Target Detection using 28-Phase Sequences

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Abstract: This paper mainly focused on the detection of Radar targets using 28-Phasesequences. Cross Ambiguity Function technique is considered to identify the presence or absence of target in various scenarios such as single stationary target, multi stationary targets, single moving target, multi moving targets and multi stationary& moving target scenario.

***Index Terms*–Cross Ambiguity Function, Binary Sequences, Contour Plots.**

I. Introduction

Sequences with good autocorrelation properties are widely used in many applications such as communications, radar, system identification etc. Binary codes are commonly used pulse compression sequences because of their easy generation and processing. However, polyphase sequences can be designed for higher mainlobe to peak sidelobe ratio over binary codes of the same sequence length. In the process of designing pulse compression sequences, the magnitude of the peak sidelobe of ACF must be low, which ensures an easily detectable mainlobe at the output of a matched filter receiver.

Golomb & Scholtz [1] addressed the generalized Barker sequences of lengths N ⩽ 13 in1965. In 1989 Zhang & Golomb [2] proposed sixty phase Barker sequences up to length 18. Frieze [3] explored Polyphase Barker sequences up to length 36. Since the Polyphase signals have larger mainlobe-to-peak sidelobe ratio over binary signals of the same code length, researchers shown interest in the design of polyphase sequences of large alphabet with longer lengths [4-11].The design of 28-Phase sequences of sequence lengths viz. N = 32, N=100, N=128, N=200 and N=500 are designed using PSOCM algorithm [12] are used here for the detection of targets.

In subsequent sections, the use of Cross ambiguity Function (CAF) technique to identify the presence or absence of targets in various scenarios are discussed. CAF is computed using 28-Phase coded transmitted signal and the received echo signal to demonstrate the detection of targets in different scenarios.

II. 28-Phase Coded Sequences

The twenty eight Phase sequence of length Nis represented by a complex number sequence as

$$\left\{s(n) = e^{j\phi(n)},\ n = 1,2,3,\ldots N\right\} \tag{1}$$

Where $\phi(n)$ is the phase of subpulse*n* of the sequence in the range $\{0, 2\pi\}$. If the number of distinct phases available to be chosen for each subpulse in a coded sequence is *M*, the phase for a subpulse can only be selected from the following admissible values.

$$\phi(n) \in \left\{0, \frac{2\pi}{M}, 2\frac{2\pi}{M}, \ldots, (M-1)\frac{2\pi}{M}\right\}$$
$$= \{\psi_1, \psi_2, \psi_3, \ldots \psi_M\}$$

For 28 phase *M* = 28, then values of $\{\psi_1, \psi_2, \psi_3, \psi_4, \psi_5 \text{and}\, \psi_6\}$ will be $0, \frac{\pi}{14}, \frac{\pi}{7}, \frac{5\pi}{28}, \frac{3\pi}{14} \ldots\ldots\ldots\ldots \frac{27\pi}{28}$.

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 [13]. The cross-ambiguity function is also related to the cyclic cross-correlation function as discussed in [14].

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

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

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 28 phase 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 (μ s), 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 are listed in table.1.

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

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

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

where f_0 is the carrier frequency of the waveform.

Table.1 Parameters for various target scenarios.

Length of 28-Phase sequence	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 28-phase 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 28-phase 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 28-phase 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 28-phase 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.

