Target Detection using Ternary Coded Sequences

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Abstract: This paper mainly focused on the detection of Radar targets using Ternary coded sequences. Since there is no conventional technique available in the literature for the detection of targets using the Ternary coded sequences CAF technique is considered as an alternative technique to identify the presence or absence of target in various scenarios such as single stationary target, multi stationary targets, single moving target and multi moving targets.

Index Terms **- Cross Ambiguity Function, Ternary Sequences, Contour Plots.**

I. INTRODUCTION

Ternary codes have been widely used in many applications but specifically in synchronization of block codes and in radar for pulse compression. Pulse compression is used to achieve the high transmit energy of a long pulse while preserving the range resolution of a short pulse. This technique is extensively used in radar systems to overcome the practical difficulty of extending the operating range of radar and preserving the accuracy of range-Doppler resolution. The range resolution of radar depends on the autocorrelation pattern of the pulse compression sequences (i. e. linear FM, Non Linear FM, Binary, Ternary, Poly phase etc.), which is nothing but the matched filter compressed output. All the sequences have certain attractive features and the choice often depends on the application. The binary sequences find more importance in pulse compression as they have +1 or -1 as elements and good aperiodic autocorrelation function with ideal energy efficiency [1]. Many researchers have been working on different ways of designing binary sequences with low Peak Side Lobe Ratio (PSLR) [1-6]. But the limitation arises when longer length sequences with low PSLR are desired. PSLR is the figure of merit of the code as this is the ratio of the peak side lobe amplitude to the main lobe peak amplitude of the autocorrelation function and is generally expressed in decibels. In his context, Moharir has shown that the ternary Barker sequences exist for lengths greater than 13 [7-8]. But as the length increases, the PSLR does not reduce significantly. To achieve better PSLR, it is necessary to switch over from binary to either polyphase or multilevel sequences. On the other hand, the multilevel or non-binary sequences have elements of unequal magnitude; hence, their energy efficiency is less than unity.

Alternatively, J. B. Seventline et al. [9] suggested the design of ternary Chaotic Pulse Compression Sequences. The design of ternary sequences using Particle Swarm Optimization with Cauchy Mutation (PSOCM) algorithm for the sequence lengths N= 32, N=100, N=200, N=500 and N=1000 is proposed in [10].The application of such optimized sequences for the detection of targets in various scenarios using Cross Ambiguity Function(CAF) is proposed in the subsequent sections. CAF is computed using ternary coded transmitted signal and the received echo signal to demonstrate the detection of targets in different scenarios.

II. TERNARY SEQUENCES

Ternary sequence uses three elements to represent any information or data. Therefore, ternary sequence may also be called as 3-alphabet code. This code consists of 1, 0 and -1.
Let 'S' be a ternary sequence of length N.

$$S = [x_0, x_1, x_2, x_3, x_4, ...x_{N-1}] \qquad (1)$$

III. CROSS-AMBIGUITY FUNCTION

The cross-ambiguity function (CAF) describes the response of a radar system to an impulse-like (point) target located at an arbitrary range and Doppler shift. In this sense, the cross –ambiguity function can be thought of as the impulse response of the radar. The ambiguity function is also referred to as the matched-filter response, and the uncertainty function [11]. The cross-ambiguity function is also related to the cyclic cross-correlation function as discussed in [12].

The cross-ambiguity function of radar is a rigorous mathematical description of radar's response to an ideal point target moving at a constant range rate. The cross-ambiguity function is therefore a two dimensional function of range delay τ and Doppler shift ν. The cross-ambiguity function $\chi_{xy}(\tau,\nu)$ of the signal $x(t)$ with the signal $y(t)$ is defined as

$$\chi_{xy}(\tau,\nu) = \frac{1}{T_d}\int_{-\infty}^{\infty} x(t)\, y(t-\tau) e^{j2\pi\nu t} dt \qquad (2)$$

where T_d is the duration of the signal $x(t)$, τ is the time delay between waveforms, and ν is the Doppler shift introduced by the moving target and $\chi_{xy}(\tau,\nu)$ describe the output of the radar receiver for various values of τ and ν.

