Sensor and Simulator Notes

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Improved Extinction Pulse method for Automated Radar Target Discrimination

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Abstract— Radar scattered time domain response can be modeled by natural poles using singularity expansion method (SEM) in resonance region. In this paper, limitation of the conventional Extinction pulse (E-pulse) method is brought out and a hybrid of conventional Extinction pulse and auto-regressive (AR) method is proposed for robust discrimination of radar targets. A new target discrimination number (TDN) is suggested, which gives very good discrimination margin for enhanced decision process. The improved Extinction pulse technique is applied on the free space targets as well as subsurface canonical metallic targets and the result obtained shows good discrimination margin. The free space target response was obtained using FDTD simulation and the subsurface target response was obtained using frequency domain measurement done for the targets buried under dry sand.

Index Terms— SEM, E-pulse, FDTD, AR, GPR

1. INTRODUCTION

Resonance based radar target discrimination schemes using time domain target response has generated considerable interest in the past [1-4]. One of the most popular methods used in recent time for resonance based target discrimination is the Extinction pulse (E-pulse) discrimination technique introduced by Rothwell et al.[2]. The E-pulse discrimination number (EDN) was introduced to quantify the discrimination process for automated E-pulse technique [3]. The pulse basis function is conventionally used for construction of E-pulse but recently other basis functions were also used and shown [11] that exponential basis function gives improved discrimination capacity. The late time response of a low SNR signal may give an erroneous result. To overcome this limitation, E-pulse method was used for early-time signal [5]. The early time E-pulse technique requires separate waveforms for each target aspect angles and thus needs significantly more storage and processing time. The combination of early time/late time was employed to overcome this limitation [6]. The possibility that some of resonant modes may not be well excited at particular incident aspect and polarization state, Lui and Shuley [13] suggested the use of full polarimetric target signature for more reliable results. Detection and imaging of radar targets buried below an interface has been of interest to microwave and radar engineers over many years. Lui et al.[12] monitored the small physical changes of hip prosthesis target below an interface using E-pulse technique.

Amidst significant developments observed in the area of resonance based target discrimination, one aspect, i.e., finding the onset of the late time, lacked serious attention of the researchers. The difficulty arises because the determination of the onset of the late time requires a priori knowledge of the target dimension. The autoregressive (AR) approach suggested by Primak el al.[10] to obtain the E-pulse directly in time domain solves the key issue of finding the late time in conventional E-pulse method[2]. However this approach is quite sensitive to noise because of the direct construction of the E-pulse from the target's response. After obtaining the E-pulse, the discrimination is accomplished by convolving it with the late-time scattered response of the target.

The present work suggests a hybrid of the conventional E-pulse method and the AR method and the use of a new target discrimination criterion to obtain a comfortable discrimination margin. The rest of this paper is organised as follows :The conventional E-pulse is briefly discussed in Section 2. The limitation of discrimination using convolved energy in late time is shown in Section 3. The hybrid E-pulse method and new target discrimination number for automated discrimination process is discussed in Section 4. Validation of this method for subsurface canonical scatterers is discussed in Section 5. Conclusion is presented in Section 6.

2. E-PULSE CONCEPT

An E-pulse is a finite duration waveform which when convolved with the anticipated target response, anhilates the contribution of a selected numbers of natural resonances to the late time target response. The time domain scattered field response of a conducting target has been observed to be composed of an early-time forced period, when the excitation field is interacting with the scatterer, followed by immediately by a late-time period during which the target oscillates freely [2]. The time domain response of a target is written as early time and late time response [2]. The late time response $r_l(t)$ is expressed by a finite sum of damped sinusoids [1-3]:

$$r_l(t) = \sum_{n=1}^{N} a_n e^{\sigma_n t} \cos(\omega_n t + \varphi_n) \tag{1}$$

where $t > T_l$; T_l is the onset of the late time, (σ_n, ω_n) is the pole of the nth resonance mode of the target described by a damping coefficient and a resonance pulsation. $(a_n \; and \; \varphi_n)$ are the amplitude and the phase of the nth resonance mode, and N is the number of modes assumed to be excited by the incident field waveform.

Let T_e be the duration of the E-pulse $e(t)$ and $T_L = T_l + T_e$. Thus the convolution of an E-pulse waveform with the late time measured response waveform is:

$$c(t) = e(t) * r_l(t), \quad t > T_L$$

$$c(t) = \int_0^{T_e} e(t') \, r_l(t - t') dt' \tag{2}$$

The convolved response of the anticipated target in late time goes to zero.

3. LIMITATIONS OF CONVENTIONAL E-PULSE

The limitation of the conventional E-pulse method [2] is demonstrated here with the help of a simulated experiment by taking the simulated time domain responses of four different metallic cylinders of same radii (10 cm) but varying lengths [cylinder-1(1 m), cylinder-2(0.75 m), cylinder-3(0.5 m), and cylinder-4 (0.25 m)]. The time domain response of cylinder of different dimensions used for discrimination process is obtained using finite difference time domain (FDTD) solver XFDTD (v7.1). A Gaussian plane wave pulse of 50 ps full width half maximum (FWHM), 50 ps rise time as shown in Fig. 1 is used as excitation for simulation. The target cylinders are individually placed vertically and the incoming plane wave with the dominant polarization matching to the axial dimension of the cylinder interacts with the target and backscattered target response is obtained. An absorbing boundary condition with seven perfectly matched layers (PML) and cell size 4 mm is used for this simulation. In conventional method the discrimination is automated by E-pulse discrimination number (EDN) [2], [3] given by the ratio of convolved energy in late time to energy of E-pulse.

$$EDN = \frac{\int_{T_l}^{T_l+W} |c(t)|^2 dt}{\int_0^{T_e} |E-pulse(t)|^2 dt} \tag{3}$$

where, W represents the time window, corresponds to 95% of the power of the convolution product for $t > T_L$ [8].

