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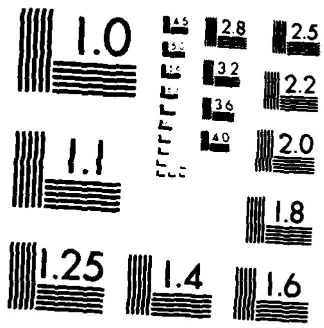

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A new scheme for radar target detection and discrimination, the radar waveform synthesis method, is investigated. This method consists of synthesizing aspect-independent excitation signals with particular waveforms which can be used to convolve with the radar return of the target to produce single-natural modes or the zero-mode of the target in the late-time period. When the synthesized excitation signals for a preselected target are convolved

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The synthesized signals for single-mode excitation and the synthesized signal for zero-mode excitation (K-pulse) have been used to convolve with measured radar returns of targets. The results of convolution indicate the applicability of this new scheme in practice.

RADAR WAVEFORM SYNTHESIS FOR TARGET IDENTIFICATION

Abstract

A new scheme for radar target detection and discrimination, the radar waveform synthesis method, is investigated. This method consists of synthesizing aspect-independent excitation signals with particular waveforms which can be used to convolve with the radar return of the target to produce single-natural modes or the zero-mode of the target in the late-time period. When the synthesized excitation signals for a preselected target are convolved with the radar return from a wrong target, the convolved outputs will be significantly different from the expected natural modes or zero-mode, thus, the wrong target can be discriminated.

The synthesized signals for single-mode excitation and the synthesized signal for zero-mode excitation (K-pulse) have been used to convolve with measured radar returns of targets. The results of convolution indicate the applicability of this new scheme in practice.

1. Introduction

The purpose of this research is to develop a new scheme of radar detection and discrimination. The new method consists of synthesizing aspect-independent excitation signals with particular waveforms which can be used to convolve with the radar return of the target to produce single-natural modes (pure damped sinusoids) or the zero-mode (zero response) of the target in the late-time period. When the synthesized excitation signals for a preselected target are convolved with the radar return from a wrong target, the convolved outputs will be significantly different from the expected natural modes or zero-mode, thus, the wrong target can be discriminated.

Over the past year, our major efforts were made on the following topics: (1) the convolution of synthesized signals for single-mode excitation with experimental radar returns, (2) the synthesis of K-pulse and its convolution with experimental radar returns, (3) methods of deconvolution for obtaining the impulse responses of targets and (4) the experiment. The progress made on these topics will be briefly discussed. We will also discuss the following topics for future study: (1) the synthesis of required waveforms for single-mode and zero-mode (K-pulse) excitation for complex targets, and (2) improvement of experimental setup, (3) deconvolution methods, and (4) a potential radar detection system based the radar waveform synthesis concept.

2. Theory on the Synthesis of Required Signals for Exciting Single-Mode or Zero-Mode Radar Return

The late-time radar return of a target is the sum of natural modes and it can be expressed as

$$h(t) = \sum_{n=1}^{N} a_n(\theta,\phi)\, e^{\sigma_n t} \cos(\omega_n t + \phi_n(\theta,\phi)) \qquad (1)$$

where σ_n is the damping coefficient and ω_n is the angular frequency of the nth natural mode, and $a_n(\theta,\phi)$ and $\phi_n(\theta,\phi)$ are the amplitude and the phase angle of the nth natural mode. It is noted that σ_n and ω_n are independent of the aspect-angle (θ and ϕ), but $a_n(\theta,\phi)$ and $\phi(\theta,\phi)$ are usually strong functions of the aspect angle. N is the total number of natural modes to be considered.

We aim to synthesize an excitation signal of duration T_e which can be convolved with the radar return h(t) to produce a single-mode or the zero-mode output in the late-time period ($t > T_e$):

$$E^o(t) = \int_0^{T_e} E^e(t')\, h(t - t')dt', \text{ for } t > T_e \tag{2}$$

where $E^o(t)$ is the convolved output signal, $E^e(t)$ is the excitation signal to be synthesized. The substitution of (1) in (2) leads to

$$E^o(t) = \sum_{n=1}^{N} a_n(\theta,\phi)\, e^{\sigma_n t}[A_n \cos(\omega_n t + \phi_n(\theta,\phi)) + B_n \sin(\omega_n t + \phi_n(\theta,\phi))], \text{ for } t > T_e \tag{3}$$

where

$$A_n = \int_0^{T_e} E^e(t')\, e^{-\sigma_n t'} \cos \omega_n t'\, dt' \tag{4}$$

$$B_n = \int_0^{T_e} E^e(t')\, e^{-\sigma_n t'} \sin \omega_n t'\, dt' \tag{5}$$

The coefficients A_n and B_n which determine the amplitudes of the natural modes of the convolved output are independent of the aspect angle (θ and ϕ). This makes it possible to synthesize the aspect-independent $E^e(t)$ for producing the single-mode or the zero-mode $E^o(t)$. For example, if we synthesize $E^e(t)$ in such a way that $A_1 = 0$ and all other A_n and B_n go to zero, then the output signal will be a cosine first natural mode as

$$E^o(t) = a_1\ (\theta,\phi)\ e^{\sigma_1 t} \cos(\omega_1 t + \phi_1\ (\theta,\phi)), \text{ for } t > T_e.$$

If we choose $E^e(t)$ in such a way that $B_3 = 1$ and all other A_n and B_n go to zero, then the output signal will be a sine third natural mode such as

$$E^o(t) = a_3(\theta,\phi)\ e^{\sigma_3 t}\ \sin(\omega_3 t + \phi_3(\theta,\phi)),\ \text{for } t > T_e.$$

If we synthesize $E^e(t)$ in such a way that all A_n and B_n vanish, then the zero-mode output is obtained:

$$E^o(t) = 0,\ \text{for } t > T_e.$$

This $E^e(t)$ is called the Kill-pulse because it nulls the late-time response completely.

The next task is to synthesize $E^e(t)$. Let's construct $E^e(t)$ with a set of basis function $f_m(t)$ as

$$E^e(t) = \sum_{m=1}^{2N} d_m\ f_m(t) \tag{6}$$

where $f_m(t)$ can be pulse functions, impulse functions or Fourier cosine functions, etc. d_m is the unknown coefficient to be determined. We need 2N of $f_m(t)$ because threre are 2N of A_n and B_n to be specified.

Substituting (6) into (4) and (5), we have

$$A_n = \sum_{n=1}^{2N} M^c_{nm}\ d_m \tag{7}$$

$$B_n = \sum_{n=1}^{2N} M^s_{nm}\ d_m \tag{8}$$

where

$$M^c_{nm} = \int_0^{T_e} f_m(t')\ e^{-\sigma_n t'} \cos \omega_n t'\ dt' \tag{9}$$

$$M^s_{nm} = \int_0^{T_e} f_m(t')\ e^{-\sigma_n t'} \sin \omega_n t'\ dt' \tag{10}$$

Equations (7) and (8) can be expressed in a matrix form as

$$\begin{bmatrix} A_n \\ B_n \end{bmatrix} = \begin{bmatrix} M_{nm}^{c} \\ M_{nm}^{s} \end{bmatrix} \begin{bmatrix} d_m \end{bmatrix} \qquad \begin{matrix} n = 1,2....N \\ m = 1,2....2N \end{matrix} \tag{11}$$

The coefficient d_m for constructing $E^e(t)$ can then be obtained from

$$\begin{bmatrix} d_m \end{bmatrix} = \begin{bmatrix} M_{nm}^{c} \\ M_{nm}^{s} \end{bmatrix}^{-1} \begin{bmatrix} A_n \\ B_n \end{bmatrix} \tag{12}$$

To synthesize $E^e(t)$ for the jth-mode excitation, we can assign $A_j = 1$ or $B_j = 1$ and let all other A_n and B_n go to zero, and then calculate $[d_m]$ from (12) accordingly.

To synthesize the Kill-pulse, or the excitation signal for the zero-mode response, all A_n and B_n are set to be zero. For this case $[d_m]$ will have non-trivial solutions only when the determinant of $\begin{bmatrix} M_{nm}^{c} \\ M_{nm}^{s} \end{bmatrix}$ vanishes. That is

$$\det \begin{bmatrix} M_{nm}^{c} \\ M_{nm}^{s} \end{bmatrix} = 0 \tag{13}$$

This condition can be met because all the elements of M_{nm}^{c} and M_{nm}^{s} are functions of the signal duration T_e, and it is possible to numerically search for the optimum value of T_e which makes (13) valid. Once the optimum T_e is determined, $[d_m]$ can be easily determined from a set of homogeneous equations generated from (11) by setting A_n and B_n to be zero.

