RADAR TARGET IDENTIFICATION AND DETECTION USING SHORT EM PULSES AND THE E-PULSE TECHNIQUE

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

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

INTRODUCTION

The E-pulse radar target discrimination scheme, a resonance cancellation technique based on the late-time behavior of the transient scattered field, has been successfully demonstrated[1,2,3,4] in the laboratory on a variety of occasions. The technique is based on the target natural frequencies and is inherently aspect-independent. Unfortunately, this approach ignores the early-time scattered field component, which is dominated by specular reflections from target scattering centers.

This paper presents an E-pulse technique which is usable with waveforms arising from specular scattering, such as the early-time response of a radar target. The technique uses resonance cancellation in the *frequency domain* to eliminate the sinusoidal functions arising from the aspect-dependent temporal positions of specular reflections. Target discrimination using early-time information is then possible using an algorithm identical to that used with late-time data, with the exception that discrimination is aspect dependent.

Cancellation of frequency-domain sinusoids is possible for any waveform which is specular in nature. This paper also shows how to enhance the detection of radar targets using transient pulses by eliminating clutter from specular structures such as the sea surface.

MODELLING OF ULTRA-WIDEBAND SCATTERING FROM RADAR TARGETS

Figure 1 shows the transient response of a 1:72 scale model of a B-52 aircraft to an excitation pulse with energy in the band 0.2-7.0 Ghz. It is typical of the return from an aircraft target, showing an early-time period (3.0-7.0 ns) dominated by localized specular reflections from scattering centers such as engine intakes and attachment points, followed by a late-time natural oscillation period consisting of global resonance information ($t > 7.0$

Ultra-Wideband, Short-Pulse Electromagnetics
Edited by H. Bertoni *et al.*, Plenum Press, 1993

ns). It is important to note that there can be no precise demarcation between the early-time and late-time portions of a scattered field response since substructure resonances are often established before the excitation signal clears the target, resulting in a resonance component to early time.

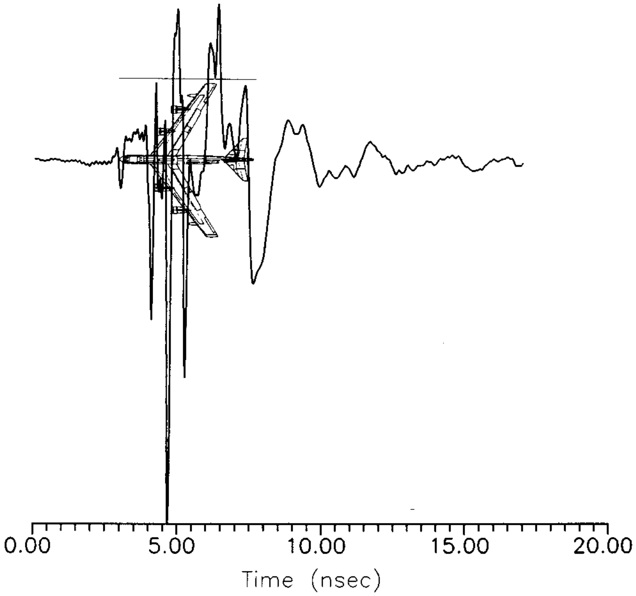

Figure 1. Response of 1:72 scale B-52 model measured at nose-on incidence in the frequency band 0.2-7.0 GHz. Polarization is in plane of wings.

Baum[5] has proposed a model of the late-time response using the aspect-independent natural resonance frequencies of the target $\{s_n = \sigma_n + j\omega_n\}$

$$r_L(t) = \sum_{n=-N}^{N} A_n e^{s_n t} \qquad t > T_L. \tag{1}$$

Here T_L designates the beginning of late time, N modes are assumed excited by the incident pulse, and the aspect-dependent complex amplitudes $\{A_n\}$, along with the natural frequencies, occur in complex conjugate pairs. This response has formed the basis for the aspect-independent late-time E-pulse technique.