IV. TARGET DETECTION SCENARIOS

The ternary sequences of length 32,100, 200 and 500 are considered to extract the range and Doppler information of a target in various scenarios using the CAF technique. The details of the simulation study are presented and various target detection scenarios are tested. All simulations are performed by using MATLAB Programming Language. At these scenarios, following parameters are considered: f_c =Carrier frequency (Giga Hz), V_{max} =Maximum target velocity (m/s), R_{max} =Maximum Range (m), t_b = Sub code Period (μs), Δf =Doppler frequency Resolution (m/s), ΔR = Range Resolution (m), ΔV =Velocity resolution (m/s). All the simulations are performed considering the pulse width of 133 μ s and the velocity resolution of 37.5m/s. The resolution values are calculated using the following formulae and listed in table 1.

Range Resolution $\Delta R = \frac{c}{2B}$ (3)

where B is equal to $\frac{1}{t_b}$ in phase coding and $\frac{N^2}{T}$ for frequency coding.

Velocity resolution $\Delta v = \frac{c}{2f_o T}$ (4)

where f_0 is the carrier frequency of the waveform.

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Table.1. Parameters for various target scenarios.

Length of ternary Code	f_c (Giga Hz)	V_{max} (m/s)	R_{max} (m)	t_b (μ sec)	Δf (Hz)	ΔR (m)	ΔV (m/s)
500	30	3750	20000	0.2667	7500	40	37.5
200	30	3750	20000	0.6667	7500	100	37.5
100	30	3750	20000	1.3333	7500	200	37.5
32	30	3750	20000	4.1167	7500	625	37.5

SINGLE STATIONARY TARGET SCENARIO

Assuming a stationary target situated at 5000m away from the radar. (i.e R =5000m. and v = 0m/s) and the complex envelope of the transmitted continuous wave signal is coded with ternary sequence of length 500, 200,100 and 32. The CAF is computed between the complex envelope of the transmitted and the received signals and displayed the result using the contour plot. The contour plots of the CAF when the transmitted signal is coded with ternary sequence of length 500, 200,100 and 32 with an enlargement around the peak point are shown in the fig. 1(a-d) respectively. It is measured from the fig.1 (a-d) that, the range resolution for the sequence length of 500,200,100 and 32 is 40m, 100m, 200m and 625m respectively and target is detected at 5000m from the radar. The range resolution and velocity resolution values listed in the table 1 are verified from fig.1 (a-d). It is observed that, as the sequence length is increased the sidelobe levels are reduced. In multi target environment, high sidelobe levels may lead to ambiguity in detection.

SINGLE MOVING TARGET SCENARIO

In this scenario, simulation is carried out assuming a target which is situated at 5000m away from the radar moving with a velocity 75m/s (i.e. R =5000 m and v=75m/s) and the transmitted continuous wave signal is coded by using the ternary sequence of length 500,200, 100, and 32. The CAF of the complex envelope of the transmitted and the received signals is computed and the result is displayed using the contour plot. The contour plots of the CAF when the transmitted signal coded with ternary sequence of length 500, 200,100 and 32 with an enlargement around the peak point are shown in the fig.2 (a-d) respectively. The target situated at 5000m far from the radar moving with a velocity v=75m/s, is detected without any ambiguity.

MULTI STATIONARY TARGET SCENARIO

In this scenario, five stationary targets are considered for simulations which are situated at different locations are as follows for different sequence lengths.

Sequence Length 500: (R_1=5000m, R_2 = 5080m, R_3=5160m, R_4=5240m and R_5=5320m with $v_1 = v_2 = v_3 = v_4 = v_5$=0m/s)

Sequence Length 200 :(R1=5000m, R2 = 5200m, R_3=5400m, R_4=5600m and R_5=5800m with $v_1 = v_2 = v_3 = v_4 = v_5$=0m/s).

Sequence length 100 :(R_1=5000 m, R_2 = 5400m, R_3=5800m, R_4=6200m and R_5=6400m with $v_1 = v_2 = v_3 = v_4 = v_5$=0m/s).

Sequence length 32 :(R_1=5000 m, R_2 = 6250m, R_3=7500m, R_4=8750m and R_5=10000m with $v_1 = v_2 = v_3 = v_4 = v_5$=0m/s).

The transmitting signal is coded with ternary sequence of length 500,200,100 and 32 and the resulting contour plots for the CAF of the transmitted and received radar signal with an enlargement around the peak points for the sequence length of 500,200 100 and 32 are shown in fig. 3(a-d) respectively. The distance between the two consecutive stationary targets is considered to be equal to twice the range resolution of the sequence. It is evident from fig. 3(a-c) that all targets are detected at chosen locations without any ambiguity. However from fig.3d it is observed that several targets appear instead of five targets. When three targets are considered, they are detected without any ambiguity (not shown in figure). Since the PSLR of 32 bit ternary sequence is not noticeable and the sidelobes near the mainlobe are added up and appeared as more number of targets instead of five. It is evident from fig. 3(a-d) as the sequence length is increased the sidelobe levels are lowered.

