Application of E-pulse Method for Remote Sensing Arbitrary Shaped Objects in Lossy Media

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Abstract — **Aspect independent radar target discrimination method, using the natural frequencies of arbitrary shaped objects, is introduced. The approach is based on the extinction-pulse (E-pulse) technique and, as the numerical simulation shows, it is relatively insensitive to random noise and to estimations of modal contents. This method allows to discriminate superwide-band radar targets down to the signal-to-noise ratio approximately 5 dB. The results of experimental research of the signals scattered by the arbitrarily shaped objects in lossy media are presented.**

I. INTRODUCTION

It is well known that the transient response of an object, exited by superwide-band impulse waveform, contains all the information about the electromagnetic scattering properties of the target in the frequency band that is defined by the spectrum of the incident impulse. So this impulse response can be used as a characteristic signature of the object. Most adequately the transient response of conducting objects is described by the resonant model, based on the singularity expansion method [1]. The mathematical model of the late-time portion of the radar target response can be decomposed into a finite sum of damped sinusoids (excited by an incident field waveform of finite usable bandwidth), oscillating at frequencies determined purely by target geometry and size.

Many recent radar target discrimination methods have utilized the late-time natural oscillation behavior of conducting targets. Traditional parametrical methods are based on an estimation of a finite quantity of parameters describing an object, for example, the well-known Prony's method, pencil-of-function method, ESPRIT, etc [2]. In contrast to these methods, this paper introduces one of the non-parametrical methods – the E-pulse technique [3]. This method applies the synthesizing of discriminate signals (E-pulses), which in the case of a numerically convolution with a late-time transient result of the target causes the zero-mode response, thus the different targets can be discriminated.

This paper quantifies discrimination using E-pulses in a way that is suitable for use in automated discrimination scheme. Examples of the performance of this automated scheme using experimental signals scattered by the arbitrarily shaped objects in lossy media with varying amounts of additive noise are presented. The paper is organized as follows.

In section II, the theoretical bases of E-pulse technique are presented and provide the approach to numerical simulations on the resonant model. Results of experimental research of signals scattered by the arbitrarily shaped objects in lossy media are presented in Section III. Concluding remarks are drawn in Section IV.

II. THE E-PULSE TECHNIQUE

It is well known that the impulse response of a conducting target to a band-limited transient excitation in the late time can be written as [2]:

$$y[n] = x[n] + \nu[n] = \\ = \sum_{i=1}^{P} |b_i| \exp\left[(\sigma_i + j\omega_i)n + j\theta_i\right] + \nu[n], \quad (1)$$

where $n = 0, 1, ..., N - 1$ are numbers of samples of signal $y[n]$; P is the number of dominant resonances induced by an exciting field; $\nu[n]$ are samples of additive Gaussian band-limited noise; $|b_i|$, θ_i are the aspect dependent amplitude and phase of i-th target mode; σ_i, ω_i are the aspect independent damping factor and natural frequency of i-th target mode.

The E-pulse technique consists of synthesizing finite duration discriminant signals:

$$e[n] = \sum_{j=0}^{M} e_j \cdot g_j[n], \quad (2)$$

where e_j are the parameters of E-pulse method; $g_j[n]$, $j = 0, \ldots, M$ is a system of orthonormal functions, $M \geq P$, e.g.

$$\sum_{n=0}^{\infty} g_j[n]\, g_k[n] = \begin{cases} 0, & j \neq k \\ \left\| g_j^2[n] \right\| = 1, & j = k \end{cases}. \quad (3)$$

As a system of orthonormal functions we have chosen a set of delta-functions which are not overlap in time:

$$g_j[n] = \delta[n - j\Delta], \tag{4}$$

where $\delta[n]$ is the Kronecker delta function; $\Delta = \{r\pi / \omega_{\max} T_s\}$ is a number of samples between neighbor δ-functions; $\{a\}$ denotes the integer part of "a"; $\omega_{\max}$ is the maximum frequency in measured response $x[n]$, $r = 1, 2, 3, \ldots$; T_s is the period of sampling. The structure of E-pulse is depicted on Fig. 1.