Altes[6] has proposed a simple model for the early-time response

$$r_E(t) = \sum_{m=1}^{M} p(t) * h_m(t - T_m) \qquad t < T_L \tag{2}$$

where p(t) is the incident pulse and $h_m(t)$ is the localized impulse response originating at the mth scattering center at the time T_m. In the frequency domain this response becomes

$$R_E(\omega) = \mathscr{F}\{r_E(t)\} = \sum_{m=1}^{M} P(\omega) H_m(\omega) e^{-j\omega T_m} \tag{3}$$

where $H_m(\omega)$ is the transfer function of the m^th^ scattering center and $P(\omega)$ is the spectrum of p(t). Hurst and Mittra[7] suggest that the transfer function can be approximated as an exponential function of frequency. Assuming that $P(\omega)$ is slowly varying then gives

$$R_E(\omega) = \sum_{m=1}^{M} B_m e^{\tau_m \omega} \tag{4}$$

where $\{\tau_m = \alpha_m - jT_m\}$ are complex times associated with the scattering center impulse responses. It is readily seen that there is a duality between the temporal late-time response (1) and the spectral early-time response (4). This duality allows the direct application of E-pulse cancellation to spectral early-time data.

THE E-PULSE TECHNIQUE FOR GENERAL EXPONENTIAL SIGNALS

The E-pulse technique has been formulated in detail for the case of late-time responses[1,2,3]. It is useful to review the basic premise of the technique in the context of a general complex exponential signal.

Consider a complex signal

$$f(x) = \sum_{k=1}^{K} C_k e^{Q_k x} \qquad X_L < x < X_F \tag{5}$$

where $\{C_k\}$ and $\{Q_k\}$ are complex numbers. An E-pulse e(x) is a real waveform of finite extent X_E which upon convolution with f(x) eliminates a preselected component of the exponential series. In the particular, the entire series can be eliminated resulting in

$$c(x) = e(x) * f(x) = \int_0^{X_E} f(x') e(x-x') dx' = 0 \qquad X_L + X_E < x < X_F . \tag{6}$$

The conditions for synthesizing such an E-pulse can be given in the context of resonance cancellation as[3]

$$E(s=Q_k) = E(s=Q_k^*) = 0 \qquad 1 \le k \le K \tag{7}$$

where E(s) is the Laplace spectrum of e(x).

Discrimination between waveforms having differing sets of complex frequencies $\{Q_n\}$ is accomplished by creating E-pulses for each frequency set. Upon convolution with an unknown waveform, the output with zero energy for $X_L + X_E < x < X_F$ identifies the frequency set. Application to the late-time response of a radar target results in an aspect-independent E-pulse waveform since the complex frequencies comprising the signal are the natural frequencies of the target. Application to the transformed early-time response of a radar target produces an aspect-dependent E-pulse since the frequencies are related to the temporal positions of the specular reflections.

To quantify discrimination an "E-pulse discrimination number" (EDN) is defined as

$$EDN = \frac{\int_{X_L+X_E}^{X_F} [c(x)]^2 dx}{\int_0^{X_E} [e(x)]^2 dx} . \tag{8}$$

In an ideal, noise-free situation the E-pulse convolution with zero EDN identifies the waveform. A more realistic scenario suggests that the convolution with the minimum value of EDN should identify the waveform. A measure of confidence is then given by the "E-pulse discrimination ratio" (EDR) defined as

$$EDR = 10\log_{10}\left\{\frac{EDN}{\min(EDN)}\right\} \quad dB \tag{9}$$

so that the identified waveform has an EDR of 0 dB, while the other values are greater than 0 dB.

DEMONSTRATION OF EARLY-TIME E-PULSE DISCRIMINATION

To demonstrate the feasibility of using E-pulses for early-time target discrimination, the scattered field response of 1:72 B-52 and 1:48 B-58 scale aircraft models have been measured using an HP 8720B network analyzer. (See Ross[8] for details on the MSU transient measurement system and calibration technique). Restrictions imposed by the anechoic chamber and the transmit/receive antenna system limit the lowest measurement frequency to 0.4 GHz. Unfortunately, this excludes the dominant resonances of larger targets. To overcome this problem, measurements were made of smaller 1:144 B-52 and 1:96 B-58 scale models over 0.4-4.4 GHz, and of larger 1:72 B-52 and 1:48 B-58 scale models over 1.0-7.0 GHz. The results were then scaled and combined to achieve an equivalent measurement of the larger targets with a bandwidth of 0.2-7.0 GHz. Figure 2 shows the time-domain pulse responses of the B-58 as a function of aspect angle, measured from nose-on (0°), as the model is rotated about its geometrical center in 5° increments, obtained by applying a cosine taper weighting function to the measured data and inverse-transforming. Note how the specular reflections rotate with the aircraft, and how the late-time period is aspect dependent, due to the changing coupling into the various natural modes. The rapid variation with aspect angle suggests that 5° increments are probably not fine enough to adequately describe the aspect dependence of early time.