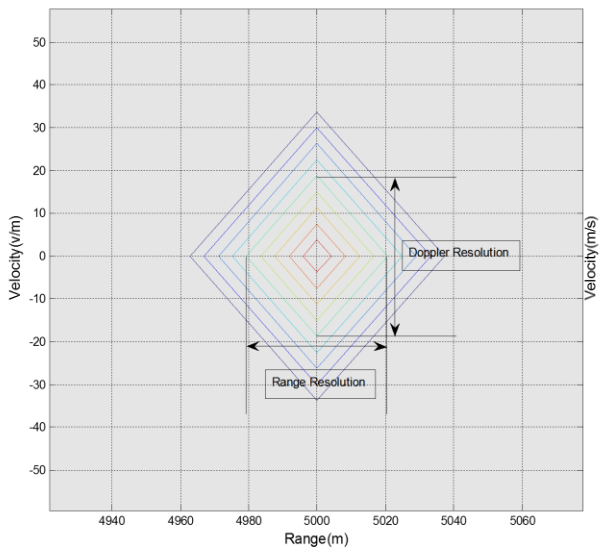


Fig. 1a

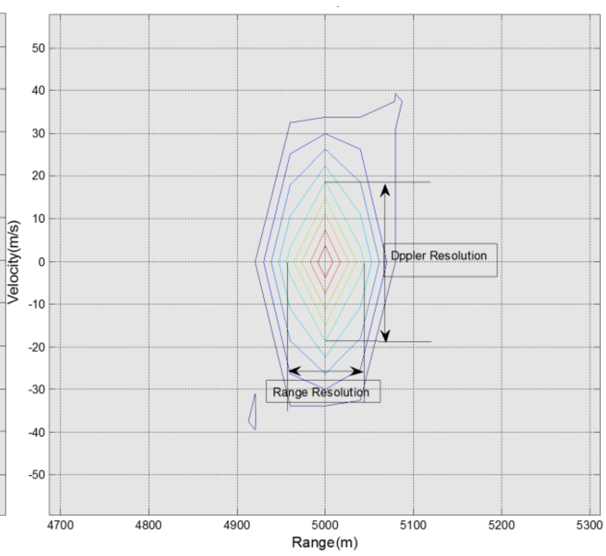


Fig.1b

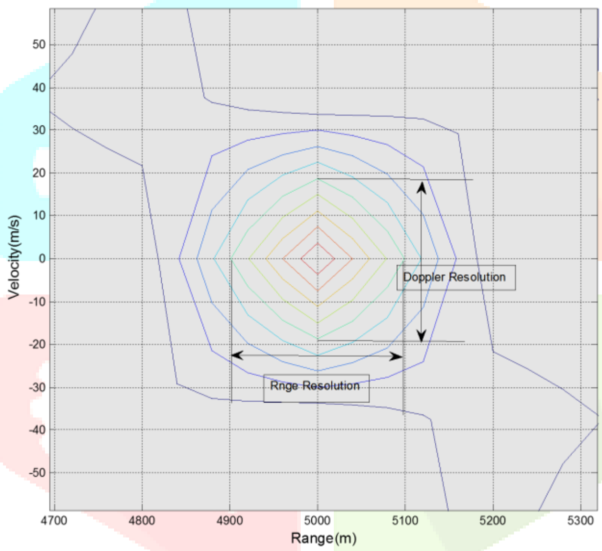


Fig.1c

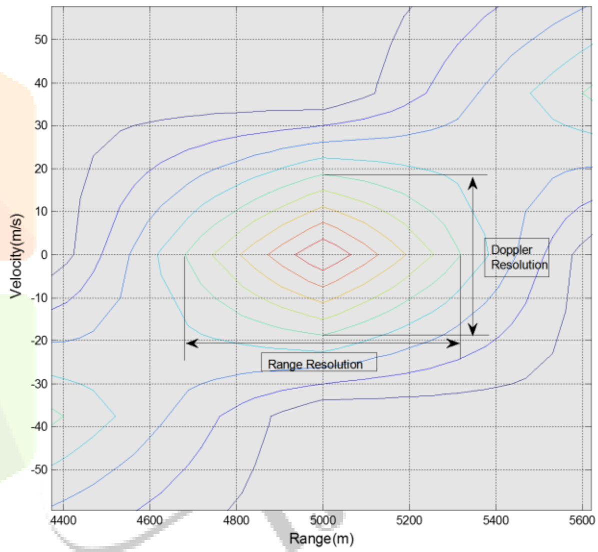


Fig.1d

Fig.1 Single Stationary Target Scenario

Contour plots of CAF of the transmitted and received signal for 28-phase sequence.
(R=5000m, *v*=0 *m*/ sec)
(a)28-phase sequence of length500 (b) 28-phase sequence of length200
(c)28-phase sequence of length100 (d) 28-phase sequence of length32