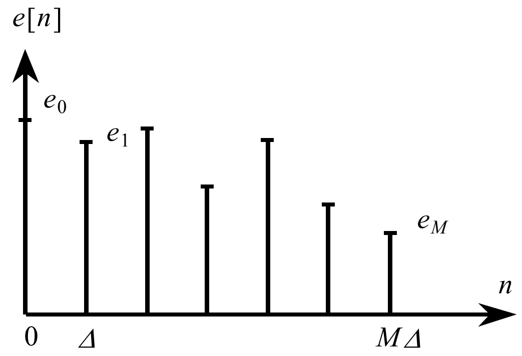

Fig. 1. The structure of E-pulse

The parameters of E-pulse are chosen so that

$$c[n] = e[n] * x[n] = \sum_{i=1}^{P} b_i z_i^n \sum_{j=0}^{M} e_j z_i^{-j} = 0, \quad n \geq M\Delta, \tag{5}$$

where the asterisk denotes convolution; $b_i = |b_i| \exp(\theta_i)$ and $z_i = \exp(\sigma_i + j\omega_i)$ are the complex residues and poles of the resonant model.

To determine the E-pulse coefficients e_j, the system of linear equations should be constructed

$$\mathbf{X}\,\mathbf{e} = -e_M \mathbf{x}, \tag{6}$$

where

$$\mathbf{X} = \begin{bmatrix} x[0] & x[\Delta] & \cdots & x[\Delta(M-1)] \\ x[1] & x[\Delta+1] & \cdots & x[\Delta M] \\ \vdots & \vdots & \ddots & \vdots \\ x[M] & x[\Delta+M] & \cdots & x[\Delta(2M-2)] \end{bmatrix};$$

$$\mathbf{x} = (x[\Delta M] \;\; x[\Delta M+1] \;\; \cdots \;\; x[\Delta(2M-1)])^T; \tag{7}$$

$$\mathbf{e} = (e_0 \;\; e_1 \;\; \cdots \;\; e_{M-1})^T.$$

Applying z-transform to the equation (5) we can obtain

$$\tilde{C}(z) = \tilde{E}(z) \cdot \tilde{X}(z), \tag{8}$$

where $\tilde{C}(z)$, $\tilde{E}(z)$, $\tilde{X}(z)$ are the z-transforms of $c[n]$, $e[n]$, $x[n]$ respectively. From another point of view $\tilde{X}(z)$ may be received from the equation (1) by using z-transform. It can be written as $\tilde{X}(z) = \tilde{P}(z)/\tilde{Q}(z)$, where $\tilde{P}(z)$ and $\tilde{Q}(z)$ are polynomials of z. The order of polynomial $\tilde{Q}(z)$ is P, and its roots are the poles of the resonant model z_i. Since $e[n]$ is finite sequence of samples (see Fig. 1), $\tilde{E}(z)$ is a polynomial, which order is M. So the inverse z-transform of $\tilde{C}(z)$ will be finite sequence only in case when P roots of the polynomial $\tilde{E}(z)$ are equal to the poles of the resonant model z_i, $i = 1, \ldots, P$. Because the change of the aspect of objects leads to the variations of amplitudes $|b_i|$ and phases θ_i of the signal $x[n]$ (1) and does not influence at the poles z_i, the duration of $c[n]$ will be aspect independent. So if the follow condition $n > M\Delta$ is performed, the result of convolution the E-pulse with the measured response, or the late-time response, of the target will be equal to zero.

Inaccuracy of constructed E-pulse and corruption by noise may lead to the deviation of the convolution from zero at the late-time period. The deviation of the late-time response $c[n]$ from the expected value of zero can be estimated by the characteristic parameter of E-pulse method (CPM) [4]:

$$\psi = \sum_{n=M\Delta}^{\infty} c^2[n] \Big/ \sum_{n=0}^{M\Delta} e^2[n], \tag{9}$$

that is the energy of $c[n]$ at the late-time period, normalized by the E-pulse energy.

The research of E-pulse method was carried out on model (1), which describe the transient response of arbitrary shaped objects. For the case of additive Gaussian band-limited noise $\nu[n]$ the signal-to-noise ratio (SNR) can be estimated as

$$q = \frac{1}{y_\nu^2} \sum_{n=0}^{N-1} x^2[n], \tag{10}$$

where σ_ν is the standard deviation of the Gaussian noise $\nu[n]$.

The sensitivity of the E-pulse method to SNR and differences in target geometry were tested by using signals (1) with different parameters σ_i and ω_i. The models of signals were corrupted with varying amounts of noise. CPM values for these cases were computed.

In [4] it was shown that in cases of random initial phases and amplitudes of the observed signal the results of convolution of the E-pulse with the measured response are identical. It's confirms the statement about aspect-independence of E-pulse method.

