Target Detection with Cross Ambiguity Function using Binary Sequences with high Discrimination

M.V.Nageswara Rao
GMR Institute of Technology
Rajam, Srikakulam (D.T)
A.P,INDIA

Prof. K.Raja Rajeswari
Andhra University
Visakhapatnam
A.P, INDIA

ABSTRACT
The aim of this paper is to explore the binary sequences with high discrimination using Particle Swarm Optimization with Cauchy Mutation (PSOCM) technique. The cross-ambiguity function method is used to detect the stationary and moving targets in various target detection scenarios. The contour plots of the cross-ambiguity function are computed as a function of delay and Doppler frequency shift. The results are compared with binary sequences of the sequence lengths N=32, N=100, N=200 and N=500.

General Terms
Signal Processing, Target detection

Keywords
Binary Sequences, Cross Ambiguity Function, Particle Swarm Optimisation.

1. INTRODUCTION
Pulse compression radar transmits a long duration pulse which is coded using phase or frequency modulation to achieve a wide bandwidth as well as to meet the requirement of energy for detection. The received echo is processed using a pulse compression filter to yield a narrow compressed pulse that separates closely spaced targets. However, this separation is accomplished at the cost of introducing sidelobes in the filter response, which may mask weak targets and possibly prevent their detection altogether. Therefore, in radar applications the pulse compression sequences with high discrimination factor are desired. The term Discrimination (D) is defined as the ratio of main peak in the autocorrelation to absolute maximum amplitude among side lobes, Moharir [1]. In this context, Barker [2] proposed binary sequences with sidelobe levels either zero or unity. The discrimination of the Barker codes is equal to the length of the code. Unfortunately, the Barker sequences for lengths greater than 13 have not been found. In view of the fact that the discrimination is the figure of merit of the code, many researchers have been start working with different ways of design of binary sequences with discrimination greater than 13 [3–5]. H. Deng's [6] work is significant in the present context. He suggested the design of binary sequences having low sidelobe levels using Simulated Annealing (SA) algorithm. Further, in the development of the modern radar theory, Woodward's [7] suggested the waveform design problem through Ambiguity Function (AF). AF is an important tool to understand the performance of designed waveform in terms of the measurement accuracy, target resolution, ambiguities in range and radial velocity, and its response to the clutters. This paper demonstrates the design of binary sequences using Particle Swarm Optimization with Cauchy Mutation (PSOCM) algorithm, for the sequence lengths N = 32, N=100 , N=200 and N=500 and applications of such optimized sequences for the detection of targets in different scenarios using Cross-Ambiguity Function (CAF) technique are also presented. In section 2, a brief description of binary sequences is presented. Section 3 explains the design procedure of binary sequences using PSOCM. Cross- ambiguity function is discussed in section 4 whereas various target detection scenarios and results are discussed in section 5.

2. BINARY SEQUENCES
A long pulse of width τ' is divided into N sub pulses; each is of width $\Delta\tau = \frac{\tau'}{N}$.Then, the phase of each sub-pulse is randomly chosen as either 0 or π radians relative to some continuous wave reference signal. It is customary to characterize a sub-pulse that has 0 phase (amplitude of +1 volt) as "1", a sub-pulse with phase equal to π (amplitude of -1 volt) is characterized by either "0". The compression ratio associated with binary codes is equal to $\xi = \frac{\tau'}{\Delta\tau}$, that is the peak value is N times larger than that of the long pulse. The goodness of a compressed binary sequence depends heavily on the phase of the individual sub-pulses. Binary sequences can be written in the form of a vector as

$$a = (a_0, a_1, .. a_{N-1}) \quad a_i \in \{-1, +1\} \tag{1}$$

The autocorrelation function (ACF) of this binary sequence is defined by

$$r = (r_{-(N-1)}, r_{-(N-1)+1}, ..., r_0, r_1, ..., r_{N+1}) \qquad r_k = \sum_{i=0}^{N-1-|k|} a_i a_{i+k} \tag{2}$$

Binary sequences having low sidelobes (i.e. values of r_k for $k \neq 0$ is very small) find a lot of demand in radar applications.