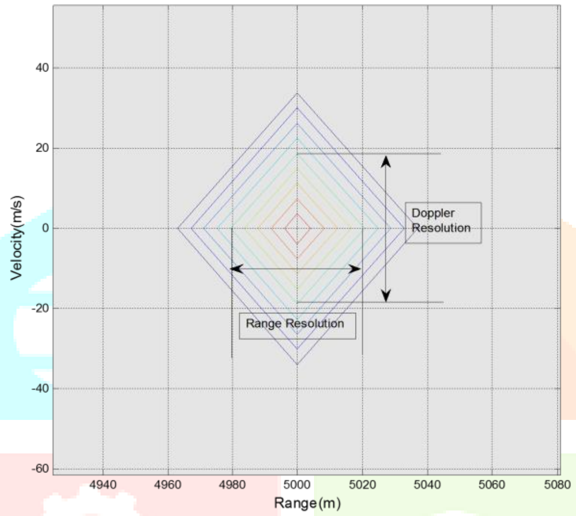

Fig.1a

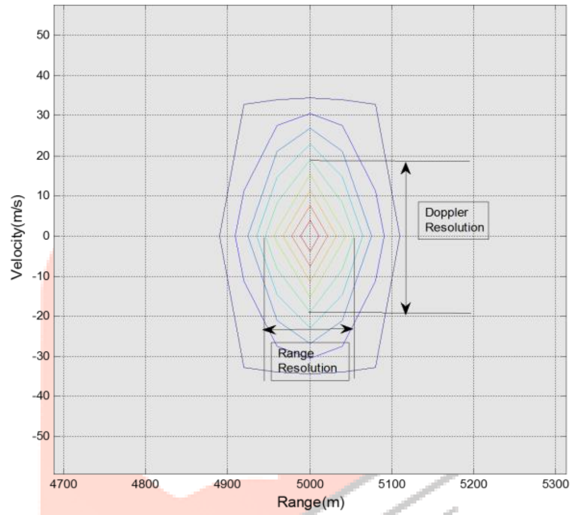

Fig.1b

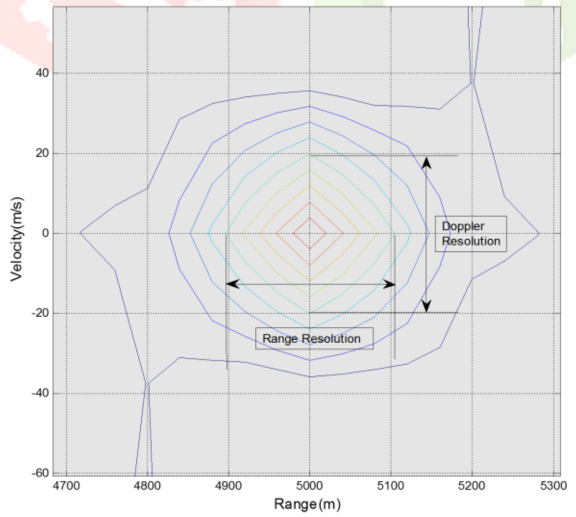

Fig.1c

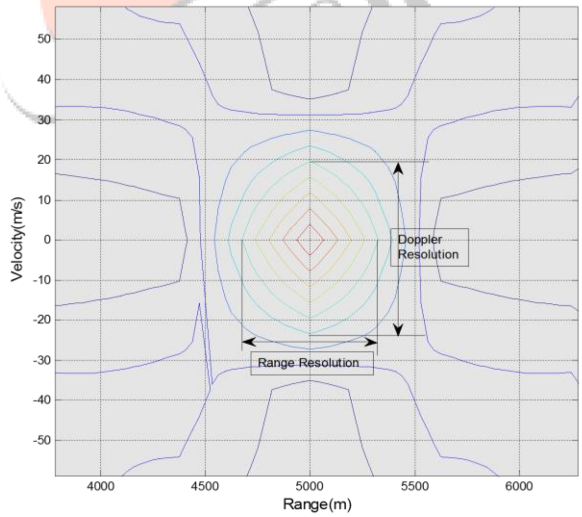

Fig.1d

Fig 1.Single Stationary Target Scenario

Contour plots of Cross - Ambiguity Function of the transmitted and received signal for Ternary sequence.
(R=5000m, v=0 m/ sec)