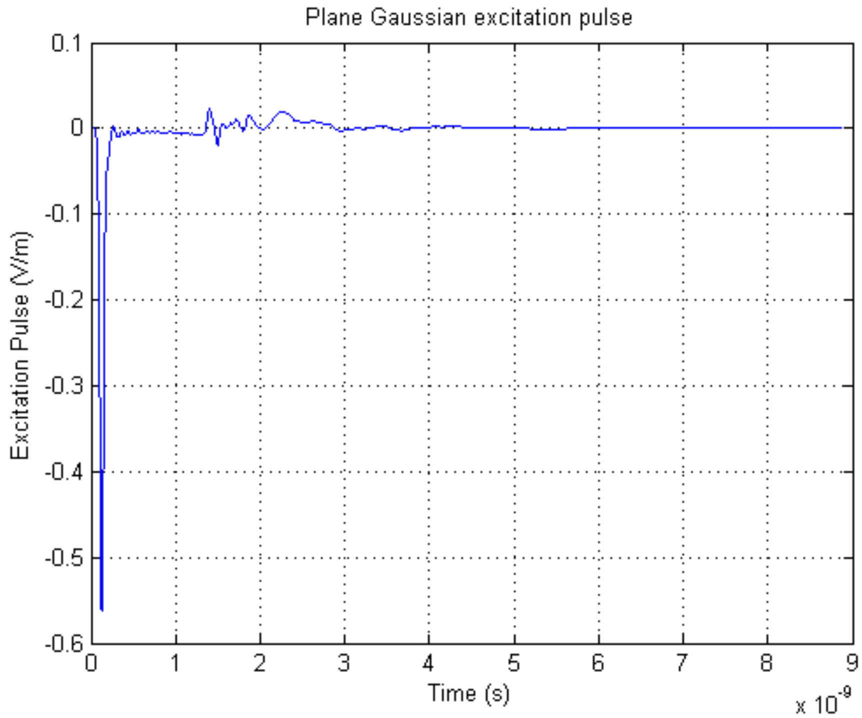


Figure 1: Excitation Gaussian plane wave

Two cases are considered in the experiment. In the first case, cylinder-4 is chosen as the anticipated target. The E-pulse of cylinder-4 is convolved with the responses of each one of the four cylinders one by one, and then the EDN is calculated and shown in the second column of Table 1 [8]. In the second case, cylinder-1 is chosen to be the anticipated target and the EDN values are shown in the third column of Table 1.

Various convolved responses obtained in the first and second cases are shown in Fig. 3 and Fig. 4 respectively. The onset of the late time $T_l + T_e$ in case-I occurs at 2.11 ns (Fig. 3) whereas that in case-II occurs at 3.22 ns (Fig. 4). Table1 clearly demonstrates that the target is correctly identified in case-I but a false alarm gets generated in case-II. The reason for this error in case-II can be understood by a close comparison of Fig. 3 and Fig. 4. Since the anticipated target in case-I is the smallest among the four cylinders, the late time of it's convolved output onsets at the earliest. For the same reason, the onset of the late time in case-II occurs at the latest. It is clear from Fig. 3 that when the late time started, the convolved response of cylinder-4 had lost much of its energy whereas the other three larger cylinders still had sufficient amount of energy left in their late responses. Hence the minimum EDN was obtained for cylinder-4. The same is not true in case-II. When the late time started in this case, already the three cylinders had lost much of their energy and so the energy left in the response of cylinder-1 is not the minimum of all four. This is aptly reflected in the EDN values and hence the false discrimination.

The anomaly lies in the fact that the energy present in the late time of the convolved response of a target depends on the largest dimension of the anticipated target. Therefore, the smallest dimensioned targets always have minimum convolved energy and minimum EDN irrespective of the choice of the E-pulse. Hence, the application of EDN as a discrimination metric is not robust and leads to wrong classification in certain cases.

Table 1: EDN (dB) values

Target Responses	EDN(dB)	
	E-pulse (cylinder-4)	E-pulse (cylinder-1)
Cylinder-1	-21.6731	-4.717
Cylinder-2	-24.1565	-9.027
Cylinder-3	-27.8478	-12.500
Cylinder-4	**-44.0497**	**-15.7139**