It is noted that for the synthesis of the excitation signal for the single-mode response, T_e can be rather arbitrary. However, to synthesize the K-pulse, T_e has to be specifically determined.

3. The Convolution of Synthesized Signals for Singe-Mode Excitation with Experimental Radar Returns

To demonstrate the applicability of our scheme in practice, we have convolved the experimental radar returns of wire targets, measured by Bruce Hollmann

of NSWC, with the corresponding synthesized signals for exciting various single-mode responses.

Figure 1 shows the results of the convolution of the measured impulse response of the 18.6" wire with the synthesized signal for the first mode excitation. Fig. 1(a) shows the synthesized signal for exciting the cosine first mode (in terms of impulse basis functions) and the convolved output. It is observed that a cosine first mode is produced in the late-time period of the convolved output. Fig. 1(b) shows the synthesized signal for exciting the sine first mode (in terms of impulse basis functions) and convolved output. A sine first mode is produced in the late-time period. To demonstrate that these late-time responses are indeed that of the first mode, a phasor output signal is constructed as

$$C(t) = A(t) - j\,B(t)$$

where A(t) is the convolved output of Fig. 1(a) and B(t) is the convolved output of Fig. 1(b). If the late-time response of A(t) is a pure cosine first mode, it can be expressed as

$$[A(t)]_{late} = a_1\, e^{\sigma_1 t} \cos(\omega_1 t + \phi_1).$$

Similarly, if the late-time response of B(t) is a pure sine first mode, it can be expressed as

$$[B(t)]_{late} = a_1\, e^{\sigma_1 t} \sin(\omega_1 t + \phi_1).$$

Thus, the late-time response of the phasor output signal should be

$$[C(t)]_{late} = a_1\, e^{\sigma_1 t}\, e^{-j(\omega_1 t + \phi_1)}$$

The logarithm of the late-time response of C(t) yields

$$\ln[C(t)]_{late} = \ln a_1 + \sigma_1 t - j(\omega_1 t + \phi_1)$$

and

$$\text{real part of } \ln[C(t)]_{late} = \sigma_1 t + \ln a_1$$

$$\text{imaginary part of } \ln[C(t)]_{late} = -\omega_1 t - \phi_1$$

Fig. 1(c) shows the real part of $\ln[C(t)]$ in comparison with the line of $(\sigma_1 t)$. It is observed that the late-time response of $Re\{\ln[C(t)]\}$ is in parallel with the line of $(\sigma_1 t)$ for the late-time period of $t/(L/C) > 3$ where $t/(L/C)$ is the normalized time with L as the wire length and C as the speed of light. Fig. 1(d) shows the imaginary part of $\ln[C(t)]$ in comparison with the line of $(-\omega_1 t)$. It is again observed that the late-time response of $Im\{\ln[C(t)]\}$ is in parallel with the line of $(-\omega_1 t)$ for the late-time period of $t/(L/C) > 3$. Figs. 1(c) and 1(d) give a positive indication that the late-time responses of the convolved outputs of Figs. 1(a) and 1(b) contain only (or predominantly) the first mode of the wire.

Figure 2 shows the results of the convolution of the measured impulse response of the 18.6" wire with the synthesized signal for the third mode excitation. Fig. 2(a) shows the synthesized signal for exciting the cosine third mode and the convolved output A(t). A cosine third mode is produced for $t/(L/C) > 3$. Fig. 2(b) shows the synthesized signal for exciting the sine third mode and the convolved output B(t). A sine third mode is produced for $t/(L/C) > 3$. Fig. 2(c) shows the real part of $\ln[C(t)]$ in comparison with the line of $(\sigma_3 t)$. C(t) is the phasor output signal of $(A(t) - j\, B(t))$ as defined in Fig. 1. It is observed that the late-time response of $Re\{\ln[C(t)]\}$ is approximately in parallel with the line of $(\sigma_3 t)$ for $t/(L/C) > 3$. Fig. 2(d) shows the imaginary part of $\ln[C(t)]$ in comparison with the line of $(-\omega_3 t)$. It is observed th-t the late time response of $Im\{\ln[C(t)]\}$ is in parallel with the line of $(-\omega_3 t)$ for $t/(L/C) > 3$. Figs. 2(c) and 2(d) confirm that the late-time responses of the convolved outputs of 2(a) and 2(b) contain predominantly the third mode of the wire.

The examples given in Figs. 1 and 2 demonstrate the capability of the present scheme to extract various single-mode outputs from the measure radar return of a target.

Two examples are given to show the capability of target discrimination provided by the present method. Fig. 3 shows the results of the convolution of the radar return of a wrong target, a 16.74" wire, with the synthesized signal for exciting the first mode of the right target, a 18.6" wire. In Figs. 3(a) and 3(b), the late-time portions of the convolved outputs look similar to the first modes of the right target. However, in Fig. 3(d) the natural frequency of the convolved output is shown to deviate from that of the right target. Fig. 3(c) does not show a clear deviation between the damping coefficient of the convolved output and that of the right target. Overall, the results given in Fig. 3 do not provide a positive discrimination of the wrong target. Therefore, it is necessary to convolve the radar return of the wrong target with the synthesized signal for exciting the third mode of th. .ight target. The results of this convolution are given in Fig. 4. In Figs. 4(a) and 4(b), the convolved outputs are significantly different from the expected third mode of the right target. Furthermore, the deviations of the natural frequency and the damping coefficient of the convolved outputs from that of the right target become quite distinct in Figs. 4(d) and 4(c). The results given in Fig. 4 do give a positive discrimination of the wrong target. To ascertain that the radar return is from a wrong target, this radar return should be convolved with synthesized signals for other natural mode excitation. The results of this section have been presented elsewhere [1.2].

4. Synthesized K-pulse and its Convolution with Experimental Radar Returns

We have synthesized the K-pulses (Kill-pulses) for a wire and a spherical target. The K-pulse of a wire target has been used to convolve with the measured radar return of the target.

Fig. 5 shows the K-pulse for a thin cylinder synthesized with the basis set of pulse functions. The optimal duration of the K-pulse was determined to be 0.944 T_1 where T_1 is the period of the first natural mode of the wire and T_1 is equal to 2.16 (L/c) with L as the length of the cylinder and c as the speed of light. Uniqueness of the K-pulse is established by demonstrating that it is independent of the basis set chosen to represent E_K^i and insensitive to the numer N of SEM modes retained in the expansion for h_n. In Fig. 5, Kennaugh's K-pulse is compared with ours. The main difference between these two K-pulses is that our K-pulse is of finite duration and Kennaugh's requires an infinite pulse duration. Fig. 6 shows the K-pulse for a spherical target synthesized with pulse functions as the basis set. The optimal pulse duration was determined to be 0.9326 T_1 where T_1 is the period of the first natural mode of the sphere and T_1 is equal to 7.26 (a/c) with a as the radius of sphere and c as the speed of light. It is noted that the waveform of the K-pulse for the spherical target is different from that for the thin cylinder.

Fig 7 shows the backscatter-field responses of an expected target (a thin cylinder) and a wrong target (another thin cylinder 5% longer than the expected target) when they are illuminated by the K-pulse of the expected target at the aspect angle of 89.9°. It is observed that the expected target gives a zero late-time response while the wrong target gives a large oscillatory late-time response. Thus, the expected target is easily discriminated from other targets.

In Fig. 8 we have convolved the synthesized K-pulse of a 6" thin cylinder (with L/a = 400 and L/c = 0.508 ns) with the experimental impulse response of this target. The convolved output shows a large early-time response followed by an insignificant late-time response. The small late-time response, instead of a zero response, can be attributed to the experimental error and noise. This example implies the applicability of the K-pulse concept in practice.

The results of this section have been reported elsewhere [4.5].

5. Methods of Deconvolution for Obtaining the Impulse Responses of Targets

Two methods have been developed to deconvolve the measured radar return of a target for the purpose of obtaining the impulse response of the target. These methods are briefly described below.

If r(t) is the linear, scatter response of an object to an excitation waveform e(t), then r(t) = (e * h)(t). One would like to deconvolve and solve for h(t), the impulse response. It is well-known that this is often an ill-conditioned problem. Two methods have been developed. The first method replaces the discretized matrix form $E \cdot H = R$ by the following problem: minimize $|h_1|+....+|h_n|$ subject to $R-\lambda \leq E \cdot H \leq R+\lambda$ where λ is a column vector chosen sufficiently small to yield acceptable residuals, yet large enough to make the problem well-conditioned. This problem is converted to a linear programming problem so that the Simplex Algorithm can be used.