(a) Ternary sequence of length500 (b) Ternary sequence of length200
(c) Ternary sequence of length100 (d) Ternary sequence of length32

MULTI MOVING TARGET SCENARIO

In this scenario, five moving targets at a range of 5000m moving with different velocities are considered for simulation. (R_1= R_2 =R_3= R_4= R_5=5000m with v_1= 0m/s, v_2=75m/s, v_3= 150m/s, v_4 =225m/s and v_5=300m/s). The transmitting signal is coded with ternary sequence of length 500,200,100 and 32. The difference in velocity between the two consecutive moving targets is considered to be equal to the twice the velocity resolution of the sequence. The resulting contour plots for the CAF of the transmitted and received radar signal with enlargement around the peak points for the sequence length of 500,200 100 and 32 are shown in fig. 4(a-d) respectively. It is obvious from fig. 4(a-c) that all the targets are detected at chosen locations without any ambiguity. However from fig. 4d it is observed that several targets appear instead of five targets. When three targets are considered, they are detected without any ambiguity (not shown in figure). Since the PSLR of 32 bit ternary sequence is not noticeable and the sidelobes near the mainlobe are added up and appeared as more number of targets instead of five. It is clear from fig. 4(a-d) that as the sequence length is increased the sidelobe levels are lowered. Thus target detection is achieved without any ambiguity.