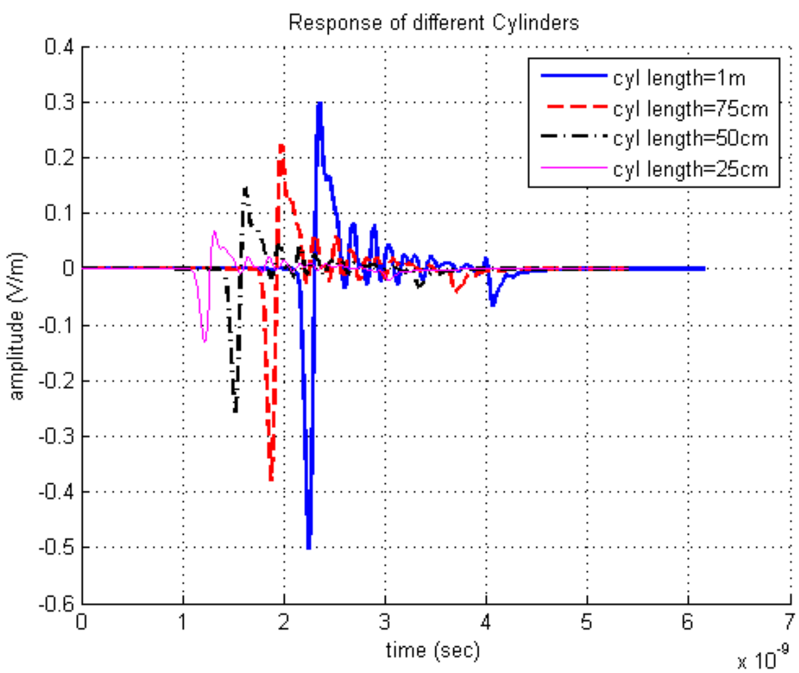


Figure 2: Time domain responses of cylinders of varying lengths

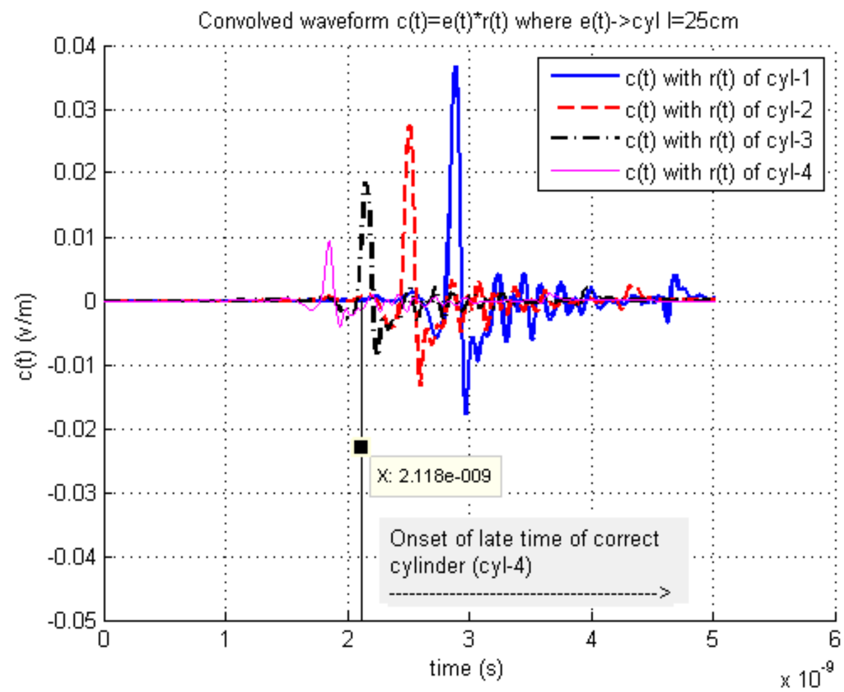


Figure 3: Convolved response of different cylinders in case-I

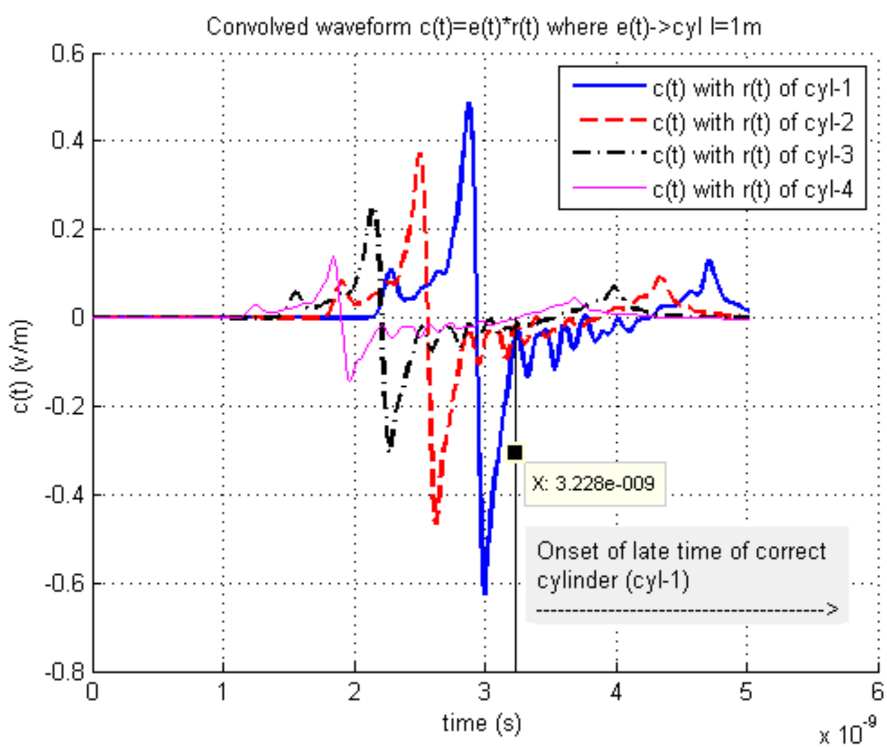


Figure 4: Convolved response of different cylinders in case-II

4. HYBRID E-PULSE METHOD

The above-mentioned limitation of conventional E-pulse method is overcome by using a hybrid method. The hybrid approach used here is combination of conventional E-pulse method [2] and the AR method [10] along with new discrimination module for ensuring robust discrimination process and improved margin of discrimination. The hybrid E-pulse discrimination process can be depicted by the block diagram shown in Fig. 5.

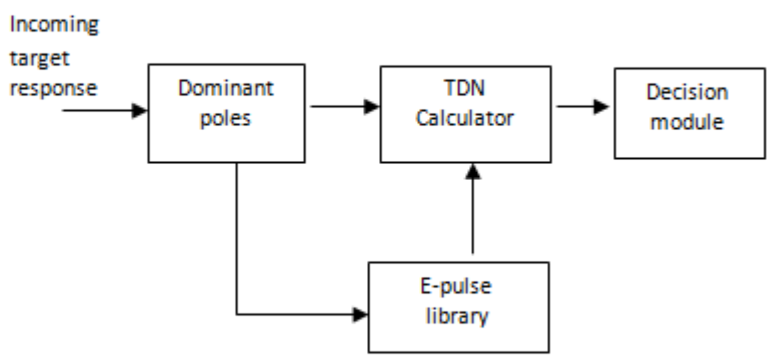


Figure 5: Block Diagram of Target Discrimination process

The steps followed in the hybrid method are as follows: determination of start of late time using AR method, extraction of poles from late time response using matrix pencil method, selection of dominant poles using stability criteria, formation of E-pulse by solving systems of linear equations as done in conventional E-pulse method and a new terminology called target discrimination number (TDN) is introduced in the target discrimination module. The steps followed are explained below.

a. Start of late time:

The determination of starting of late time from time domain target response is one of the critical requirement for natural resonance based discrimination process. Auto regressive (AR) method is used to determine the start of late time. To get the start of late time, the following algorithm is followed [10].

- For the available target response data set $\{R_k\}$, i=1,…….,N , a subset of data $\{r_j\} = \{R_j\}$, j=k,….,N is considered , where k>l , l being the index of the data point at which the late-time starts. Let k=N-1 initially.
- The AR coefficients for $\{r_j\}$ are determined using the Yule-Walker algorithm. The Yule-Walker algorithm estimates the parameters of AR model, by replacing the theoretical covariance with the estimated value.
- If the change in the AR parameters with respect to their previous values is lower than a threshold, then whole process is repeated after decreasing k. Otherwise the k is stored. The smallest k gives the index of the data point at which the response time starts.
- To this start time, three times the excitation pulse width in terms of data samples is added to avoid the forced impulse response in late time. This gives the required start of late time for Hybrid E-pulse method.

The forced part and the late time portion of the impulse response of 1 m cylinder found using above algorithm is shown in Fig. 5.