The second method is to minimize $\|E \cdot H-R\|^2 + \lambda\|H\|^2$ where again λ is chosen small enough to yield acceptable residuals and large enough to make the problem well-conditioned.

These methods have been used to solve problems involving a Hilbert matrix and also to obrain the impulse responses of simple targets from the measured radar returns.

These methods have been presented elsewhere [6].

6. Experiment

A facility for the measurement of transient electromagentic waves scattered by various targets illuminated by short-duration, transient TEM waves has been improved and modified over the past year. The experimental arrangement is indicated in Fig. 9.

A spherical TEM wave with electric field E^i is radiated by a monocone antenna imaged over a large ground screen, and illuminates the test target. The (imaged) biconical-horn transmitting antenna has a polar angle of θ_0=8°, a characteristic impedance of $Z_0=160\Omega$, an axial height of $h\simeq 2.4$m, and is driven by a 50Ω coaxial feed from below the ground screen. The ground screen has dimensions of approximately 16x20 ft., and is composed of 9 individual 4x8 ft. aluminum-sheet modules mounted on wooden tables 16 in. above the floor; this arrangement provides flexibility in the ground-screen configuration, and the aluminum sheets are joined by aluminum tape (after leveling) in any particular arrangement. Incident and scattered waves E^i and E^s are probed by a short monopole antenna of length $\ell=1.6$ cm which is imaged over the ground screen and located between the transmitting monocone and the target scatterer at a fixed distance $r\simeq 1.6$m from the transmitter. The receiving probe is electrically short at all frequencies in the spectrum of the incident and scattered waveforms, and is therefore modelled as an ideal differentiator. It is found that a clutter-free measurement time window of about $T_m=20$ ns is available between the time E^i strikes the probe and the arrival of reflections from the cone end, ground-screen edges, etc.

Excitation is provided by a mercury-switched nanosecond pulser, which produces pulses of about 100ps risetime and variable duration $1\text{ns}<t_p<1\mu\text{s}$ with amplitudes as great as V_p = 500V at a 1kHz rate, and feeds the transmitting monocone following a variable delay. The excitatory pulses are transmitted essentially without distortion by the TEM bicone, such that E^i can simulate impulse or step waveforms by appropriate adjustment of T_p. A ps-risetime sampling oscilloscope is triggered by the pulser output, and displays the excitatory signal on vertical channel B; the signal from the receiving probe is sampled by channel A of the same scope. Both the horizontal sweep voltage and the channel A or B vertical output are analog-to-digital converted under the control of a microcomputer. The oscilloscope sample density is typically adjusted such that a single horizontal sweep (typically 10 ns real time) is completed approximately 5s after initialization, corresponding to a total of about 5000 samples at the 1kHz pulser repetition rate.

The A-D converter acquires time and probe-signal data periodically with a specified, adjustable conversion period T_c>500μs controlled by the microcomputer. The data-acquisition software program A-D converts N (1<N<10) reference/clutter waveforms and target responses, with as many as 500 data points each, in rapid succession; all of this data is stored in microcomputer RAM. Following all data acquisition, a digital-signal-processing probram is executed which averages the N sets of reference and scatter signal data by recovering that data from RAM, setting its d-c level to zero, normalizing its amplitude, and interpolating each data set to a common time scale. The averaged data is recorded on magnetic typae and subsequently transferred, via telephone modem with a microcomputer software program, to the MSU CYBER-750 computer system where it is stored in permanent disk files.

Final data processing is accomplished on the CYBER-750 system, where valuable library programs are available for data smoothing and plotting. When E^i consists of a ns pulse, the receiving-probe data is integrated to annul the differentiation introduced by that probe; this procedure is found to be sensitive to the zero d-c level set by the earlier data processing, as well as any drift in that level, because the integration accumulates those errors. An advantage of the integration, however, is that it provides inherent noise reduction by signal averaging. The integration of probe response can be eliminated as a data processing step by transmitting an E^i which is an integrated version of the desired target illumination; e.g., E^i=u(t)=unit step generator output yields the target impulse response by differentiation when the probe signal is not integrated. The latter responses are relatively noisy due to the absense of the integral-averaging of any noise in the received signal (which is in fact enhanced by the differentiation), and subsequent smoothing is necessary.

7. Future Plans

The following topics will receive major attention in the future.

(1) The Synthesis of Required Waveforms for Single-Mode and Zero-Mode (K-pulse) excitation for Complex Targets

We will make a major effort for this topic during the next year. The following approach will be used for this study:

(a) Experimentally measure the impulse response (or smoothed impulse response) from the complex target at an aspect angle. This impulse response in the late-time period can be expressed as

$$h(t) = \sum_{n=1}^{N} a_n(\theta)\, e^{\sigma_n t} \cos(\omega_n t + \phi_n(\theta))$$

where N can be truncated in practice.

(b) Extract the first few natural frequencies of the target from h(t) based on Prony's method. For example, we seek for $S_1 = \sigma_1 + j\omega_1$, $S_2 = \sigma_2 + j\omega_2$ and $S_3 = \sigma_3 + j\omega_3$. We than assign our desired three natural modes to be

$$e^{\sigma_1 t} \cos \omega_1 t,\ e^{\sigma_2 t} \cos \omega_2 t \text{ and } e^{\sigma_3 t} \cos \omega_3 t$$

(c) The radar signal for exciting the desired first natural mode in the late-time period can be synthesized by solving the following equation:

$$\underbrace{e^{\sigma_1 t} \cos \omega_1 t}_{\text{known}} = \int_0^{T_e} \underbrace{E^e(t')}_{\text{unknown}} \; \underbrace{h(t-t')dt'}_{\text{known from experiment}}$$

where T_e is the properly specified signal duration, and $E^e(t)$ is the required radar signal for exciting the first-mode backscatter. The above equation can be solved for $E^e(t)$ by using the convolution techniques described in section 4 or other numerical method which is under study at the present time.

(d) It can be proved that once $E^e(t)$ is determined for a certain aspect angle, it will remain aspect-independent to excite the single-mode, late-time backscatter of the target at any aspect angle. The proof of this phenomenon is omitted here.

(2) Improvement of Experimental Setup

We will continue to improve our experimental setup for measuring impulse responses of radar targets. Improvement will be pursued through better pulse generation and sampling, as well as through improved data processing.

(3) Deconvolution Methods

We will continue to develop appropriate deconvolution methods which can be used to obtain the impulse responses of the targets from the measured radar returns of the targets.

(4) A potential Radar Detection System Based on Radar Waveform Synthesis Concept

We will study the system feasibility of a potential radar detection system based on the radar waveform synthesis concept.

Fig. 10 depicts a potential radar detection system based on the radar waveform synthesis concept. The system consists of a network of computers and each of them is assigned to store the required signals for exciting various single-mode or zero-mode response for a particular friendly target. All the relevant friendly targets are assumed to be covered in the network of computers. Whan an approaching target is illuminated by an interrogating radar signal, the radar return is divided and fed to each computer after amplification and signal processing. Inside each computer the stored excitation signals are convolved with the radar eturn. In principle, only one of the computers will produce various single-mode and zero-mode outputs in the late-time period; the rest of the computers should produce irregular outputs. The computer producing the single-mode and zero-mode outputs will then be identified with the target. If none of the computers produces single-mode and zero-mode outputs in the late-time period, the approaching targets will not be a friendly target.

8. Personnel

The following personnel have participated in this research program.

(1) Kun-Mu Chen, Professor and principal investigator.

(2) Dennis P. Nyquist, Professor and senior investigator.

(3) Byron Drachman, Associate Professor of mathematics, consultant.

(4) Che-I Chuang, Graduate Assistant.

(5) Lance Webb, Graduate Assistant.

(6) Edward Rothwell, Graduate Assistant.

9. Publication

The results of this research program have been published in the following papers or presented in the following meetings during the past year.

[1] K.M. Chen, D.P. Nyquist, D. Westmoreland, C.I. Chuang and B. Drachman, "Radar waveform synthesis for single-mode scattering by a thin cylinder and application for target discrimination", IEEE Trans. on Antennas and Propagation, Vol. AP-30, No.5, 867-880, Sept. 1982.