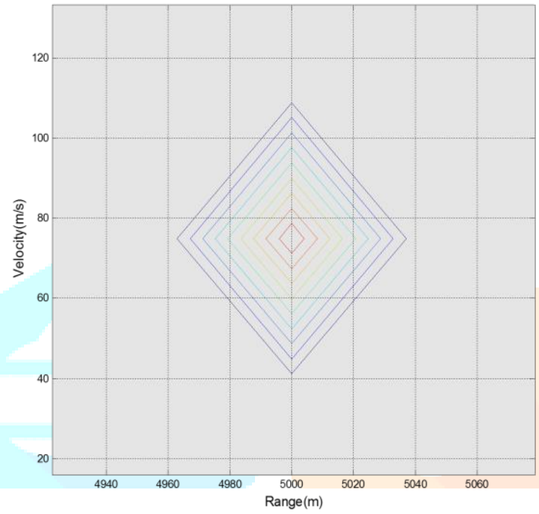

Fig.2a

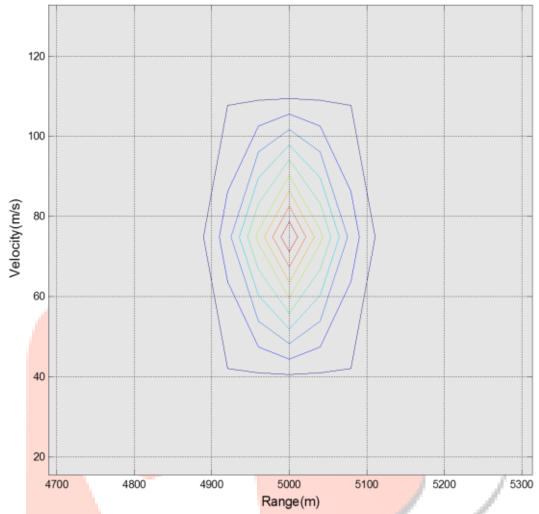

Fig.2b

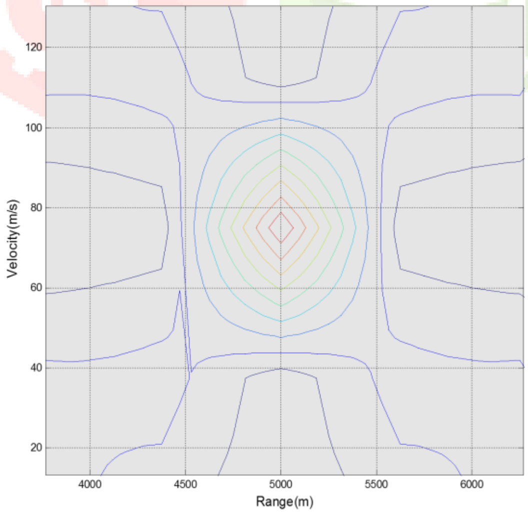

Fig.2c

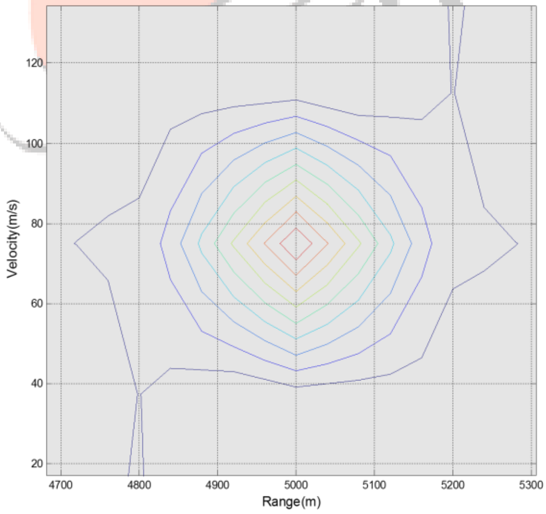

Fig.2d

Fig.2Single Moving Target Scenario

Contour plots of Cross - Ambiguity Function of the transmitted and received signal for Ternary sequence.
(R=5000m, v =75 m/ sec)

(a) Ternary sequence of length500 (b) Ternary sequence of length200
(c) Ternary sequence of length100 (d) Ternary sequence of length32

MULTI STATIONARY AND MULTI MOVING TARGET SCENARIO

In this scenario, five targets are considered for simulation of which three targets are stationary and the other two are moving. The targets selected for simulation at different locations are as follows:

Sequence length 500:

Stationary targets (R_1=5000m, R_2 = 5160m, and R_3=5320m). Moving targets (R_4=5080m and R_5=5240m with $v_4 = v_5$ = 75m/s).

Sequence length 200:

Stationary targets (R_1=5000m, R_2 = 5400m and R_3=5800m).Moving targets (R_4=5200m and R_5=5600m with $v_4 = v_5$ = 75m/s).

Sequence length 100:

Stationary targets (R_1=5000m, R_2 = 5800m and R_3=6600m).Moving targets (R_4=5400m and R_5=6200m with $v_4 = v_5$ = 75m/s).

Sequence length 32:

Stationary targets (R_1=5000m, R_2 = 7500m and R_3= 10000m) and two moving targets (R_4=6250m and R_5=8750m with $v_4 = v_5$ = 75m/s).

The contour plots of the CAF of the transmitted and received radar signal with enlargement around the peak points is shown in fig. 5(a-d). It is observed that in all the cases, the targets are detected exactly at the assumed locations.