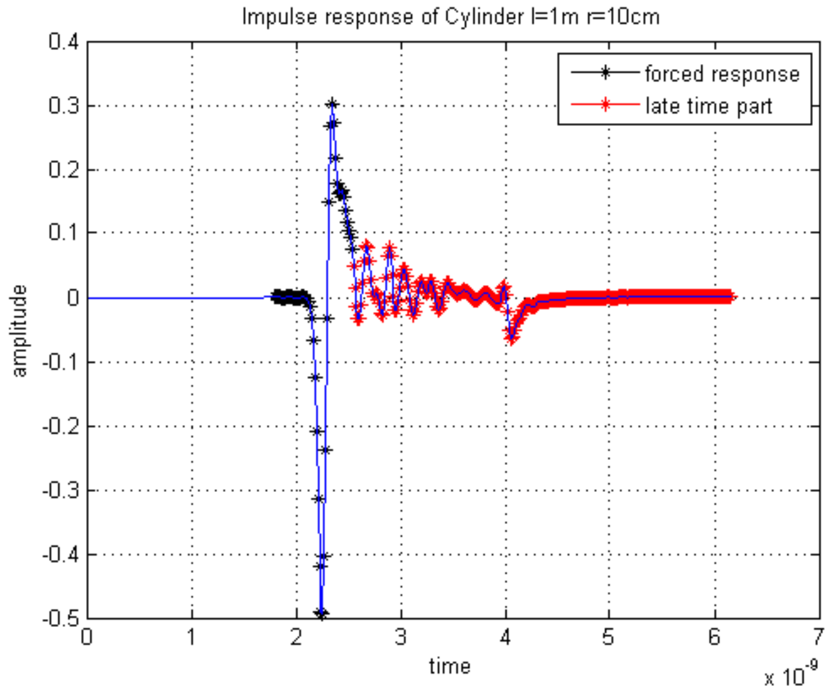


Figure 6: Waveform showing the forced response and the late time part of response of cylinder-1

b. Extraction of Poles:

Matrix pencil method is used for extraction of poles from the time domain target response. This method is used for the approximation of a function by a sum of complex exponentials [7]. It is more robust to noise and computationally more efficient. It provides smaller variance of parameters in the presence of noise than polynomial method. It is a one-step process.

c. Selection of Dominant poles:

The poles extracted from the target response may have many parasitical poles, less contributing poles and dominant poles. The dominant poles are enough to faithfully reconstruct late time target response with minimal mean square error. The selection of these dominant poles is done using following two criteria [9]:

1) The poles lying on the right half of the s-plane ($\sigma_m > 0$) representing the instability of the system, and the purely real poles($\omega_m = 0$), which contribute only to the damping, are eliminated.
2) Neglecting the pairs of poles with weight $\frac{|R_m|}{|\sigma_m|}$ much lower than the weight $\frac{|R_d|}{|\sigma_d|}$ of the dominant pair of poles.$\left\{\left(\frac{|R_m|}{|\sigma_m|}\right)_{norm} > threshold\right\}$, where $\frac{|R_m|}{|\sigma_m|}$ is normalized by $\frac{|R_d|}{|\sigma_d|}$.

All the poles extracted from late time response of cylinder-1of length 1 m and the dominant poles are shown in Fig. 7. The reconstructed response from the dominant poles closely follows the original late time response as shown in Fig. 8.

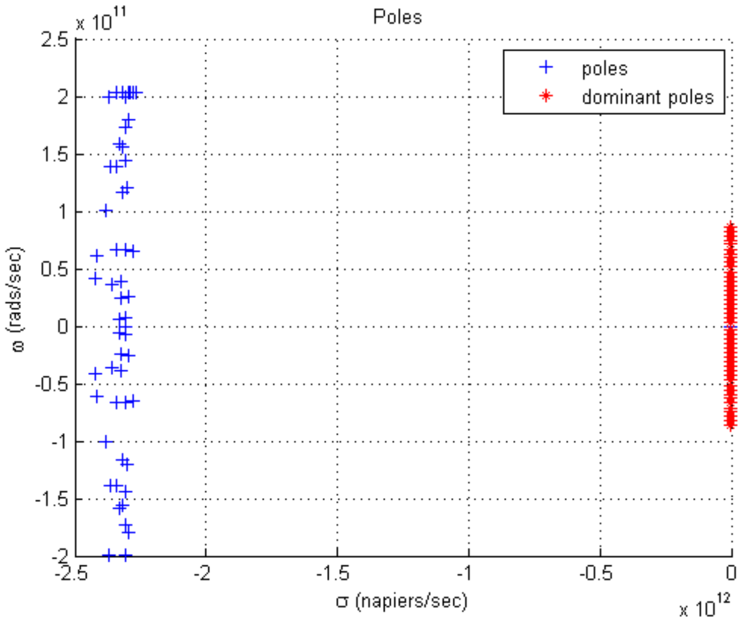


Figure 7: Poles extracted using matrix pencil method and dominant poles

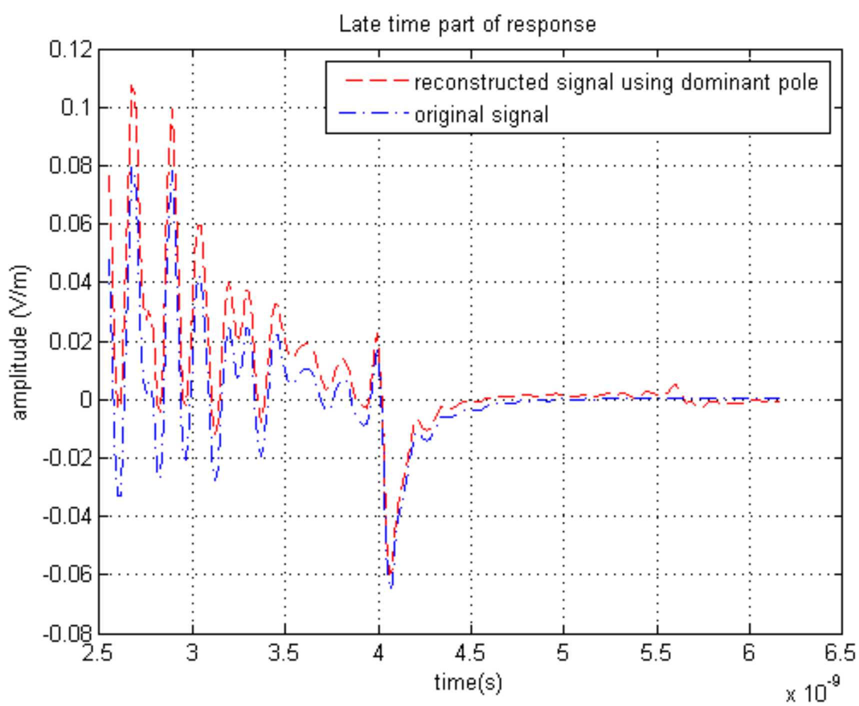


Figure 8: Original response and reconstructed response

d. E-pulse Waveforms:

An extinction pulse (E-pulse) is defined as a finite duration waveform which, upon interaction with a particular target, eliminates a preselected portion of the target's natural mode [2]. The equation (2) showing the convolution of an E-pulse waveform *e(t)* with the late time response waveform can be rewritten as:

$$\sum_{n=1}^{N} a_n e^{\sigma_n t}[A_n \cos(\omega_n t + \varphi_n) + B_n \sin(\omega_n t + \varphi_n)] \tag{4}$$

Where, $t > T_L = T_l + T_e$, T_e is the finite duration of *e(t)* and:

$$A_n = \int_0^{T_e} e(t')e^{-\sigma_n t'} \cos(\omega_n t')\, dt' \tag{5a}$$

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

E-pulse waveform is designed to eliminate the entire finite expected natural mode spectrum of the target, know as natural E-pulse, which nullify late time response of the anticipated target. The derivation of natural E-pulse [2] is as follows:

Laplace transform of *e(t)* is given by:

$$E(s) = L\big(e(t)\big) = \int_0^{T_e} e(t)e^{-s_n t} dt \tag{6}$$

$$= \int_0^{T_e} e(t)e^{-\sigma_n t}(\cos(\omega_n t) - j\sin(\omega_n t))dt$$

$$= \int_0^{T_e} e(t)e^{-\sigma_n t} \cos(\omega_n t)\, dt - j\int_0^{T_e} e(t)e^{-\sigma_n t} \sin(\omega_n t)\, dt$$

$$\text{From (5a), } A_n = R_e\{L(e(t))\} = R_e[E(s)] \tag{7a}$$

$$\text{From (5b), } B_n = -I_m\{L(e(t))\} = -I_m[E(s)] \tag{7b}$$

The condition that convolved response of anticipated target in late time is zero:

$$c(t) = 0 \tag{8}$$

requires from (2)

$$A_n = B_n = 0, 1 \le n \le N \tag{9a}$$

$$R_e[E(s)] = 0;\ I_m[E(s)] = 0 \tag{9b}$$

$$[E(s)] = 0 \tag{9c}$$

The natural E-pulse can be expressed as set of basis functions:

$$e(t) = \sum_{m=1}^{2N} \alpha_m f_m(t) \tag{10}$$

Where, $f_m(t)$ is the pulse basis function defined as:

$$f_m(t) = \begin{cases} g(t-(m-1)\Delta), & if\ (m-1)\Delta \le t \le m\Delta \\ 0, & otherwise \end{cases} \tag{11}$$

Where, Δ is the pulse width. The Laplace transform of the pulse basis function is given as:

$$F_m(s) = \int_0^{T_e} g(t-(m-1)\Delta)e^{-st}dt$$

$$= F_1(s)e^{s\Delta}\, e^{-sm\Delta}$$

$$F_m(s) = F_1(s)e^{-(m-1)s\Delta} \tag{12}$$

$$\begin{bmatrix} 1 & z_1 & z_1^2 & : & : & : & : & z_1^{2N-1} \\ : & : & : & : & : & : & : & : \\ : & : & : & : & : & : & : & : \\ 1 & z_N & z_N^2 & : & : & : & : & z_N^{2N-1} \\ 1 & z_1^* & (z_1^*)^2 & : & : & : & : & (z_1^*)^{2N-1} \\ : & : & : & : & : & : & : & : \\ : & : & : & : & : & : & : & : \\ 1 & z_N^* & (z_N^*)^2 & : & : & : & : & (z_N^*)^{2N-1} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ : \\ \alpha_N \\ \alpha_{N+1} \\ : \\ : \\ \alpha_{2N} \end{bmatrix} = 0 \tag{13}$$

Where, $z = e^{-s_n\Delta}$

The above Z matrix is a Vandermonde matrix and the equation (13) is a homogeneous, and thus has solution only when the determinant of the matrix is zero. The determinant of a Vandermonde matrix is given by:

$$\prod (z_i - z_j)$$

Where, i = 1,… 2N, j = 1, …, (N-1) and i > j

The homogeneous equation of the form $AX = 0$, either $X = 0$ or $A = 0$.

For nontrivial solution, i.e. $X \neq 0 \therefore \det A = 0$

$$\prod(z_i - z_j) = 0 \tag{14}$$

The only possible solution is $z_i = z_i^*$

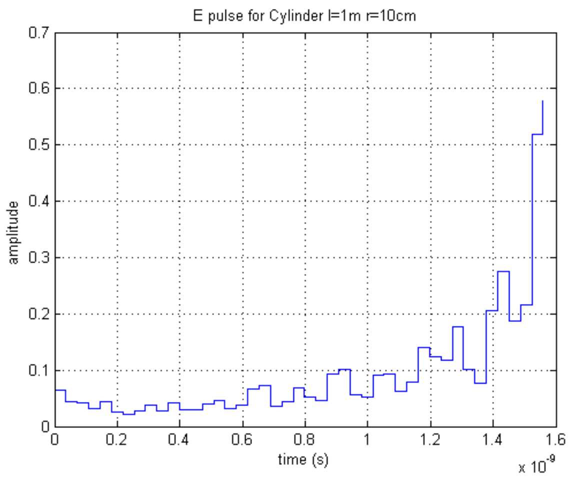
$$\Delta = \frac{p\pi}{\omega_i} \tag{15}$$

Where, p = 1, 2, 3,………..

