Auto-Regressive Filter-Based E-Pulse Discriminating Scheme

Serguei L. Primak, Joe LoVetri, Zsuzsanna Damjanschitz, and Satish Kashyap

Abstract—**Ultrawide-band radar target discrimination schemes have been of great interest during the last two decades. One of the most used methods is the so-called E-pulse discrimination scheme [1], which is based on the late-time impulse response of a target. Traditional techniques to construct the proper E-pulses require the determination of the natural frequencies as an intermediate step. Here, we present a technique that allows us to obtain the required E-pulses directly. The approach suggested is applied to two simple three-dimensional (3-D) targets: a rectangular cavity and a strip with a fin.**

***Index Terms*—Radar target recognition, ultrawide-band radar.**

I. Introduction

Radar target identification methods using the time-domain impulse response of a target, so-called ultrawide-band (UWB) radar discrimination schemes, have generated considerable interest recently [2]. One of the most frequently used techniques, the so-called E-pulse scheme, was described in [1] and is based on the discrimination of the target using the late portion of the target response. The late-time response contains free oscillations that are defined by the natural frequencies of the corresponding target. This technique is aspect independent and produces reasonable results even in a noisy background. The original procedure assumes that the natural frequency of the target is known *a priori* or can be estimated from the measurements [1]. A large variety of techniques to determine natural frequencies are available [3]. It has also been shown that this intermediate step is very sensitive to the level of noise in the measurements. Some techniques were independent on such an estimation, however, they utilize a computationally expensive optimization [4]–[6]. Another problem is that the length of the E-pulse defined by the natural frequencies is relatively large, making the scheme more sensitive to noise. Here, we suggest a technique based on the auto-regressive (AR) representation of the E-pulse, which does not use *a priori* knowledge about the natural frequencies and can produce shorter E-pulses than those obtained by conventional methods.

II. Model of the Late-Time Response and E-Pulse Discrimination Scheme

In [8], Baum proposed a simplified model of the late-time response of a target to a short incident pulse

$$r(t) = \sum_{n=1}^{N} r_n \cdot \exp(\sigma_n t) \cdot \cos(\omega_n t + \phi_n), \qquad t > T_l. \quad (1)$$

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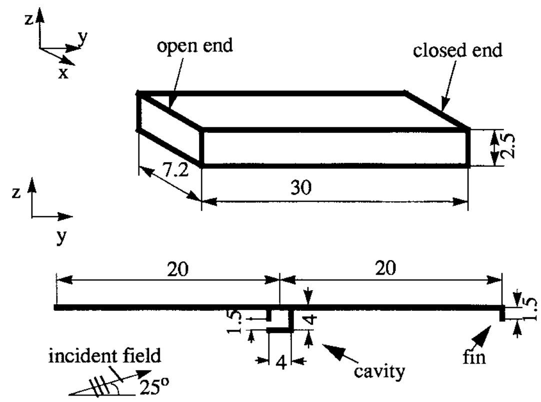

Fig. 1. Geometry of the rectangular cavity and the strip with fin used in the FDTD simulation; dimensions are given in centimeters.

Here, $s_n = \sigma_n + j\omega_n$ are the aspect independent natural frequencies of the nth target mode, r_n and ϕ_n are aspect dependent modal amplitudes and phases, N is a number of natural frequencies, and T_l is the aspect-dependent time instance at which the late-time response begins.

The E-pulse waveform $e(t)$ for a particular target is defined [1] such that

$$c(t) = \int_{T_L}^{t} e(\tau) r(t-\tau)\, d\tau = e(t) * r(t) = 0, \qquad t > T_L = T_l + T_e \quad (2)$$

where T_e is the duration of $e(t)$, and $r(t)$ is the response of the target from any aspect angle. The original procedure to derive the E-pulse for a given target consists of two steps: 1) extraction of poles from the measured impulse response of the target or its scale model [1] and 2) obtain the desired waveform for $e(t)$ using one of several methods described in [1] and [5]–[10].

To achieve target discrimination using E-pulses, the response from an unknown target $v(t)$ is convolved with each of the E-pulses in a data base $c_i(t) = e_i(t) * v(t)$, $1 \leq i \leq I$ where I is the number of models stored in the database. In an ideal situation if $c_k(t)$ in late-time is zero, we have a match kth target. Realistically, the convolution which is closest to zero identifies the target.