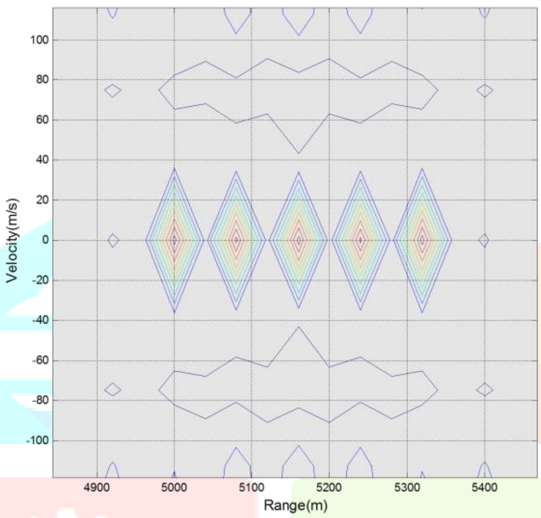

Fig.3a

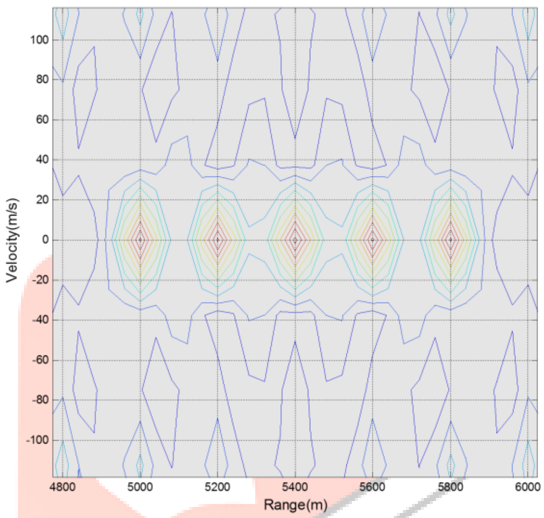

Fig.3b

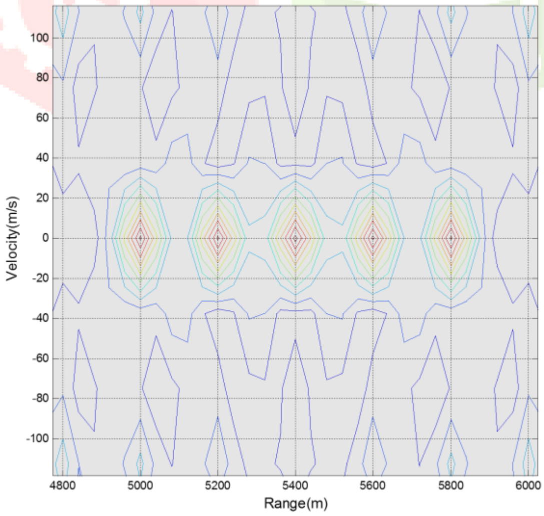

Fig.3c

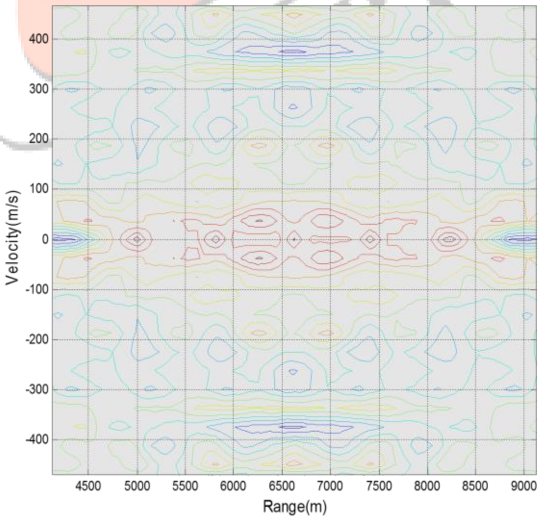

Fig.3 d

Fig.3 Multi Stationary Target Scenario

(a) Ternary sequence of length500

(R_1=5000m, R_2 = 5080m, R_3=5160m, R_4=5240m and R_5=5320m with $v_1= v_2= v_3= v_4 = v_5$=0m/s)

(b) Ternary sequence of length200

(R1=5000m, R2 = 5200m, R_3=5400m, R_4=5600m and R_5=5800m with $v_1= v_2= v_3= v_4 = v_5$=0m/s).

(c) Ternary sequence of length100

(R1=5000 m, R_2 = 5400m, R_3=5800m, R_4=6200m and R_5=6400m with $v_1= v_2= v_3= v_4 = v_5$=0m/s).

(d) Ternary sequence of length32

(R1=5000 m, R_2 = 6250m, R_3=7500m, R_4=8750m and R_5=10000m with $v_1= v_2= v_3= v_4 = v_5$=0m/s).