3. DESIGN OF BINARY SEQUENCES USING PSOCM
Kennedy and Eberhart [8] developed an algorithm known as Particle Swarm Optimization (PSO), which is motivated from the organisms such as bird flocking and fish schooling. The major limitation of PSO is its tendency of trapping into local minimum. Changhe Li at.el [9] proposed an algorithm which

is a combination of PSO and Cauchy Mutation and they showed that the trapping at local optima points can be minimized with higher probability by introducing Cauchy mutation into the position and velocity equations of PSO. In the present work, PSOCM algorithm is used to optimize the order of the binary sequence to achieve good auto correlation properties. The basic step to apply the PSOCM algorithm to the design of binary sequences is as follows.

Step1: (Initialization): Generate initial particles by randomly generating the position and velocity for each particle (in this case, these are binary sequences).

Step 2: Evaluate each particle's fitness, which is sum of the squares of the auto correlation energy of sidelobes that can be calculated as

$$E = \sum_{k \neq 0}^{N-1} | r(k) |^2 \tag{3}$$

Step 3: For each particle, if the fitness (E) is less than its previous best (P_{id}) fitness, update P_{id}.

Step 4: For each particle, if the fitness (E) is less than the best one (P_{gd}) of all the particles, update P_{gd}.

Step5: For each particle, do

a) Generate a new particle p according to the following formulae

$$X_{id}^{'} = X_{id} + V_{id}^{'} \tag{4}$$

$$V_{id}^{'} = \omega V_{id} + \eta_1 rand()(P_{id} - X_{id}) + \eta_2 rand()(P_{gd} - X_{id}) \tag{5}$$

where $X_{id}^{'}$ and X_{id} represent the current and the previous position of the id^{th} particle, Whereas V_{id} and $V_{id}^{'}$ are the previous and the current velocity of the id^{th} particle. Here X_{id} represents the position binary coded sequence. P_{id} and P_{gd} are the individual's best positions and the best position found so far, $0 \leq \omega < 1$ is an inertia weight which determines how much the previous velocity is preserved (chosen $\omega = 0.99$). This signifies that the previous velocity is almost preserved but not preserved completely to avoid escaping from the optimum value, η_1 and η_2 are the accelerating constants assigned a random value picked between 0 to1 from an uniform distribution, *rand*() picks a value from a uniform probability distribution.

b) Generate a new particle *p'* according to the formulae

$$V_{id}^{'} = V_{id} \exp(\delta) \tag{6}$$

$$X_{id}^{'} = X_{id} + V_{id}^{'} \delta_{id} \tag{7}$$

where δ and δ_{id} denote Cauchy random numbers

c) Compare p with *p'*, choose the one with lesser fitness function.

Step 6. (Stopping criterion): If the stop criterion is satisfied, then stop, else go to Step 3.

Based on the above described algorithm binary sequences for the sequence lengths N=32, N=100, N=200 and N=500 are optimized. Figs. 1-4 show the autocorrelation functions of binary sequences of lengths 32, 100 200 and 500 respectively. The autocorrelation sidelobe peaks (ASP) and discrimination for all the four sequences achieved are shown in Table-I. The results show that the discrimination values are higher than that of the results shown in literature [6].

Table 1.Auto correlation sidelobe peaks and Discrimination

Parameter	Sequence length			
	32	100	200	500
Max(ASP)	3	5	9	17
Discrimination (D)	10.67	20.00	22.22	29.41