A quantitative method of determining "closest to zero" is the E-pulse discrimination number (EDN) [1]

$$\text{EDN} = \int_{T_L}^{T_L+W} c^2(t)\, dt \Big/ \int_{T_L}^{T_L+W} e^2(t)\, dt. \quad (3)$$

It is a measure of the deviation from the expected value of zero late-time energy. The choice of window duration W depends on the duration of the target response. The E-pulses producing the smallest EDN identifies the target.

Most of a target cannot be considered as "purely" resonant. This means that the total response consists of a number of sharp pulses, as well as late-time portion of the response, representing dispersive waveguide modes, etc. It was shown in [7] how to create E-pulses for this situation preserving the main property of the E-pulses; they remain aspect-independent fixed-length waveforms allowing signal annihilation according to (2).

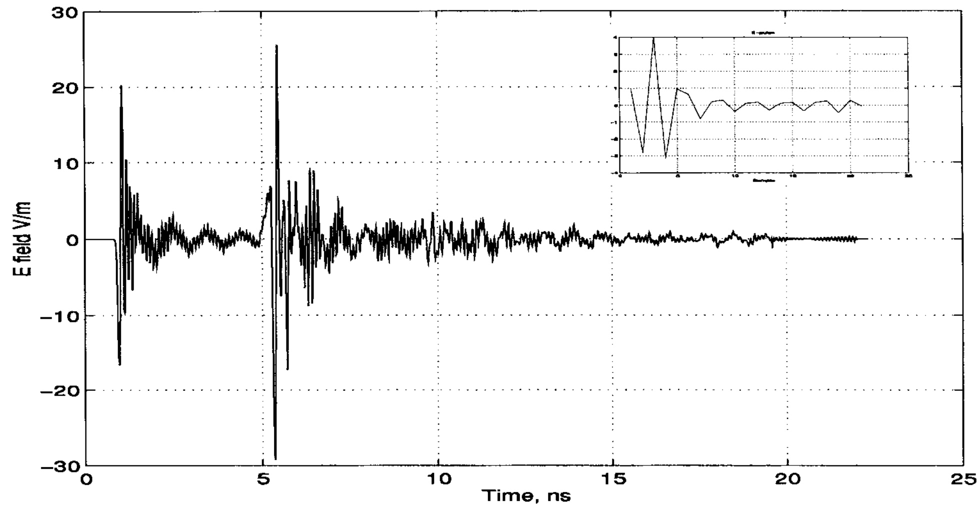

Fig. 2. Impulse response and corresponding E-pulse (inset) for the cavity.

III. AR Based E-Pulses

Since we assume the model of the target response in the form (1), it should satisfy the following auto-regressive (AR) equation [3]

$$y_k + a_1 \cdot y_{k-1} + a_2 \cdot y_{k-2} + \cdots + a_n \cdot y_{k-n} = 0, \quad \sum_{i=0}^{n} a_i \cdot y_{k-i} = 0 \tag{4}$$

where $a_0 = 1$. Since this can be thought of as a convolution sum and since it is equal to zero, the vector $[a_n \quad a_{n-1} \quad \cdots \quad a_1 \quad 1]$, represents the discretized E-pulse. Determination of the AR model can be achieved without the calculation of the natural frequencies in (1), using Yule–Walker algorithm, discussed in details in [3].

To find where exactly the late-time part of a target response begins, we have used the following algorithm.

1) Suppose the available data set is $\{D_i\}$, $i = 1, \cdots, N$. Then consider a subset of data $\{d_j\} = \{D_j\}$, $j = k, \cdots, N$ where $k > l$, l being the index of the data point at which the late time starts.
2) Determine the AR parameters for $\{d_j\}$.
3) If the change in the AR parameters with respect to their previous values is lower than a threshold, decrease k and return to 1); otherwise stop.

In other words, we estimate the AR parameters successively for each response by starting from the end of the response and adding more and more data points to the data set being analyzed. These AR parameters were compared to each other and when a change between two successive sets was observed, the beginning of the late-time part was identified.

In contrast to the E-pulses constructed using the procedure described in [1], where the duration of the AR based E-pulse depends on the time step between samples and so it can be made relatively short. This allows us to process a wider window when convolving with the unknown target response and thus outperform longer E-pulses when signal to noise ratio is considered. In our simulations the time step is $\Delta t = 0.01$ ns, so the total length of the corresponding E-pulse is $T_e = 0.2$ ns. The dominant pole has frequency $\omega = 1.2$ GHz. This means that the length of the E-pulse, obtained using the traditional technique is (taking into account the same 20 poles as in the AR model) $T_e = 2\pi/\omega \approx 5.2$ ns.