[2] K.M. Chen and D. Westmoreland, "Radar waveform synthesis for exciting single-mode backscatters from a sphere and application for target discrimination", Radio Science, Vol. 17, NO. 3, 574-588, June 1982.

[3] Lance Webb, Bryron Drachman, K.M. Chen, D.P. Nyqusit and C-I Chuang, "Convolution of synthesized radar signals for single-or zero-mode excitation with experimental radar returns", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

[4] D.P. Nyquist and K.M. Chen, "Kill-pulse synthesis using time-domain SEM", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

[5] Byron Drachman, "Two methods to deconvolve: L_1-method using simplex algorithm and L_2-method using least squares and a parameter", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

[6] Lance Webb, K.M. Chen, D.P. Nyquist and B. Hollmann, "Extraction of single-mode backscatters by convolving synthesized radar signal with a radar return", presented at 1983 International IEEE/AP-S Symposium, University of Houston, Houston, Texas, May 23-26, 1983.

[7] Edward Rothwell, D.P. Nyquist and K.M. Chen, "Synthesis of Kill-pulse using time-domain SEM", presented at 1983 International IEEE/AP-S Symposium, University of Houston, Houston, Texas, May 23-26, 1983.

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[1] Lance Webb, Byron Drachman, K.M. Chen, D.P. Nyquist and C-I Chuang, "Convolution of synthesized radar signals for single-or zero-mode excitation with experimental radar returns", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

[2] Lance Webb, K.M. Chen, D.P. Nyquist and B. Hollmann, "Extraction of single-mode backscatters by convolving synthesized radar signal with a radar return", presented at 1983 International IEEE/AP-S Symposium, University of Houston, Houston, TExas, May 23-26, 1983.

[3] E.M. Kennaugh, "The K-pulse concept", IEEE Trans. on Ant. and Prop. AP-29, No. 2, pp. 327-331, March 1981.

[4] D.P. Nyquist and K.M. Chen, "Kill-pulse synthesis using time-domain SEM", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

[5] Edward Rothwell, D.P. Nyquist and K.M. Chen, "Synthesis of Kill-pulse using time-domain SEM", presented at 1983 International IEEE/AP-S Symposium, University of Houston, Houston, Texas, May 23-26, 1983.

[6] Byron Drachman, "Two methods to deconvolve: L_1-method using simplex algorithm and L_2-method using least squares and a parameter", presented at 1983 National Radio Science Meeting, Boulder, Colorado, Jan. 5-7, 1983.

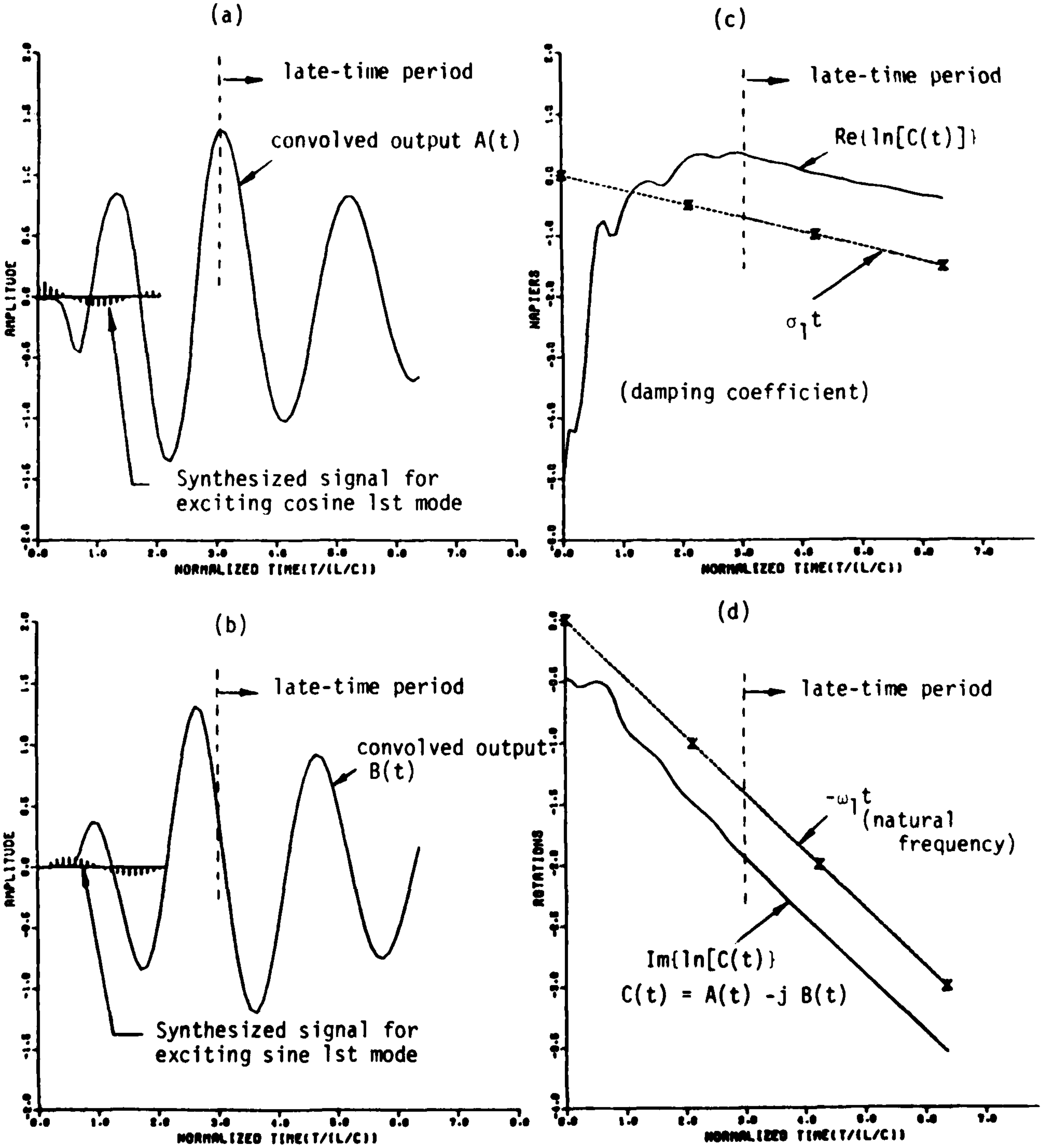


Fig. 1. Convolution of the impulse response of a 18.6" (length) wire with the synthesized signal for the first mode excitation.