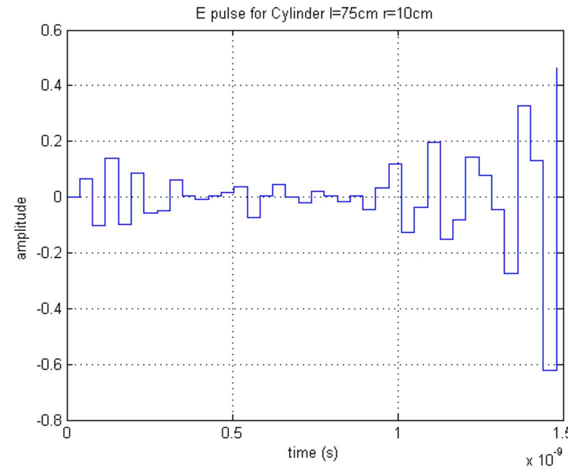
The *E*-Pulse signal duration depends only on the imaginary part of one of the natural frequencies. The minimal T_e value is calculated by choosing the greatest value of ω_i.

$$(T_e)_{min} = \frac{2N\pi}{\omega_i} \tag{16}$$

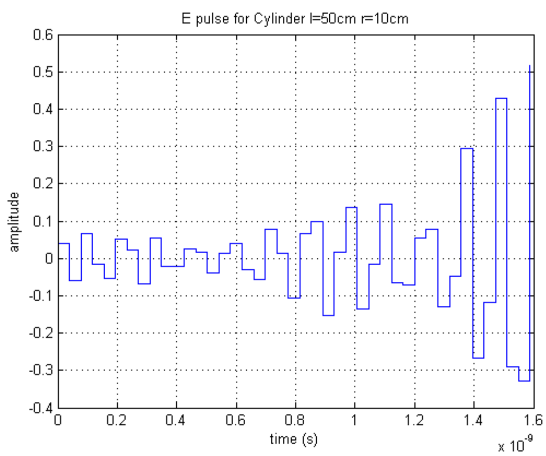
Once Δ determined, the amplitudes of the basis functions are calculated using the theory of determinants. The orthonormal basis of the vandermonde matrix in equation (16) gives the E-pulse amplitudes. The E-pulse constructed for the various cylinders is shown in Fig. 9.



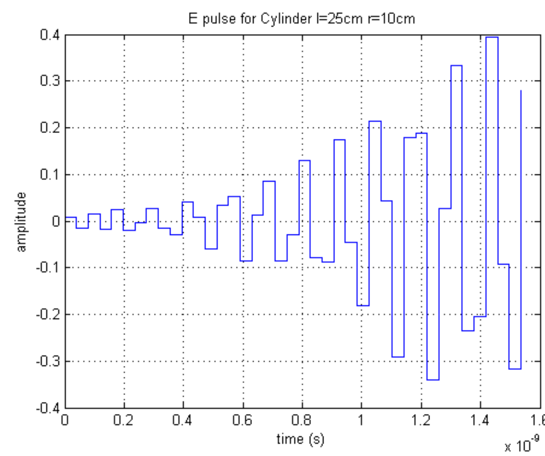
a) Cylinder-1



b) Cylinder-2



c) Cylinder-3



d) Cylinder-4

Figure 9: E-pulse for different cylinders

e. Target Discrimination Module:

Unlike E-pulse Discrimination number (EDN in dB), which is the ratio of convolved energy in late time to energy of E-pulse; wherein convolution energy depend on starting of late time and in turn on the target dimensions, hence smaller targets will always give minimum EDN value irrespective of the incoming target response. Therefore a more fundamental methodology is applied wherein equation (17) is used for the discrimination process.

If the discrete time domain response of a target is described by it's pole matrix Z and it's E-pulse by the column vector α, then, the condition for the target discrimination is simply:

$$\begin{bmatrix} 1 & z_1 & z_1^2 & : & : & : & : & z_1^{2N-1} \\ : & : & : & : & : & : & : & : \\ : & : & : & : & : & : & : & : \\ 1 & z_N & z_N^2 & : & : & : & : & z_N^{2N-1} \\ 1 & z_1^* & (z_1^*)^2 & : & : & : & : & (z_1^*)^{2N-1} \\ : & : & : & : & : & : & : & : \\ : & : & : & : & : & : & : & : \\ 1 & z_N^* & (z_N^*)^2 & : & : & : & : & (z_N^*)^{2N-1} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ : \\ \alpha_N \\ \alpha_{N+1} \\ : \\ : \\ \alpha_{2N} \end{bmatrix} = 0 \tag{17}$$

where, $z = e^{-s_n \Delta}$ and Δ is the pulse width, N is the number of dominant poles in the unknown target response, and $2N$ is the total number of samples in the E-pulse. The parameters required to construct the natural E-pulse are obtained by solving Eq. 17.

In general, if $R = Zx$, where Z is a $2N \times 2N$ matrix of poles and x is an arbitrary E-pulse vector of size $2N$, then Eq. 5, implies that a target is discriminated iff x is in the null space of Z. Since $x \neq 0$, this translates to a linear dependency among the rows/columns of Z. Now, each row element r_i of R is the inner product of the corresponding row vector of Z with the E-pulse vector x. For the true target's E-pulse α, these inner products will tend to zero and in turn the metric $\|R'\|_1$, where $\| \ \|_1$ is the 1-norm and $R' = [|r_i|^2]$, will also tend to zero. To make the target's convolved response size independent, one can normalize this metric with the 1-norm $\|x'\|_1$ of the E-pulse vector, where $x' = [|x_i|^2]$, x_i is the i^{th} row element of x. A new discrimination metric called Target Discrimination Number (TDN) is suggested as:

$$TDN = \frac{\|R'\|_1}{\|x'\|_1} \tag{18}$$

$$TDN_{dB} = 10 \ log_{10} \ (TDN) \tag{19}$$

This new discrimination parameter normalizes the energy in the residue with the energy of the E-pulse. One could have also used 2-norm or ∞-norm for the normalisation; however, no significant differences were observed in the TDN values for the four cylinders chosen in the experiment and hence 1-norm is used in this work for the calculation of the TDN. However, in future, the authors propose to investigate the effect of choosing the other norms on the target discrimination process. The robustness of the method was checked by using the same four simulated target responses of Section III. The TDN (dB) values obtained are tabulated in Table 2. The lowest value of the TDN is found to correspond to the expected target in each column of the table. The margin of discrimination is much larger in this case than the other similar methods reported in the literature [8], [10].