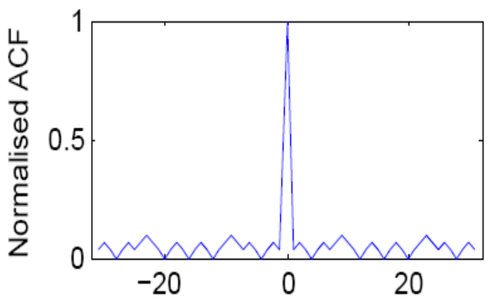


Fig. 1 ACF of binary sequence of length N=32

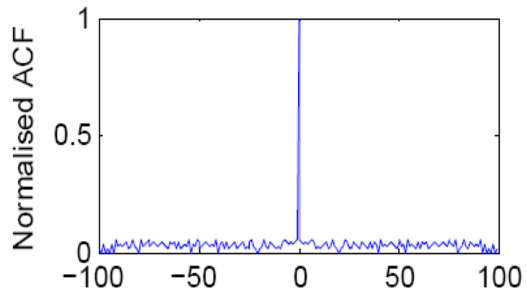


Fig. 2 ACF of binary sequence of length N=100

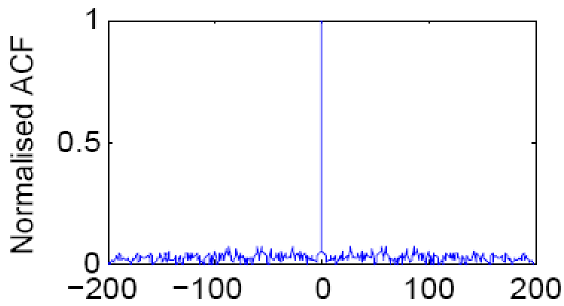


Fig. 3 ACF of binary sequence of length N=200

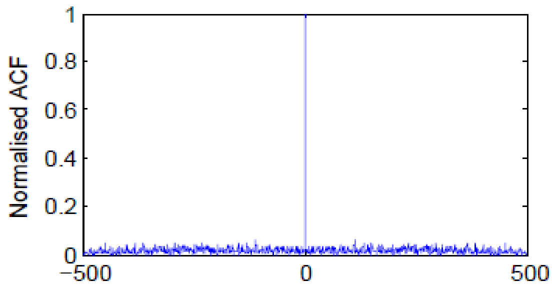


Fig 4 ACF of binary sequence of length N=500

4. CROSS AMBIGUITY FUNCTION

Time-frequency signal representations (TFRs) are widely used mathematical tools for efficient coding of signals and as a statistics for signal detection and parameter estimation [10]. Ambiguity Function (AF), which is a quadratic TFR, has been used extensively for investigating the ambiguity properties of the modulated waveforms used in various fields such as radar, sonar, radio astronomy, communications etc. The ambiguity function represents the response of a filter matched to a given finite energy signal when the signal is received with a delay τ and a Doppler shift v relative to the nominal values (zeros) expected by the filter [11]. The Ambiguity Function is defined as

$$|\chi(\tau, v)| = \left| \int_{-\infty}^{\infty} s(t)\, s^*(t+\tau) e^{j2\pi vt} dt \right| \tag{8}$$

where s(t) is the complex envelope of the signal. A nonzero v implies a target moving at a certain radial velocity with respect to radar. Positive τ refers to round trip delay time when the target is away from the radar by a certain distance [11].

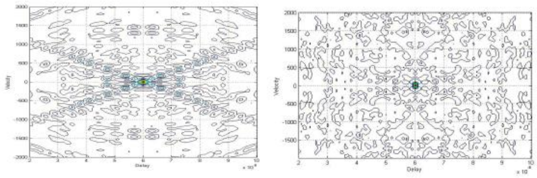
In equation (8), if s(t) and s*(t+τ) are the complex envelopes of the transmitted signal and the resulting equation is the Ambiguity Function or Auto-Ambiguity Function. Ambiguity Function is used for determining the characteristics of the designed waveform in respect of measurement accuracy, ambiguities in range and velocity, and target resolution. [10].

However, in equation (8), when $s(t)$ is the complex envelope of transmitted signal and $s(t+\tau)$ is the complex envelope of the received signal (with or without noise) then $\chi(\tau, v)$ is called Cross-Ambiguity Function (CAF). Therefore Cross-Ambiguity Function is useful for determining the waveform effects in response to clutter. Hence, this paper presents the use of Cross-Ambiguity Function for the detection of targets in various target scenarios.

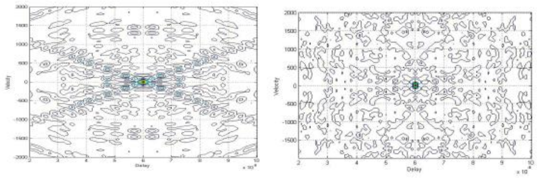
5. TARGET DETECTION SCENARIOS

Figs.5-9 show the contour plots of various target scenarios. In each figure the delay (proportional to range) and Doppler frequency (proportional to radial velocity) are plotted on x-axis and y-axis respectively. In Figs 5-6, contour plots are showing single stationary and moving target scenarios respectively. In each plot because of the symmetry, the target appears in two quadrants for convenience, here we consider only right quadrant. In Fig. 5 the target is stationary (zero Doppler shift) whereas range is corresponding to τ = 60μ s. However in moving target scenario the target Doppler shift is taken as v = 1000 m/s and τ = 60μ s, which is evident in Fig. 6.