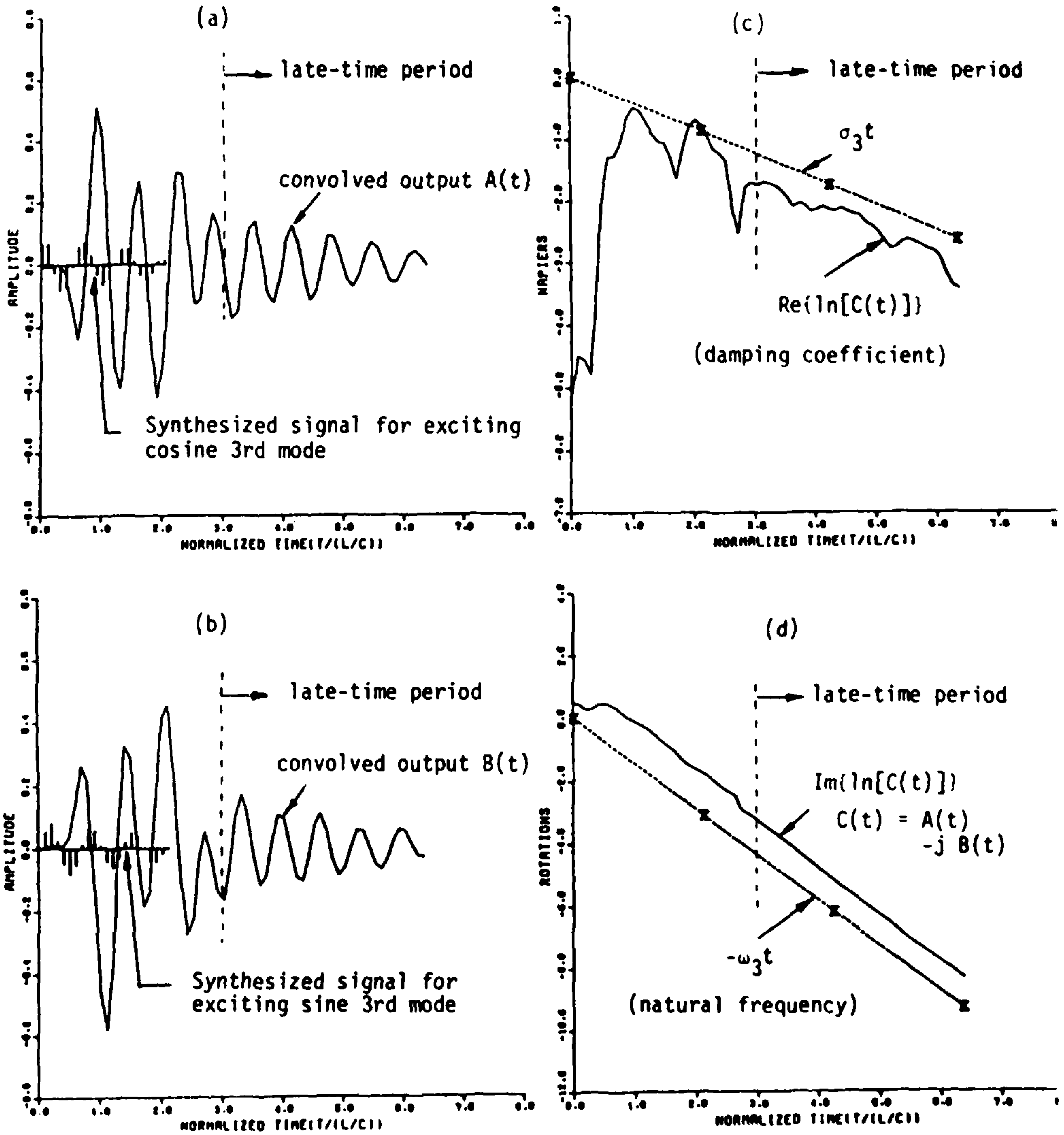


Fig. 2. Convolution of the impulse response of a 18.6" (length) wire with the synthesized signal for the third mode excitation.

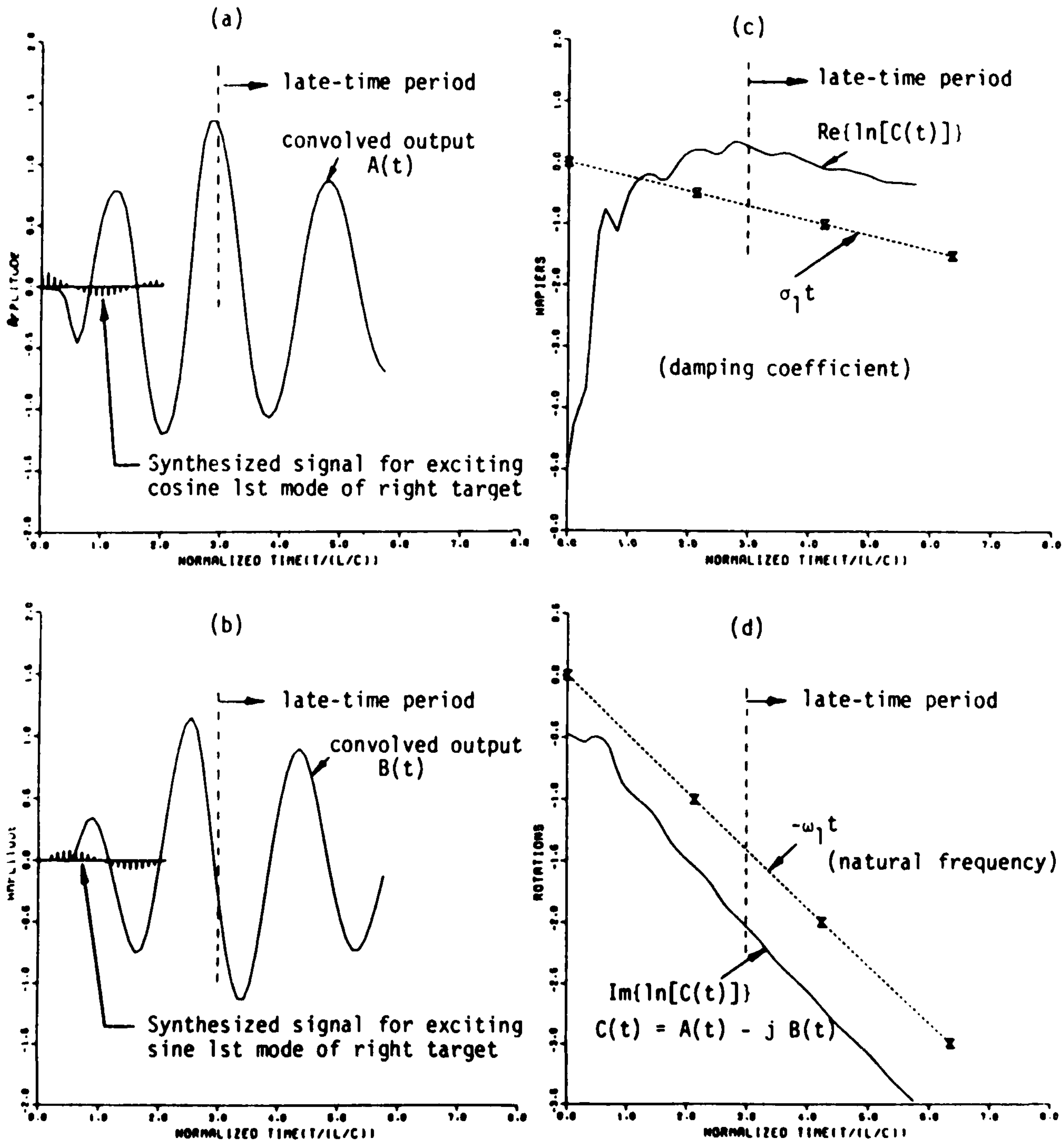


Fig. 3. Convolution of the impulse response of a wrong target, a 16.74" wire, with the synthesized signal for exciting the first mode of the right target, a 18.6" wire.