As a result of numerical simulations we obtained that the E-pulse method is practically aspect-independent technique of radar target discrimination and allows effectively identify arbitrarily shaped objects down to the signal-to-noise ratio approximately 5 dB.

III. EXPERIMENTAL RESULTS

For the experimental researching of E-pulse method the objects with the simple geometric shape such as sphere, solid cylinder with different sizes were used. These objects were placed into the water, and after that were exited by ultra-wide band triangular pulses with effective duration about 0.5 nanoseconds.

The laboratory system scheme for the obtaining measured responses of arbitrarily shaped objects in lossy media is shown on Fig. 2. Main parameters of this system are follow:

- antenna: dielectric dipole;
- frequency band: 0.5 … 3 HHz;
- effective period of sampling: 0.1 ns;
- pulse power: 50 W;
- signal-to-noise ratio: up to 5 dB.

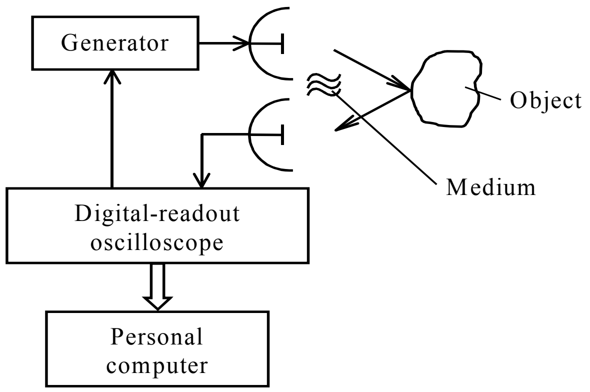

Fig. 2. The laboratory system scheme for the obtaining measured responses

The measured responses of the brass cylinder (a) with radius R = 22 millimeters, length L = 100 millimeters and dielectric sphere (b) with radius R = 25 millimeters and $\varepsilon \approx 3$ in water with permittivity $\varepsilon = 81$ are shown on the Fig. 3.

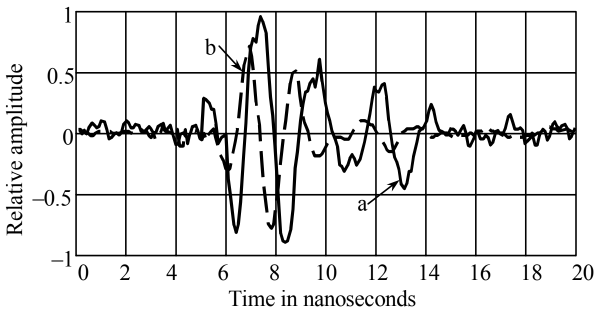

Fig. 3. The measured response of objects in water. a) The brass cylinder with radius R = 22 mm and length L = 100 mm; b) Dielectric sphere with radius R=25 mm, $\varepsilon \approx 3$

To test efficiency of E-pulse method for identification of radar targets in the presence of noise we have added Gaussian band-limited noise to the measured response. The level of this noise was evaluated by using (10). For example, the realization of measured response of brass cylinder with signal-to-noise ration 5 dB is depicted on Fig. 4. This SNR is corresponding to the maximum level of noise when the E-pulse method is still working.

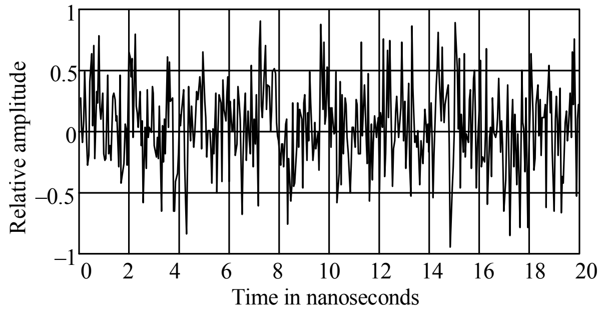

Fig. 4. The measured response of the brass cylinder, the signal-to-noise ratio is q = 5 dB

The convolution of the E-pulse, constructed for cylinder, with the measured response of the brass cylinder is depicted on the Fig. 5. Compared to early time, the late-time region has been effectively annulled. In this case the characteristic parameter of method (9) is equal to zero.