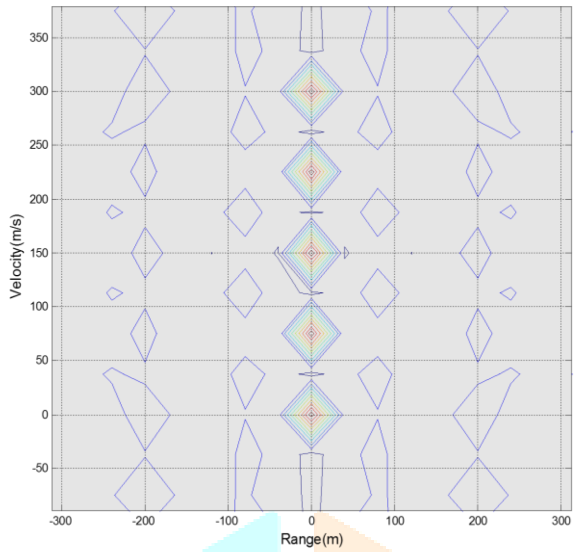

Fig. 4a

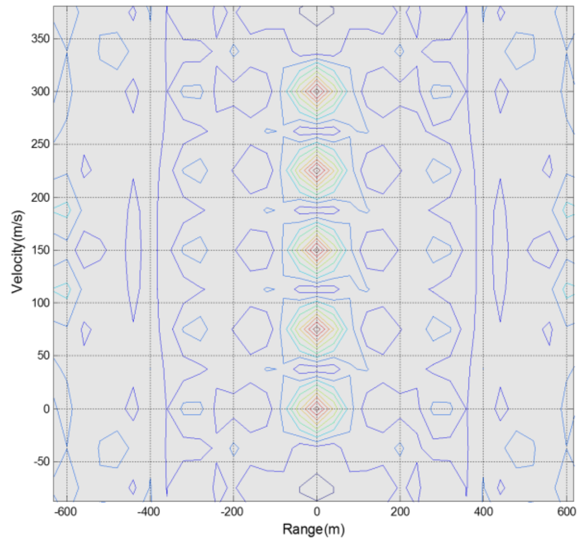

Fig.4b

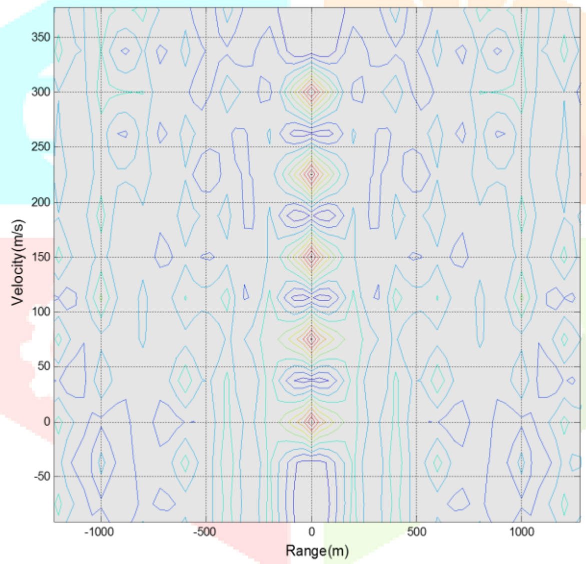

Fig.4c

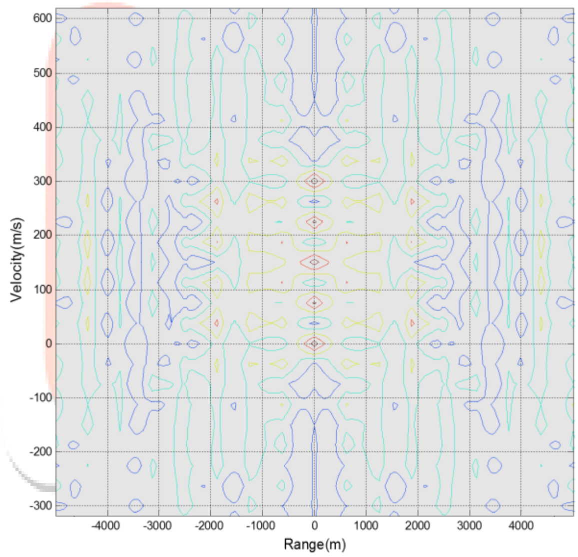

Fig.4d

Fig. 4 Multi Moving Target Scenario

(R_1= R_2 =R_3= R_4= R_5=5000m with v_1= 0m/s, v_2=75m/s, v_3= 150m/s, v_4 =225m/s and v_5=300m/s)