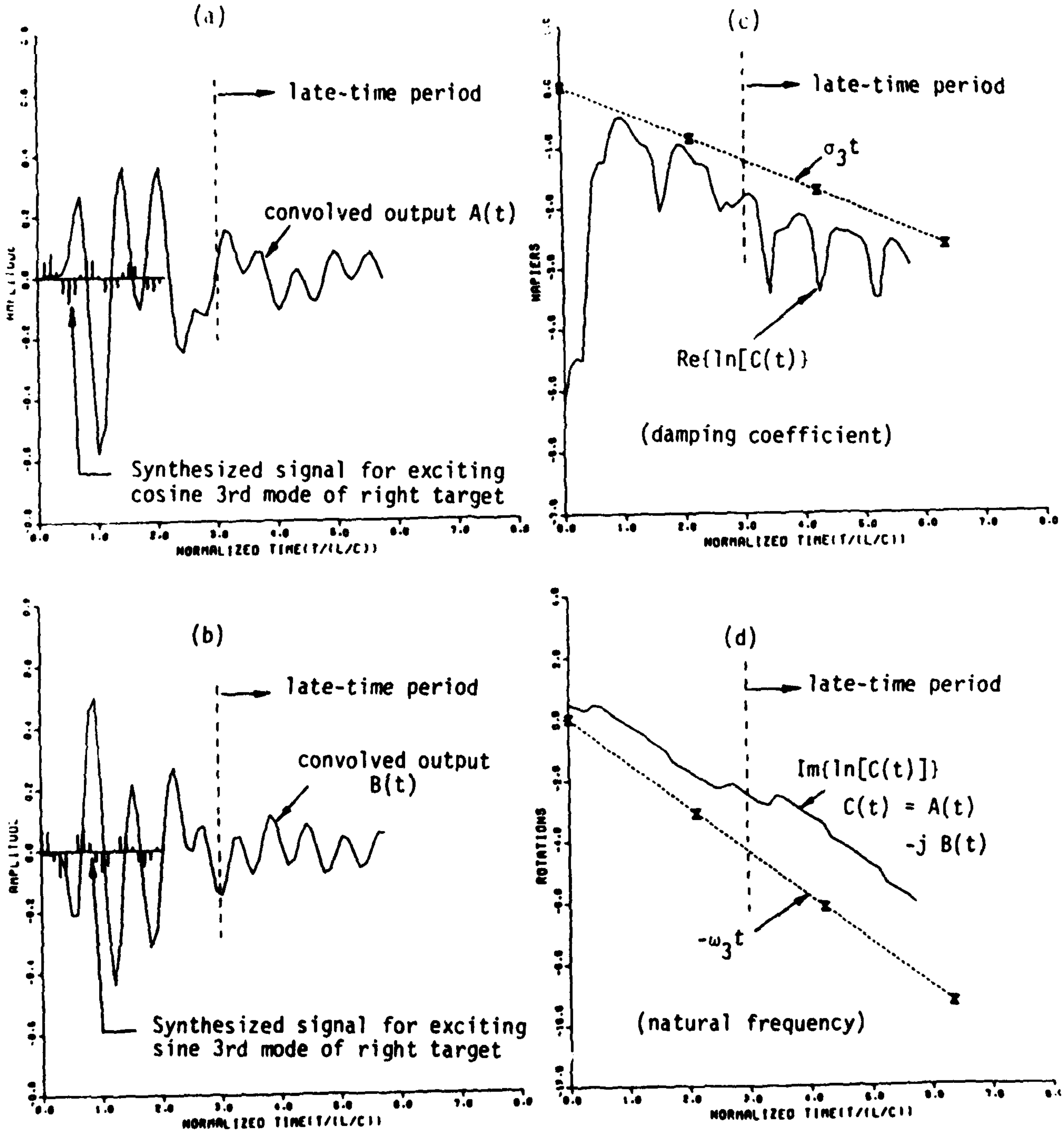


Fig. 4. Convolution of the impulse response of a wrong target, a 16.74" wire, with the synthesized signal for exciting the third mode of the right target, a 18.6" wire.

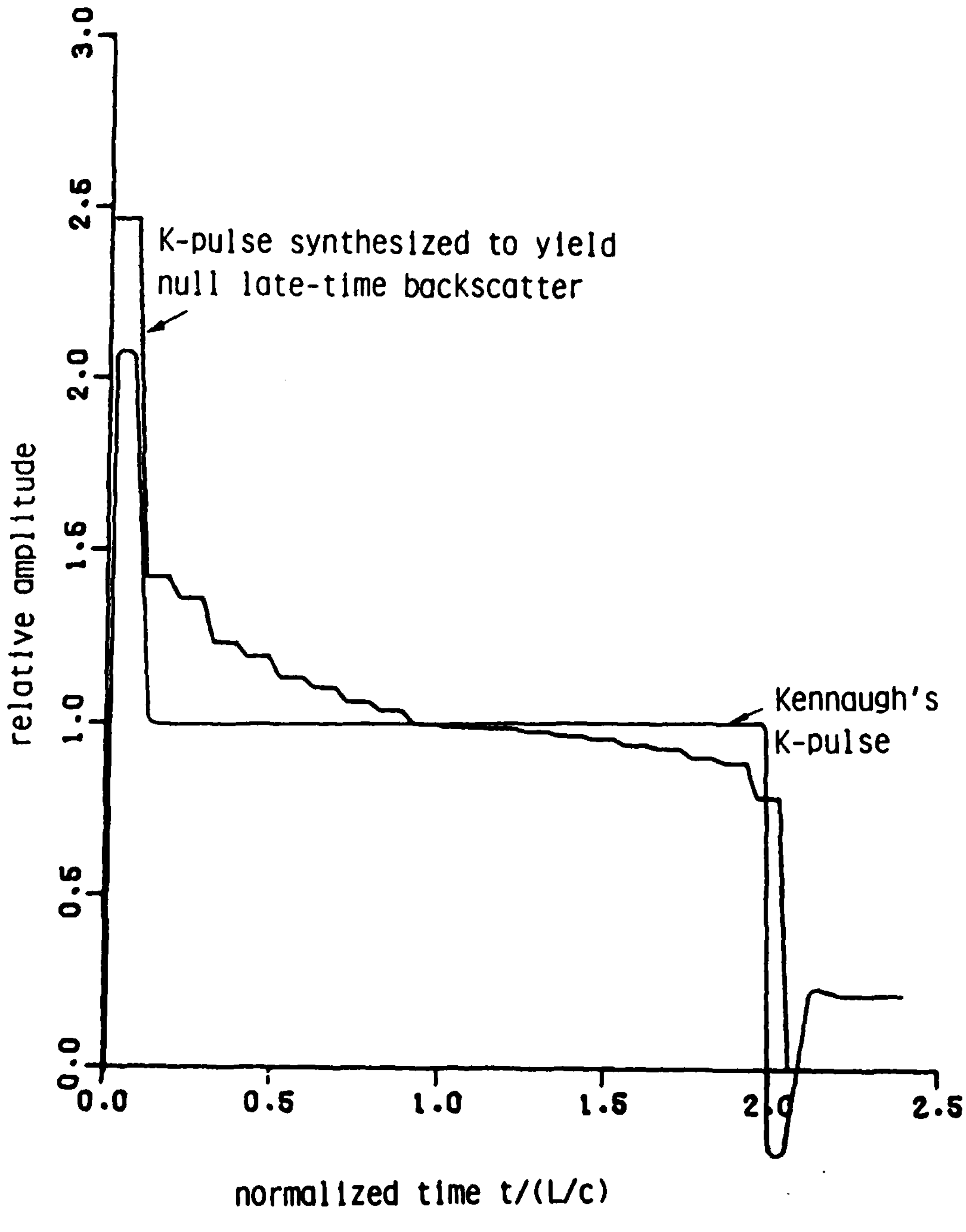


Figure 5. Comparison of K-pulse synthesized to yield null late-time backscatter from a thin cylinder with Kennaugh's K-pulse.

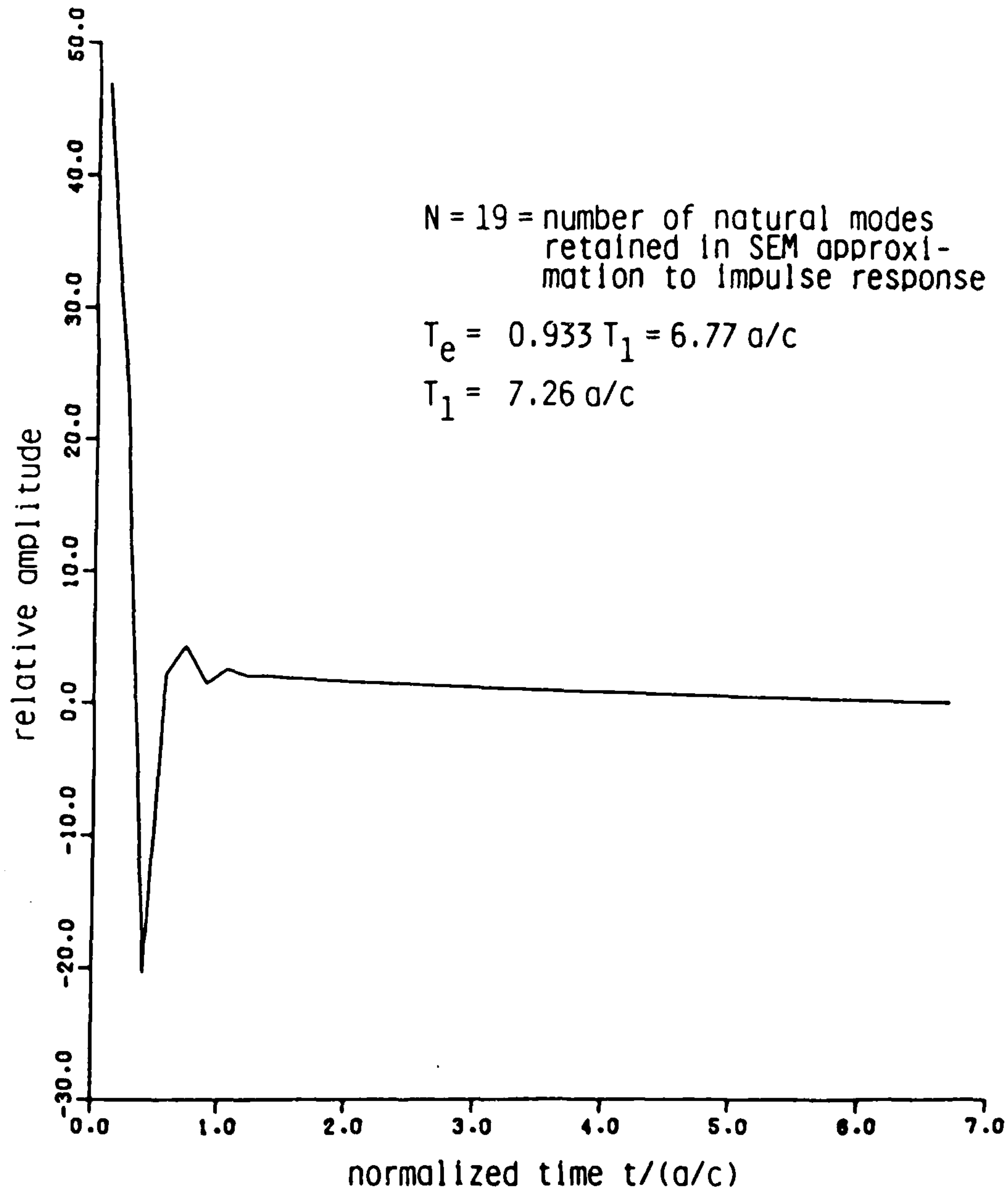


Figure 6. Principal-mode K-pulse (synthesized from pulse basis functions) which annuls the late-time backscatter from a conducting spherical target.