E-pulse waveforms have been constructed for the early-time component of each measured waveform by truncating the time-domain waveform after the two-way transit time of the target along the aspect angle, transforming the result into the frequency domain, performing mode extraction[3] and applying the synthesis equations (7). A discrimination test is then performed by assuming one waveform arises from an unknown target of unknown aspect angle and convolving that waveform with each of the E-pulses. The smallest EDN value then identifies the target and its aspect angle with confidence given by the EDR.

Figure 3 shows the resulting values of EDR obtained from each of the E-pulse convolutions. Response and E-pulse numbers 1-7 represent the B-58 at aspects of 0° to 30° in 5° increments, and numbers 8-14 represent the B-52 at aspects 0° through 30°. Note that EDR values greater than 15 dB have been truncated for display purposes. It is easily seen that the correct waveform has been identified in all cases, with usually a high level of

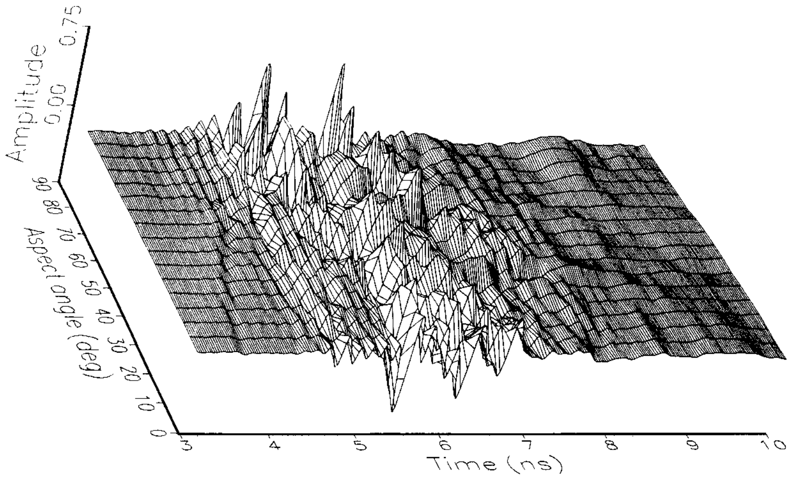

Figure 2. Response of 1:48 scale B-58 model measured at various incidence angles in the frequency band 0.2-7.0 GHz. Polarization is in plane of wings.

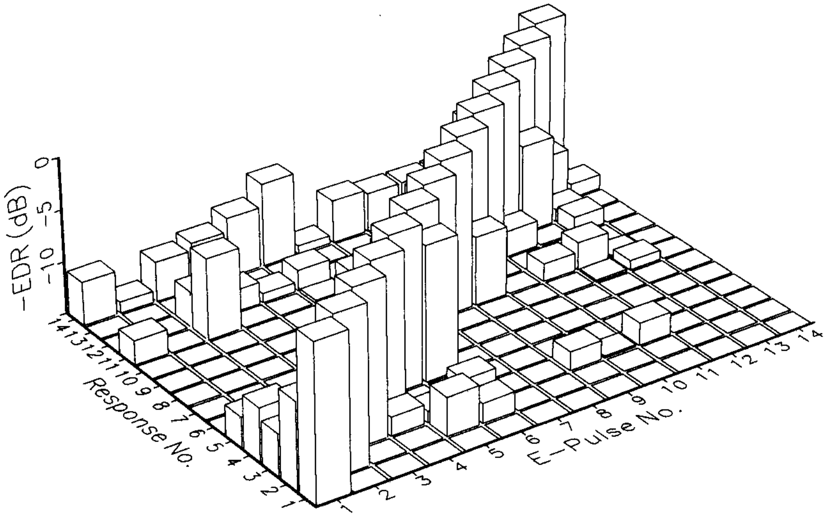

Figure 3. Early-time discrimination of B-52 and B-58 at aspects of 0° to 30° from nose-on.

confidence. Especially important is that any waveform from the B-52 is discriminated from any B-58 waveform with high confidence, and vice-versa. However, the fact that convolution of the 30° B-52 E-pulse with the 25° B-52 response is highly different than its convolution with the 30° B-52 response suggests that a much finer discretization on aspect angle is required. That is, a B-52 response at 28° might not be associated with the B-52 unless E-pulses are created for finer increments in aspect angle.

