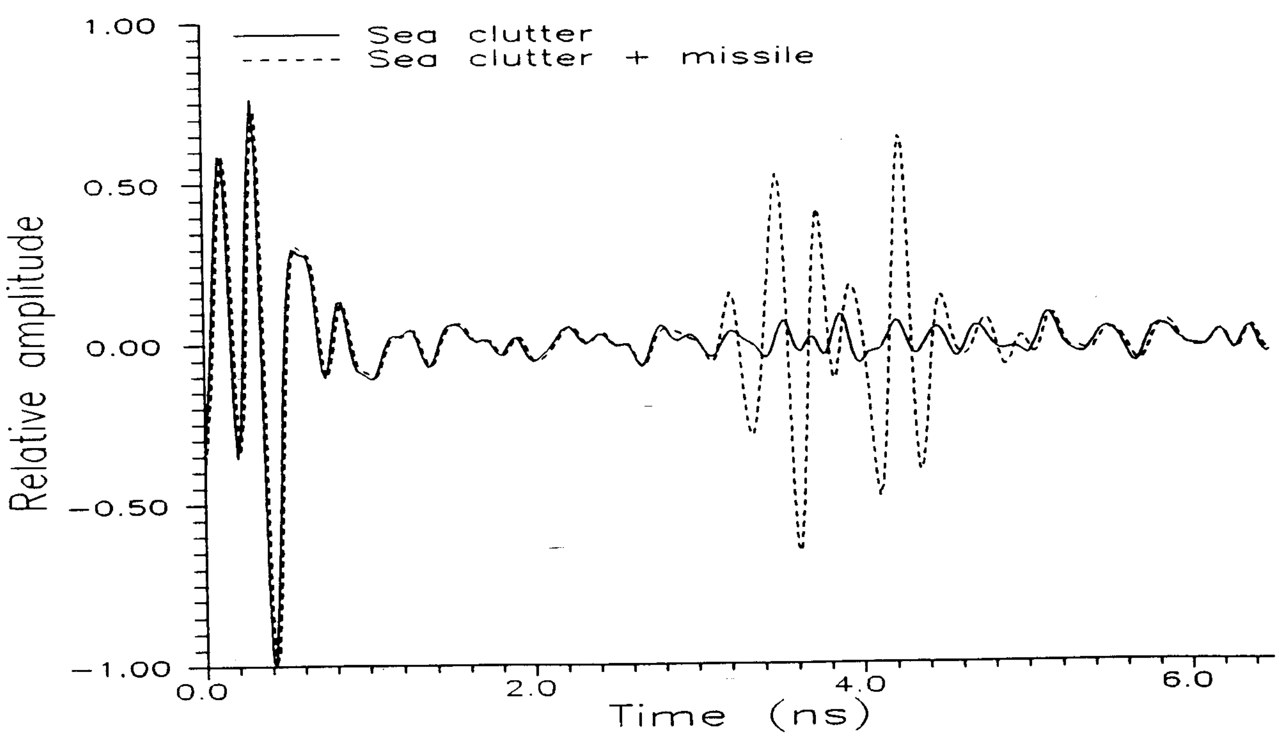
- sea clutter represented as a sum of a few damped sinusoids, and CRTW obtained via E-pulse technique



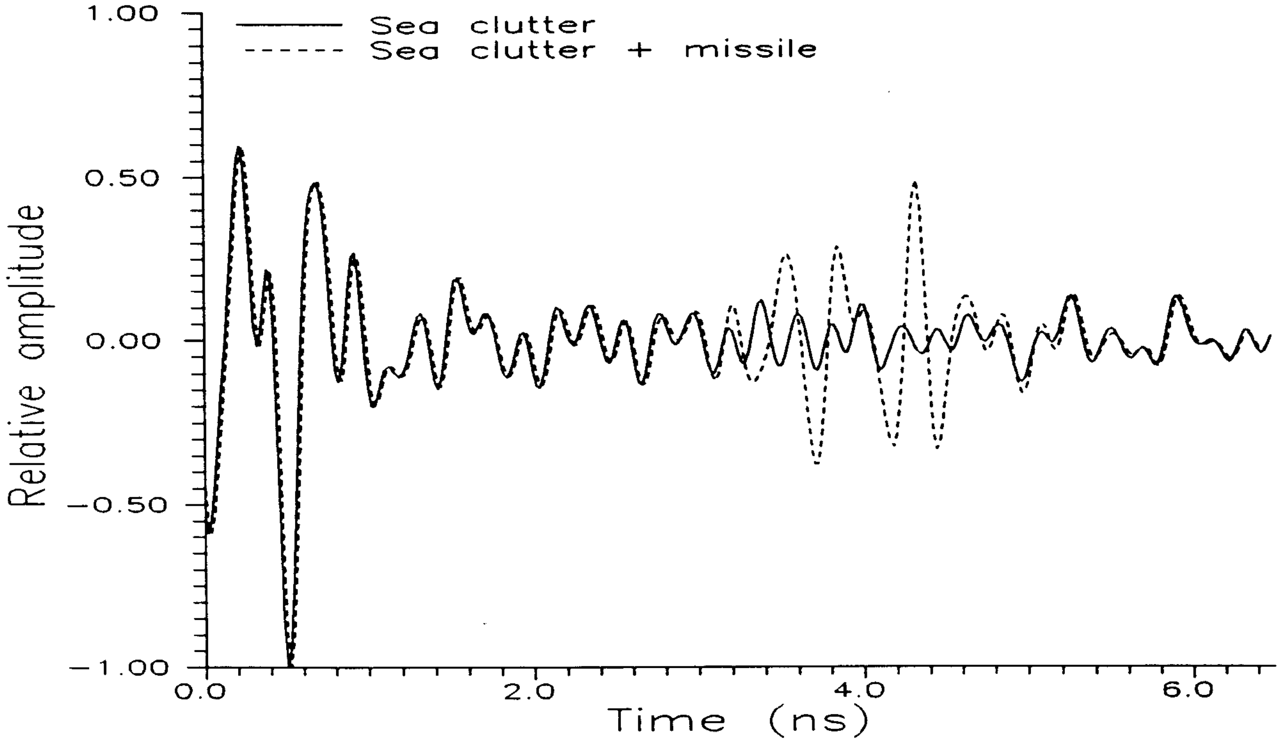
- Frequency-domain sea clutter and spectrum of CRTW



- When CRTW hits the sea surface w/ and w/o 2" missile response, the return response



● When CRTW of sea clutter/2" missile hits the sea surface w/ and w/o 2" missile response, the return response



Conclusions

- Measured and theoretical sea clutter response matched well, showing specular nature of clutter

- Both frequency-domain E-pulse and CRTW help to reduce sea clutter, revealing target response; i.e. improve detection