IV. Numerical Simulations

To validate our technique we used impulse responses obtained for cavity and a finned strip shown in Fig. 1. These responses were simulated using finite-difference time-domain (FDTD) technique. Discretized response of the length of 4500 samples was obtained with sample time $\Delta t = 0.01$ ns.

TABLE I
EDN Numbers Obtained by Convolving the Cavity and Strip Responses at Three Different Angles with the Two E-Pulses

Cavity response	Cavity E-pulse	Strip E-pulse	Strip response	Strip E-pulse	Cavity E-pulse
0°	0.015	0.16	10°	0.07	0.81
30°	0.030	0.20	40°	0.14	0.78
60°	0.045	0.16	70°	0.16	0.75

The beginning of the late-time response was determined as 1200th and 1500th samples, respectively. E-pulses were created using the AR parameters as described in the previous section. Using 20 AR parameters the E-pulses for both objects were calculated. As described earlier, the convolution has to be close to zero from $t > T_L = T_l + T_e$ and, therefore, the convolution results were considered only from steps 1220 and 1480, respectively. In order to show the aspect independence of this new E-pulse, the responses of the two objects at three different angles, $\theta = 0, 30^\circ, 60^\circ$ for the cavity and $\theta = 10^\circ, 40^\circ, 70^\circ$ for the strip were simulated and the EDN numbers for every possible combination were calculated (Table I). The AR E-pulses were obtained using the $\theta = 0^\circ$ for cavity and $\theta = 10^\circ$ for the strip. One example of calculated impulse response and corresponding E-pulse are shown in Fig. 2.

It can be seen from Table I that, since the EDN numbers obtained by convolving the cavity E-pulse with the three cavity responses are lower than the EDN numbers obtained by convolving a different E-pulse with the same responses, this method discriminates well between the two targets.

Although the two E-pulses were obtained from the responses exclusively at angle 0° for cavity and 10° for strip, they could discriminate between the two targets at any angle. This brings evidence to the aspect independence of this type of E-pulse.

V. Conclusions

We have shown how the AR model can be used to create a new family of E-pulses and how target identification can be achieved when using enough parameters in the AR model. The length of such E-pulses may be less then those obtained by the traditional methods.

Identification of an unknown target was accomplished by convolving its response with the E-pulses available in our database, after which the EDN's were calculated. Both methods showed that when using 20 parameters in the AR model, "unknown" targets could be identified correctly.

REFERENCES

[1] P. Ilavarasan, J. E. Ross, E. J. Rothwell, K. Chen, and D. P. Nyquist, "Performance of an automated radar target discrimination scheme using E pulses and S pulses," *IEEE Trans. Antennas Propagat.*, vol. 41, pp. 582–588, May 1993.

[2] D. G. Dudley, "Progress in identification of electromagnetic systems," *IEEE Trans. Antennas .Propagat. Soc. Newslett.*, vol. 30, no. 4, pp. 5–11, Aug. 1988.

[3] L. L. Sharf, *Statistical Signal Processing. Detection, Estimation, and Time Series Analysis.* Reading, MA: Addison-Wesley, 1991.

[4] J.-P. R. Bayard, "Optimization method versus E-pulse method in the context of target discrimination," *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 111–115, Jan. 1991.

[5] Q. Li, E. J. Rothwell, K.-M. Chen, and D. P. Nyquist, "Scattering center analysis of radar targets using fitting scheme and genetic algorithm," *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 198–207, Feb. 1996.

[6] F. Y. S. Fok, D. L. Moffatt, and N. Wang, "K-pulse estimation from the impulse response of a target," *IEEE Trans. Antennas Propagat.*, vol. 35, pp. 926–933, Aug. 1987.

[7] S. Primak, J. LoVetri, Z. Damyanshitz, and S. Kashyap, "E-pulse technique for dispersive scatterers," in *Ultra-Wideband Short-Pulse Electromagnetics 3*, C. Baum, Ed. New York: Plenum, 1997, pp. 327–335.

[8] C. E. Baum, "On the singularity expansion method for the solution of electromagnetic interaction problems," Interaction Note 88, Air Force Weapons Lab., 1971.

[9] A. Gallego, M. C. Carrion, D. P. Ruiz, and A. Medouri, "Extending E-pulse technique for discrimination of conducting spheres," *IEEE Trans. Antennas Propagat.*, vol. 41, pp. 1460–1462, Oct. 1993.

[10] S. Primak and S. Briskin, "An FIR approach to the discrimination of damped sinusoids," *IEEE Signal Processing Lett.*, vol. 2, pp. 207–209, Nov. 1995.