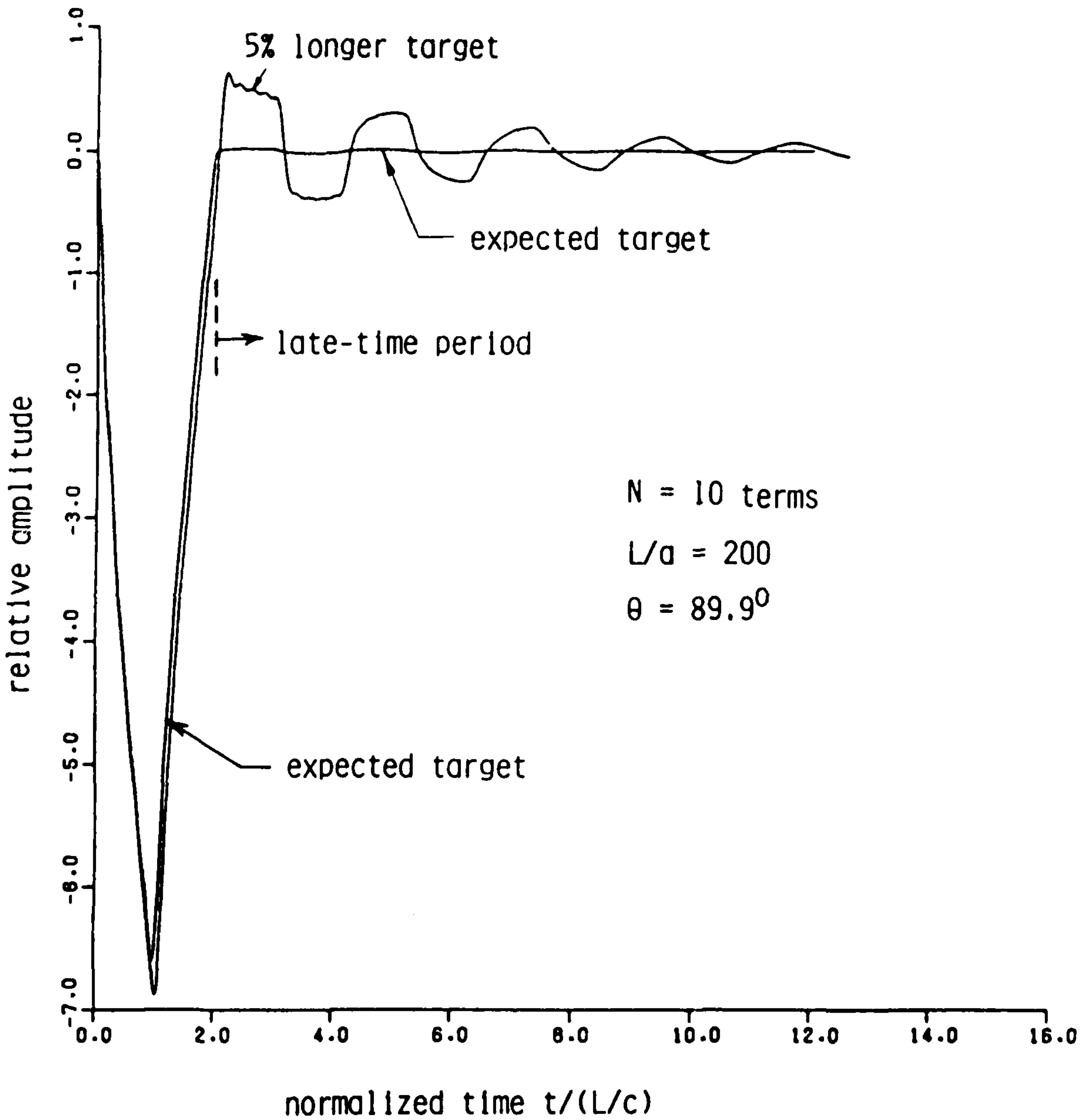


Figure 7. Backscatter-field response of expected and 5% longer than expected thin-cylinder targets to normally-incident K-pulse; indicates potential target discrimination.

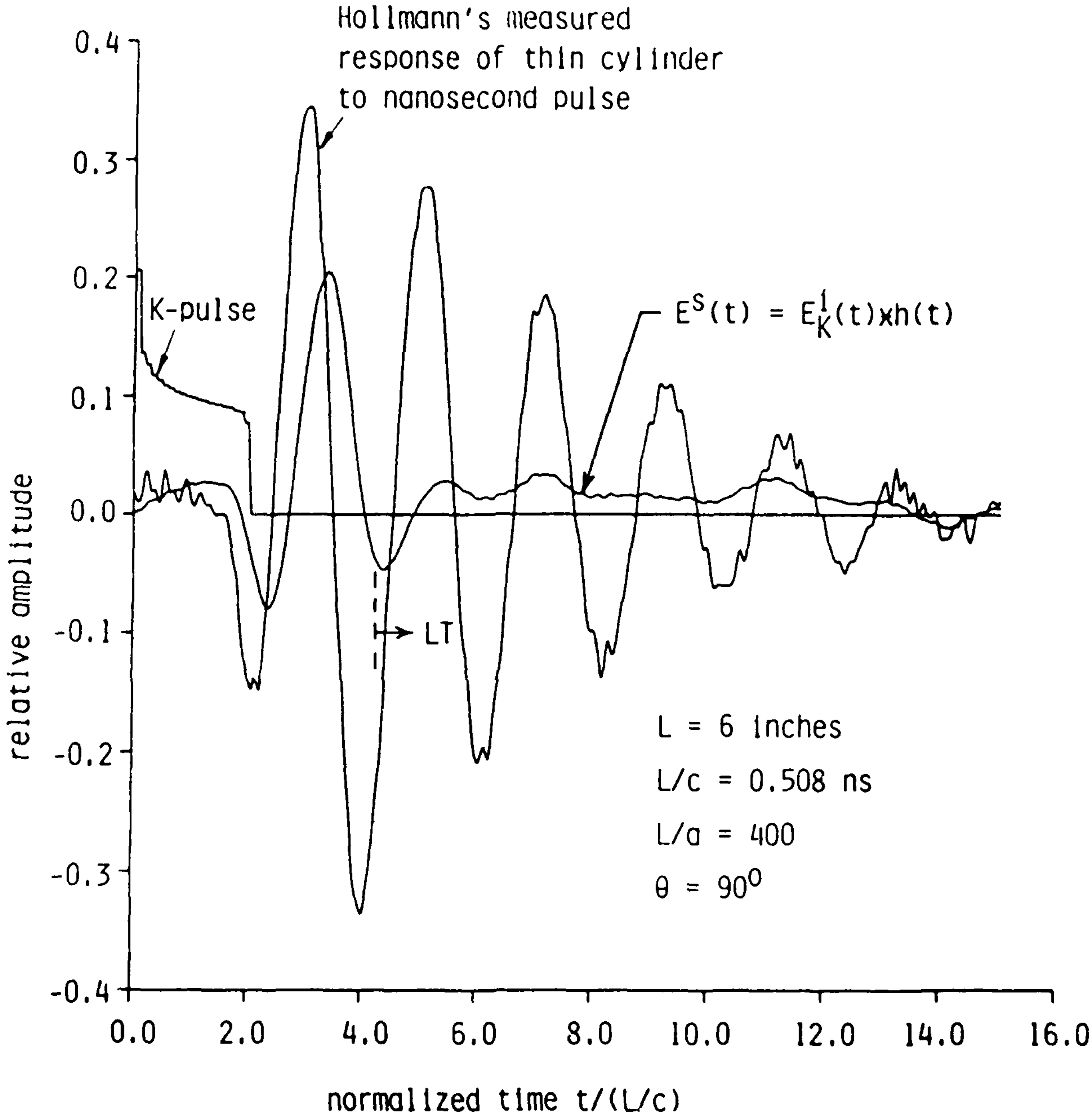


Figure 8. Convolution of synthesized K-pulse with response of thin cylinder to normally-incident, nanosecond pulse illumination (measured by B. Hollmann). Note the relatively insignificant late-time response.