ENHANCEMENT OF TARGET DETECTION BY REDUCTION OF SEA CLUTTER

The detection of radar targets near the sea surface using transient signals is made difficult by the presence of a strong clutter return from a disturbed sea. However, if the scattering from water wave crests is primarily specular within the band of the interrogating signal, the E-pulse resonance cancellation technique can be used to eliminate the clutter return, thus increasing the probability of detection.

Assume that the sea surface consists of wave crests of nonuniform heights separated by the water wavelength λ_w. If the scattering from these wave crests is nearly specular, the transient back-scattered electric field response can be approximated precisely as in (2). At near-grazing incidence, the time between specular reflections is approximately

$$T_m = \frac{2m\lambda_w \cos(\theta_0)}{c} \tag{10}$$

where θ_0 is the incidence angle measured from grazing incidence, and M in (2) is the number of wave crest reflections within the time window of interest. Because of the form of the scattered field response, E-pulse cancellation can be used to eliminate the sea clutter response over part of its frequency band.

Figure 4 shows the time domain response of a simulated sea surface measured in the

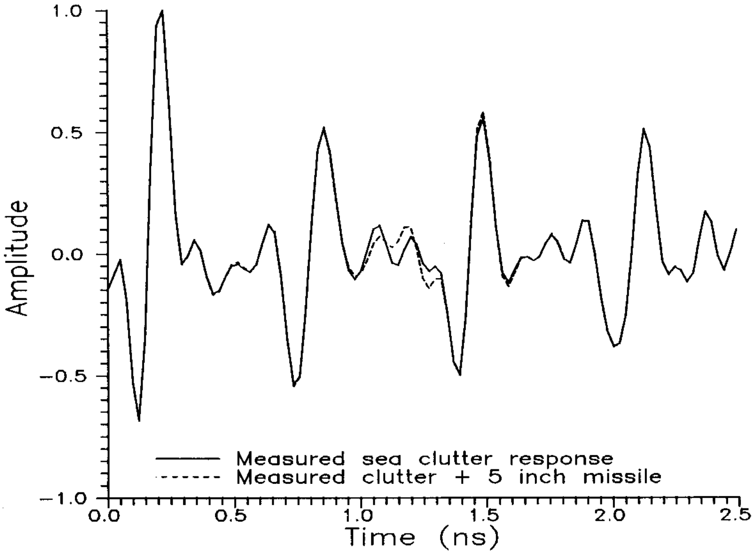

Figure 4. Measured response of simulated sea surface with and without addition of 5 inch missile response.

frequency band 1.0-7.0 GHz. The surface has been constructed from an aluminum sheet of width 12" adhered to styrofoam in a sinusoidal pattern, with six wave crests of height 1" and spatial wavelength 4". The measurement has been done with horizontal polarization at an incidence angle of 17° from grazing, with the reflections from the first four wave crests shown. Specular reflections from the wave crests are quite apparent, separated by about 0.65 ns, as predicted by (10).

To eliminate the sea clutter, an E-pulse of width 3.9 GHz has been constructed from the transform of the sea clutter response. Convolution of the E-pulse with the real part of the transform domain sea clutter, Figure 5, reveals that after a frequency of 3.9 GHz the convolved output is nearly zero, and the sea clutter above that frequency has been eliminated.