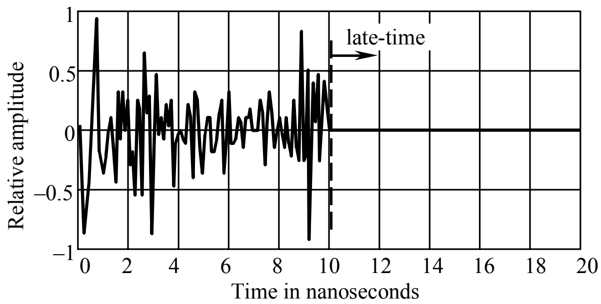

Fig. 5. The convolution of the E-pulse for the cylinder with the measured response of the brass cylinder

In contrast with previous situation the result of convolution of the E-pulse, constructed for cylinder, with the measured response of the dielectric sphere is not equal to zero in late-time period (see Fig. 6). The CPM for this case ψ = 43 dB. It is clear seen that the E-pulse is not matched with this measured response.

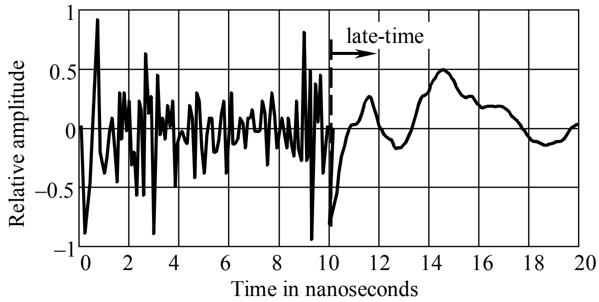

Fig. 6. The convolution of the E-pulse for the cylinder with the measured response of the dielectric sphere

The same result can be obtained by convolving the E-pulse, constructed for dielectric sphere, with the measured response of the brass cylinder (see Fig. 7). The CPM similarly much more than zero result: $\psi = 39$ dB.

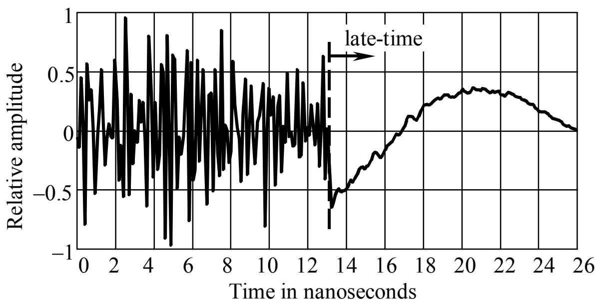

Fig. 7. The convolution of the E-pulse for the dielectric sphere with the measured response of the brass cylinder

It is important to stress the fact that duration of E-pulses is determined by the minimal resonant frequency in measured response of the objects. For the brass cylinder and dielectric sphere they are 10 and 13 nanoseconds respectively.

If the measured response of the object is corrupted by the noise the late-time portion of the convolution of the E-pulse with this response will not be zero (see Fig. 8).

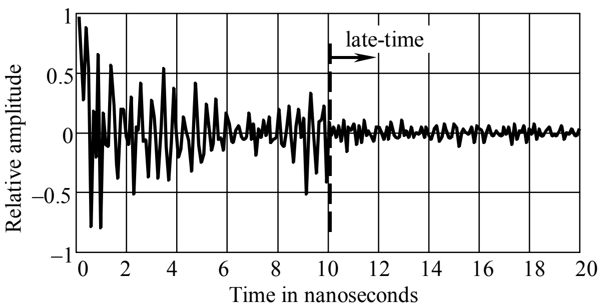

Fig. 8. The convolution of the E-pulse for the cylinder with the measured response of the brass cylinder, the signal-to-noise ratio is $q = 10$ dB

In particular, for the case when the signal-to-noise ratio $q = 5$ dB the CPM is equal $\psi = 30$ dB. This leads to the situation when the "right" target can't be discriminated because the level of noise is too big.

So the result of experimental research confirms the fact that the E-pulse method is an aspect independent technique for radar target discrimination in lossy media.

IV. CONCLUSIONS

The approach for radar target discrimination has been presented. It is based on the E-pulse technique, and has been shown to be relatively insensitive to random noise. This technique can be readily used in applications where different targets are considered and the discrimination decisions are made by computer.

The results of numeral simulation and experimental research are given to demonstrate the performance of the E-pulse method to discrimination of the arbitrarily shaped objects in lossy media with high probability of a right identification down to the signal-to-noise ratio 5 dB.

V. REFERENCES

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