Table 2: TDN(dB) values obtained for different combinations of target and E-pulse

Target→	Cylinder l=1m r=10cm	Cylinder l=75cm r=10cm	Cylinder l=50cm r=10cm	Cylinder l=25cm r=10cm
E-Pulse ↓	1	2	3	4
1	**-98.0122**	4.7113	-0.0231	-2.9028
2	4.6226	**-91.0573**	3.5902	0.9556
3	2.6345	-4.6167	**-93.2396**	-2.3345
4	3.1486	-2.3107	0.5229	**-101.0636**

5. DISCRIMINATION OF SUBSURFACE SCATTERERS

The improved discrimination margin is demonstrated using hybrid E-pulse method in the earlier section on the set of time domain response data of different cylinders obtained from FDTD simulation. The method was further validated using measured response of canonical metallic scatterers buried under dry sand. The metal pieces of different shape and size were buried 8 cm below the surface of dry sand and bistatic antenna head was placed 20cm above the sand surface as depicted in Fig. 10. The metallic targets used for the experimentation are made of aluminium of different shapes like rectangles (M1, M2, M3, and M4), cylinder (M5) and rectangular strip (M6) as shown in Fig. 11. The measurement was done using stepped frequency method in the frequency range of 500 MHz to 3.2 GHz using network analyser and bistatic ultra wide band (UWB) antennas. The UWB antenna used for the experiments is reflector backed printed hybrid monopole. The ground penetrating radar (GPR) test bed filled with dry sand used for the experimentation and antenna search head of handheld GPR is shown in Fig.12. The frequency domain response of various canonical scatterers obtained from the measurement was converted to time domain response using inverse Fourier transform. The response of the different targets was obtained individually and their E-pulse library was created. The hybrid E-pulse method was applied on the time domain response of these subsurface scatterers and the TDN value obtained is shown in Table 3.