(a) Ternary sequence of length500 (b) Ternary sequence of length200

(c) Ternary sequence of length100 (d) Ternary sequence of length32

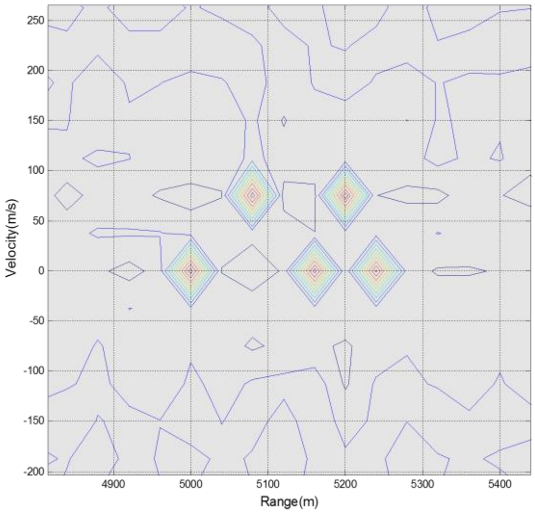

Fig. 5a

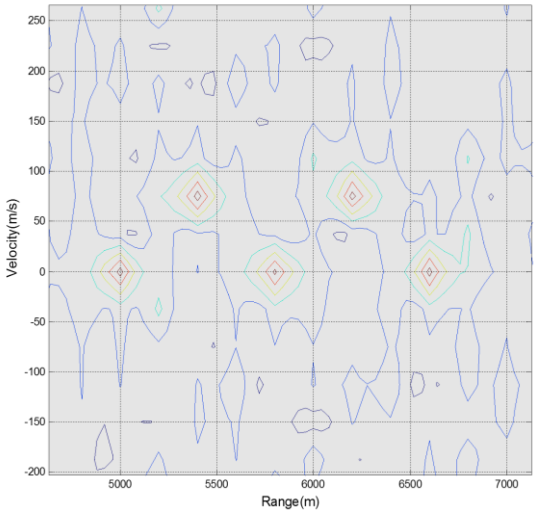

Fig.5b

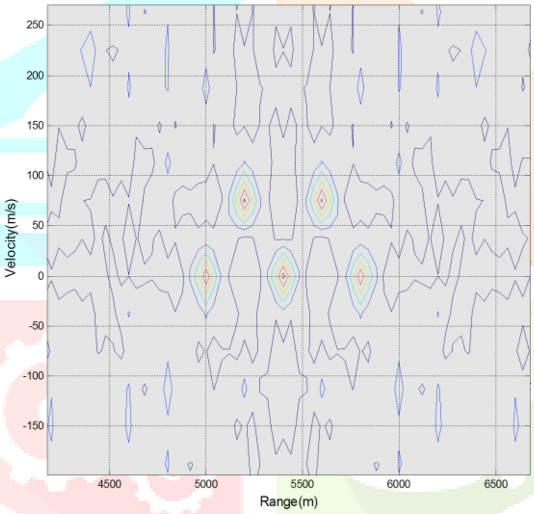

Fig. 5c

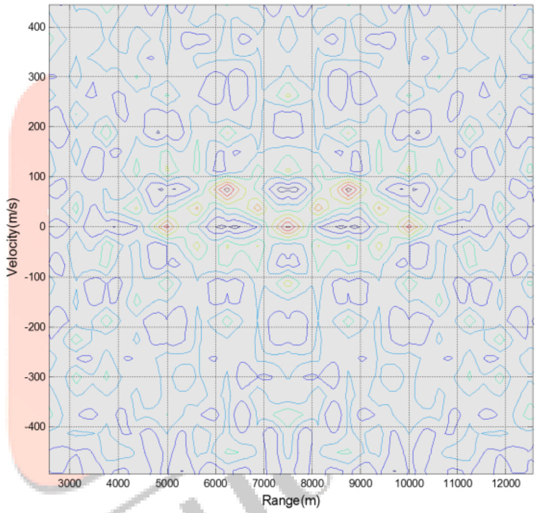

Fig.5d

Fig. 5 Multi Stationary and Moving Target Scenario

(a) Ternary sequence of length500

Stationary targets (R_1=5000m, R_2 = 5160m, and R_3=5320m). Moving targets (R_4=5080m and R_5=5240m with $v_4 = v_5$ = 75m/s).

(b) Ternary sequence of length200

Stationary targets (R_1=5000m, R_2 = 5400m and R_3=5800m).Moving targets (R_4=5200m and R_5=5600m with $v_4 = v_5$ = 75m/s).

(c) Ternary sequence of length100

Stationary targets (R_1=5000m, R_2 = 5800m and R_3=6600m).Moving targets (R_4=5400m and R_5=6200m with $v_4 = v_5$ = 75m/s).

(d) Ternary sequence of length32

Stationary targets (R_1=5000m, R2 = 7500m and R_3= 10000m)
and two moving targets (R_4=6250m and R_5=8750m with $v_4 = v_5$ = 75m/s).

V. CONCLUSIONS

CAF technique is considered to identify the presence or absence of targets. It is evident from the contour plots shown in Figs. 1 to 5 that using the Ternary sequences of length 500, 200 and 100, the targets are detected successfully even in complex situation such as - (i) five targets at same distance from the radar but moving with different velocities (ii) five stationary targets at different ranges. Since, the sidelobe suppression and discrimination (D) of 32 bit sequence is less compared to the higher length sequences, due to which a few of the peak sidelobes of different targets are added up that leads to an ambiguity in the case of multi-moving and multi-stationary target scenarios. However, it is clearly evident from the Figs. from 1 to 5 that as the sequence length increases the resolution as well as detection performance also increases. It is concluded that, CAF technique can be used as an alternative for radar target detection in all scenarios.

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