Similarly in multi-target scenarios, both stationary as well as moving targets are considered in Figs. 7-8. Fig. 7 shows the multi stationary targets, Target 1 is taken with τ =80μ s and target 2 with τ =60μ s, and Fig 8 shows the multi moving targets with Target: 1(τ =80μ s, v=500 m/s), and Target: 2 (τ =60μ s, v=1000 m/s). The positions of each targets corresponding to their values can be clearly seen in the respective figures. It can also be observed as the sequence length is increased the sidelobe levels are decreased.

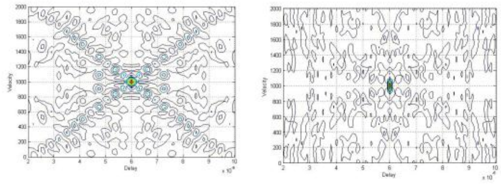


5 (a) **5 (b)**

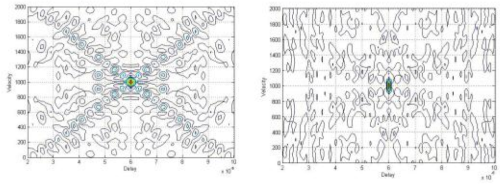


5(c) **5 (d)**

Fig. 5 Stationary single target scenario with τ=60μ s.
(a) Sequence Length N=32, (b) Sequence Length N=100, (c) Sequence Length N=200, (d) Sequence Length of 500



6(a) **6(b)**

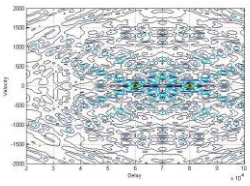


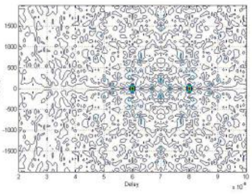
6(c) **6(d)**

Fig. 6 Moving single target scenario with *v*=1000 m/s τ=60μ s.

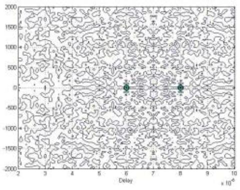
(a)Sequence Length N=32, (b) Sequence Length N=100,

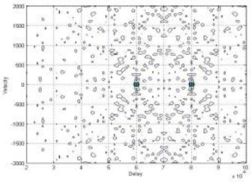
(c) Sequence Length N=200, (d) Sequence Length of 500





7(a) **7(b)**





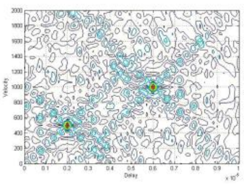
7(c) **7(d)**

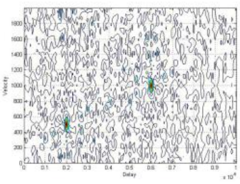
Fig. 7 Stationary multi target scenario with

Target.1 τ =80μ s, Target: 2 τ =60μ s

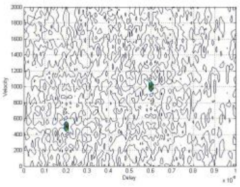
(a) Sequence Length N=32, (b) Sequence Length N=100,

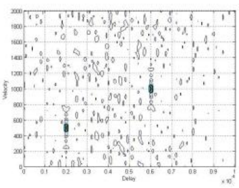
(c) Sequence Length N=200, (d) Sequence Length of 500





8(a) **8(b)**





8(c) **8(d)**

Fig. 8 Moving multi target scenario with

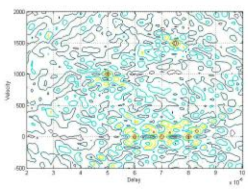
Target: 1(τ =80 µ s, *v*=500 m/s)

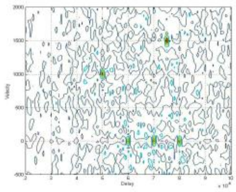
Target: 2 (τ =60 µ s, *v*=1000 m/s)