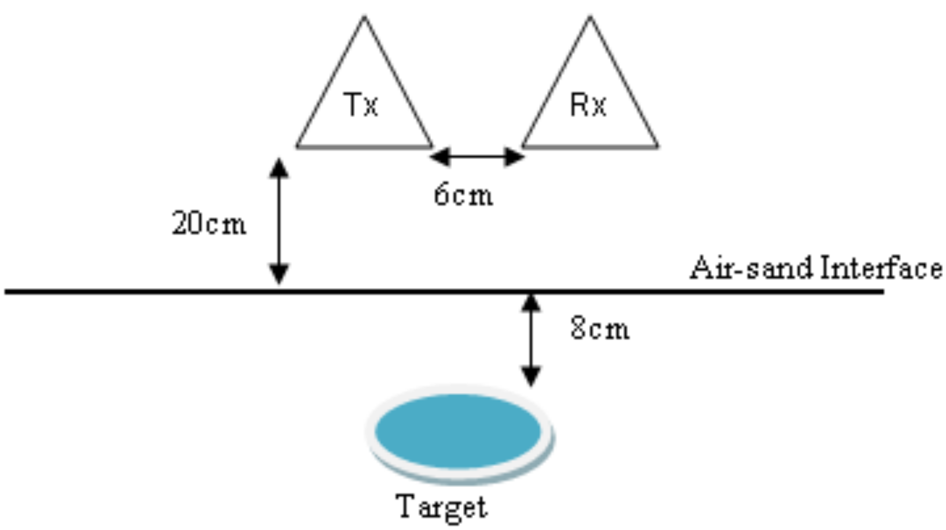


Figure 10: Schematics of subsurface target response measurement setup

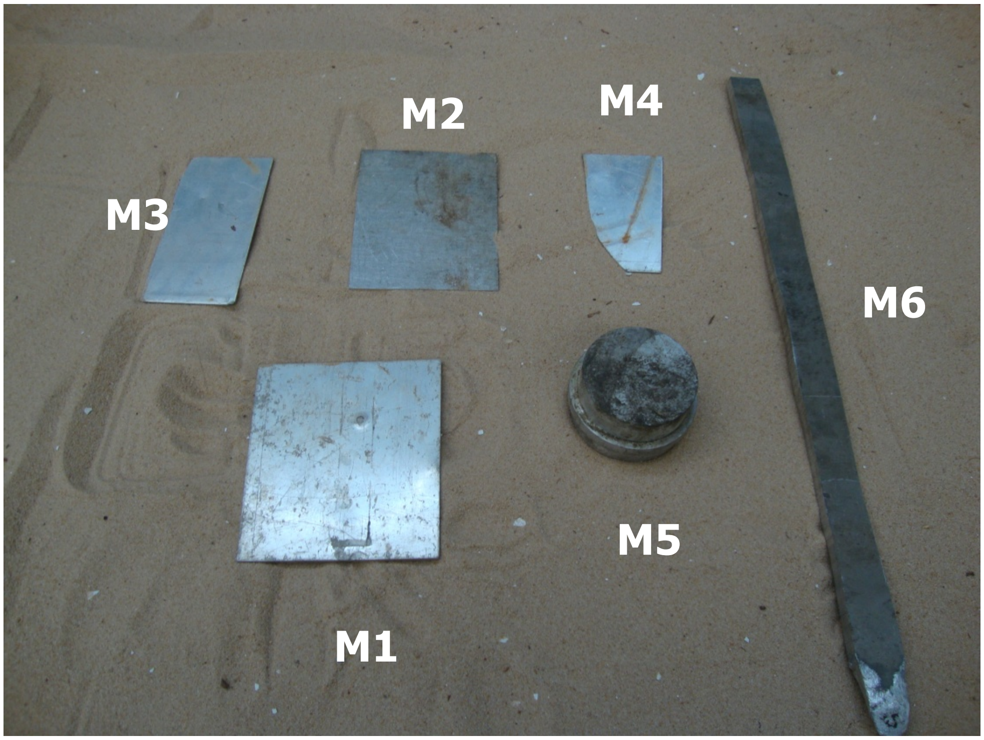


Figure 11: Subsurface Canonical Scatterers used for target discrimination

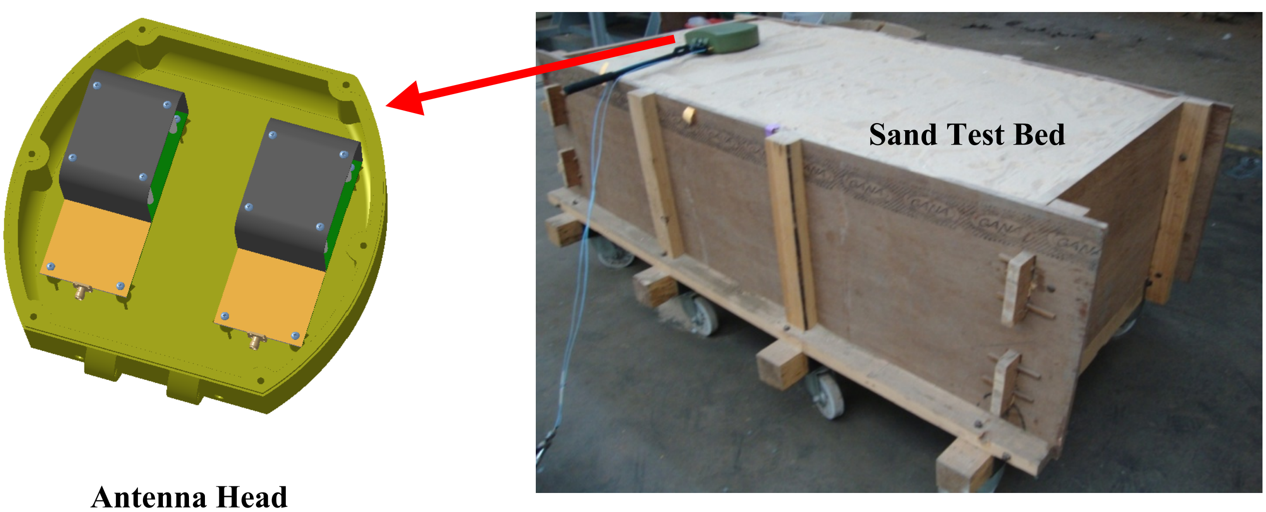


Figure 12: Sand Test Bed used for scattering experiment

Table 3: TDN (dB) values for different combination of Scatterers and E-pulses

Target→ / E-Pulse↓	M1 (17 cm x 15 cm)	M2 (16 cm x 13 cm)	M3 (17 cm x 9 cm)	M4 (13 cm x 7 cm)	M5 (dia 10 cm)	M6 (62 cm x 4 cm)
1	**-82.007**	-3.1175	-43.6205	-44.0608	-21.7801	-30.7502
2	-16.1058	**-80.5446**	-13.5786	-12.4182	-15.2949	-14.6258
3	-23.9218	0.4475	**-82.6404**	-52.8881	-13.5298	-22.052
4	-17.9856	2.7547	-35.2914	**-83.2996**	-9.4673	-15.4639
5	-31.7526	-7.9731	-45.9107	-48.3525	**-81.4082**	-26.6325
6	-35.2889	-6.9524	-36.6731	-44.2656	-29.017	**-83.7832**

6. CONCLUSION

The vulnerability of the conventional E-pulse method in target discrimination application is highlighted in this work. A modified E-pulse method is proposed to overcome this limitation. The method has been tested for subsurface targets and demonstrated the potential to reduce the frequency of the false alarms thereby improving the robustness of the automated radar target discrimination process.

REFERENCES

1. C.E Baum, “The singularity expansion method,” in Transient Electromagnetic Field,L.B Felsen,Ed. New York: Springer-Verlag,1976,pp.129-179.Baum, C.E., “Radiation of Impulse-like Transient Fields,” Sensor and Simulation Note#321, 25 November 1989.
2. Edward J. Rothwell et al., “Frequency Domain E-pulse Synthesis and Target Discrimination”, IEEE Transactions on Antennas and Propagation, Vol. AP-35,No. 4,April 1987.
3. 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.
4. M. C. Carrion, A. Gallego, J. Porti,and D. P. Ruiz., “Subsectional-Polynomial E-Pulse Synthesis and Application to Radar Target Discrimination” *IEEE Transactions on Antennas and Propagation,* Vol. 41, No. 9, September 1993.
5. E. J. Rothwell, K. M. Chen, D. P. Nyquist, P. Ilavarasan, J. E. Ross, R. Bebermeyer, and Q. Li, “A general E-pulse scheme arising from the dual early-time / Late-time behavior of Radar Scatterers,” IEEE Transactions on Antenna and Propagation, Vol. 42, No. 9, Sept. 1994.
6. Li. Q, Ilavarasan P, Ross J. E., Rothwell E. J., Chen Y. F, Nyquist D. P., “Radar Target identification using combined early/late time E-pulse technique,” *IEEE Transactions on Antenna and Propagation*, pp. 1272-1278, Vol. 46, Issue: 9, Sep. 1998.

7. Tapan K. Sarkar and Odilon Pereira., “Using the matrix pencil method to estimate the parameters of sum of complex exponentials”, *IEEE Antennas and propagation* Mag.,Vol.37,No.1,pp.48-55,Feb 1995.
8. R. Toribio and J. Saillard., “Identification of Radar Targets in Resonance Zone: E-Pulse Techniques”, *Progress in Electromagnetic Research*, PIER 43,39-58,2003.
9. Janic Chauveau, Nicole de Beaucoudrey, and Joseph Saillard, “Selection of Contributing Natural Poles for the Characterization of Perfectly Conducting Targets in Resonance Region”, *IEEE Transactions on Antennas and Propagation* ,Vol 55,No. 9, 2007.
10. Serguei L. Primak et al. , “Auto-Regressive Filter-Based E-pulse discriminating scheme”, IEEE Transactions on Antennas and Propagation Vol 45, No. 1, 1999.
11. J. D. Morales, D. Blanco, D. P. Ruiz, and M. C. Carrion, “Radar Target Identification via Exponential E-pulse Synthesis,” IEEE Transactions on Antennas and Propagation, pp. 2064-2072, Vol. 55, Issue:7, July 2007.
12. H. S. Lui, F. Aldhubaib, N. V. Z. Shuley, and T. H. Hon, “Subsurface Target recognition based on transient electromagnetic scattering,” IEEE Transactions on Antenna and Propagation, Vol. 59, No. 10, pp. 3398-3401, Oct. 2009.
13. H S. Lui and N. V. Z. Shuley, “Resonance based Target Recognition Using Ultrawide band Polarimetric Signature,” *IEEE Transactions on Antennas and Propagation,* Vol. 60., No. 8, pp. 3985-3988, Aug. 2012.