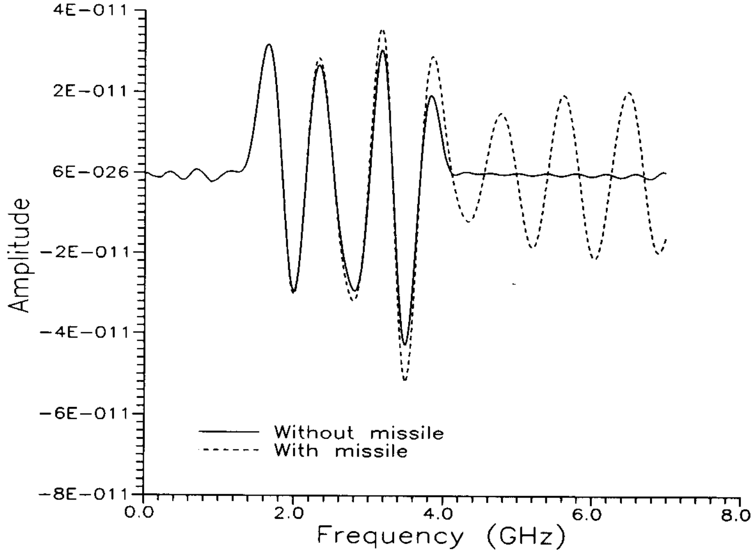

Figure 5. Convolution of frequency-domain E-pulse with transform of measured return from simulated sea surface, with and without addition of missile response.

As an example of target detection in clutter, the measured response of a 5" long aluminum missile model has been added to the sea clutter data, as shown in Figure 4, with a peak amplitude chosen to be 10% of the peak clutter amplitude. The convolution of the E-pulse with the target+clutter response, as shown in Figure 5, reveals that the missile response is still present. When the real and imaginary convolved outputs are windowed from 4.0-7.0 GHz and inverse transformed into the time domain a distorted, bandlimited version of the missile response is recovered, as shown in Figure 6. Thus, the missile can be easily detected even with the large sea clutter component present.

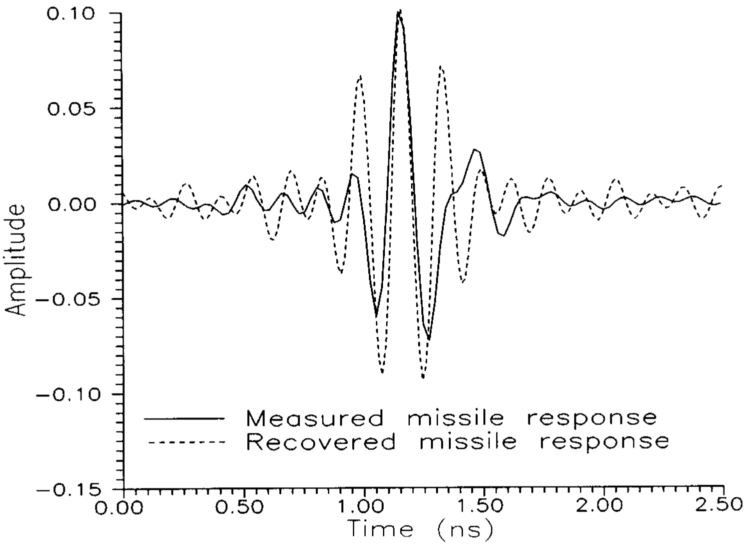

Figure 6. Response of 5 inch missile recovered from frequency-domain convolution.

REFERENCES

1. E.J. Rothwell, D.P. Nyquist, K.M. Chen and B. Drachman, Radar target discrimination using the extinction-pulse technique, *IEEE Trans. Antennas Propagat.* AP-33:929 (1985).
2. K.M. Chen, D.P. Nyquist, E.J. Rothwell, L. Webb and B. Drachman, Radar target discrimination by convolution of radar return with extinction-pulses and single-mode extraction signals, *IEEE Trans. Antennas Propagat.* AP-34:896 (1986).
3. C.E. Baum, E.J. Rothwell, K.M. Chen and D.P. Nyquist, The singularity expansion method and its application to target identification, *Proc. IEEE.* 79:1481 (1991).
4. K.M. Chen, D.P. Nyquist, E.J. Rothwell and W.M. Sun, New progress on E/S pulse techniques for noncooperative target recognition, *IEEE Trans. Antennas Popagat.* 40:829 (1992).
5. C.E. Baum, Emerging technology for transient and broad-band analysis and synthesis of antennas and scatterers, *Proc. IEEE.* 64:1598 (1976).
6. R.A. Altes, Sonar for generalized target description and its similarity to animal echolocation systems, *J. Acoust. Soc. Am.* 59:97 (1976).
7. M.P. Hurst and R. Mittra, Scattering center analysis via Prony's method, *IEEE Trans. Antennas Propagat.* AP-35:986 (1987).
8. J.E. Ross. "Application of Transient Electromagnetic Fields to Radar Target Discrimination," Ph.D. Dissertation, Michigan State University (1992).