(a)Sequence Length N=32, (b) Sequence Length N=100,

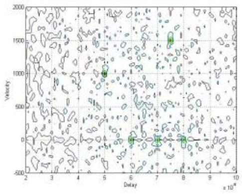
(c) Sequence Length N=200, (d) Sequence Length of 500

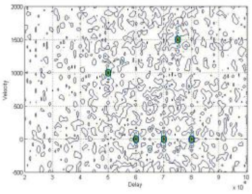
In Fig. 9, combination of multi stationary and moving targets is considered. In Fig. 9(a),(b)and(c) it is observed that using sequence length N=32, N=100and 200 the sidelobe levels are higher which leads to an ambiguous detection in case of moving targets, whereas using sequence length N=500 all the targets are detected without any ambiguity, which can be clearly seen in Fig. 8 (d). This clearly shows that the detection capabilities of binary sequences are increasing with the increase in sequence length. With PSOCM, binary sequences of any lengths can be designed as per the desired accuracy.





9(a) **9(b)**





9(c) **9(d)**

Fig. 9 Stationary and moving multi target scenario with

Target: 1(τ =80 µ s), Target: 2 (τ =70µ s),

Target: 3(τ =60 µ s Target: 4 (τ =75 µ s, *v*=1500 m/s),

Target: 5(τ =50 µ s, *v* =1000 m/s)

(a) Sequence Length N=32, (b) Sequence Length N=100,

(c) Sequence Length N=200, (d) Sequence Length of 500

The detection performances in all above cases are considered with and without noise (Noise level of 10dB), but it is observed that that there is no appreciable difference in detection and measurements of the target range and velocity. Therefore, the results are not shown for noise cases.

6. CONCLUSION

In general auto ambiguity function is used for the design of radar signals to achieve desired delay-Doppler resolution. However, this paper demonstrates the detection of target (targets) using CAF technique, which is shown to be an alternative technique for the detection of targets. The work is mainly focused on - (i) Design of binary sequences using PSOCM optimization technique and one sequence for each sequence lengths of 32, 100,200 and 500 are optimized. It is observed that the sidelobe levels are less than the sequences presented in the literature [6]. (ii) Detection procedure of single and multi-targets for stationary scenario, moving scenario, stationary and moving scenario is also presented.

The detection of targets using cross ambiguity function needs lot of computation time therefore processing on large signal matrices make the cross ambiguity function hard to compute and require very large memory. This technique to be practically appropriate in tactical electronic warfare arena, require very powerful digital signal processing hardware. Cross ambiguity function is a rather raw representation of target range and velocity information. As a future work for autonomous target detection and tracking issues, the cross ambiguity diagram can be analyzed through pattern recognition and other feature extraction techniques.

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M.V.NAGESWARA RAO received his master's degree in Systems Signal Processing from Osmania University in 2003. Presently, he is a professor, Department of ECE, GMR Institute of Technology, Rajam, A.P; India. His primary research interests are Radar Signal Processing., Machine Intelligence and Stochastic Algorithms.

K. RAJA RAJESWARI is graduated in ECE from Andhra University during 1976. She obtained her M.E. and Ph.D. also from the same university. Presently, she is professor in the Department of ECE, College of Engg. Andhra University, India. She is member for of IEEE, Chair person Board of Studies, Council member for IETE, New Delhi. Her research interests include Radar/Sonar Signal Processing and Wireless mobile communications. She has more than 100 papers published to her credit in reputed international/national journals and conferences. She is co-author of the textbook *EDC* published by Pearson Education, New Delhi and author of the textbook on *Signals and Systems* by PHI, New Delhi. She visited China, Malaysia, Singapore, and USA for presenting papers and chairing various technical sessions in IEEE sponsored conferences. She has guided twelve PhD's and leading the research team consisting of twenty scholars. She is recipient of Best Researcher Award, Dr.Servepalli RadhaKrishnan Best Academician award from Andhra University, IETE Prof.SVC Aiya Memorial award in the year 2009, Best Teacher award for the year 2006, Best Academician award for the year 2009 and received many national awards in recognition of her excellence in academics and research.