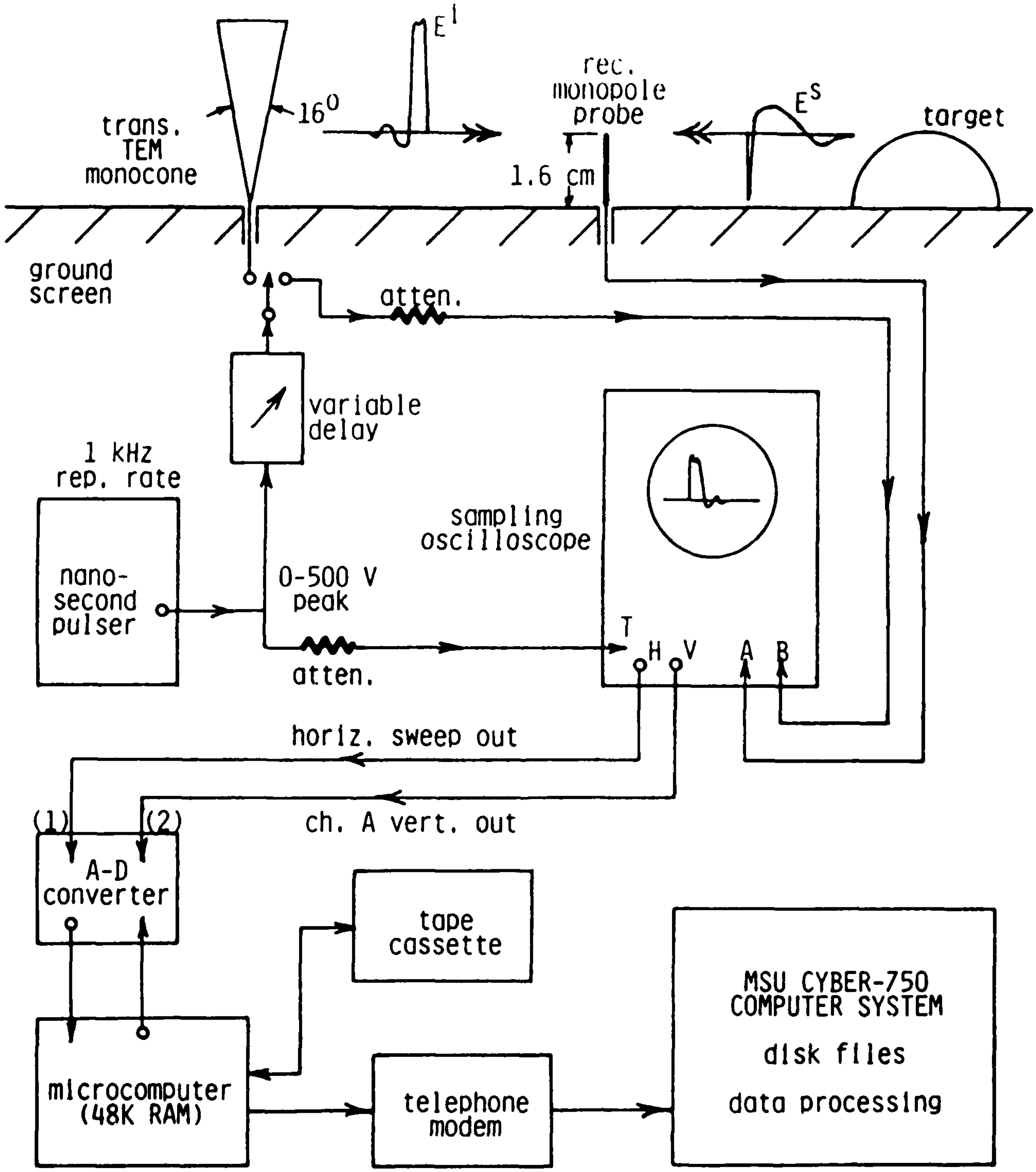
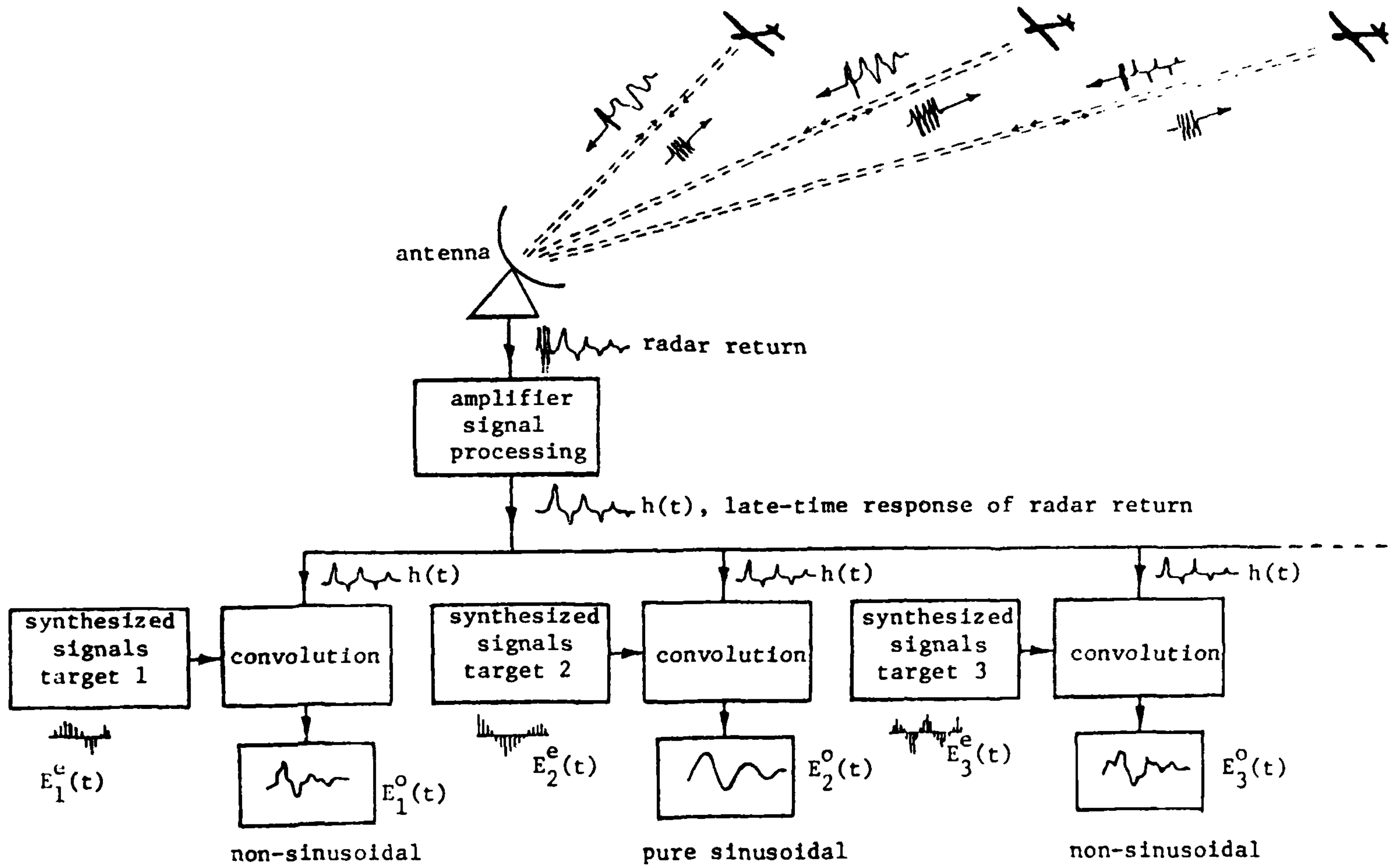


Figure 9. Experimental arrangement for measurement of transient scattered EM waveforms.



$$E_n^o(t) = \int_0^{T_e} E_n^e(t')\, h(t - t')\,dt'$$

Fig. 10. A proposed target identification and discrimination system.

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