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: (R1=5000m, R2 = 5080m, R3=5160m, R4=5240m and R5=5320m with v1 = v2 = v3 = v4 = v5= 0m/s)
Sequence Length 200: (R1=5000m, R2 = 5200m, R3=5400m, R4=5600m and R5=5800m with v1 = v2 = v3 = v4 = v5= 0m/s)
Sequence Length 100:(R1=5000 m, R2 = 5400m, R3=5800m, R4=6200m and R5=6400m with v1 = v2 = v3 = v4 = v5= 0m/s)
Sequence Length 32:(R1=5000 m, R2 = 6250m, R3=7500m, R4=8750m and R5=10000m with v1 = v2 = v3 = v4 = v5= 0m/s)

The transmitting signal is coded with 28-phase 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 infig.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 discrimination factor (DF) of 32 bit 28-phase 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.

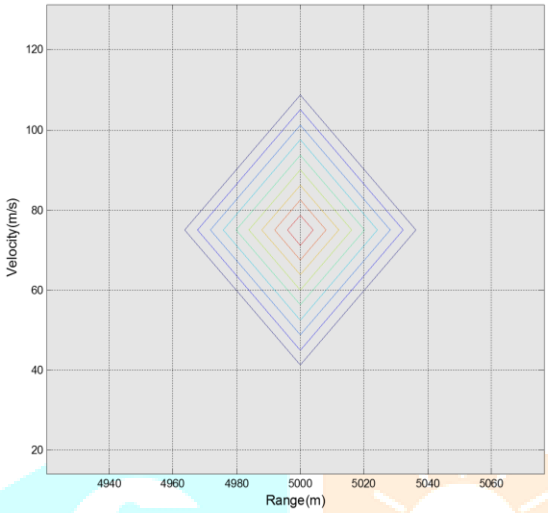


Fig.2a

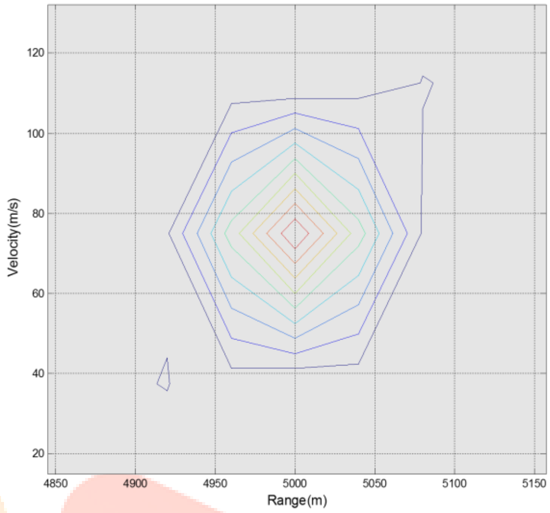


Fig.2b

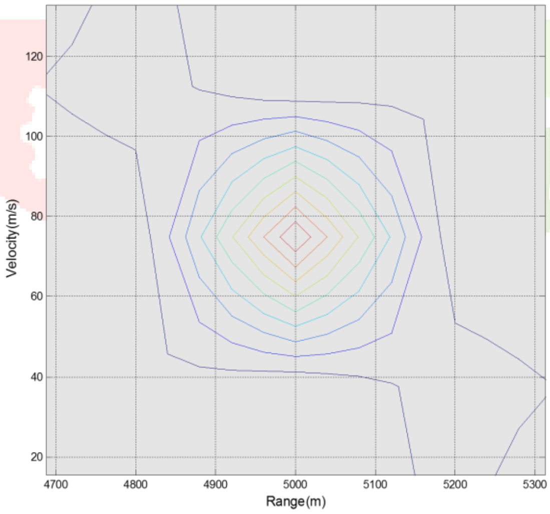


Fig.2c

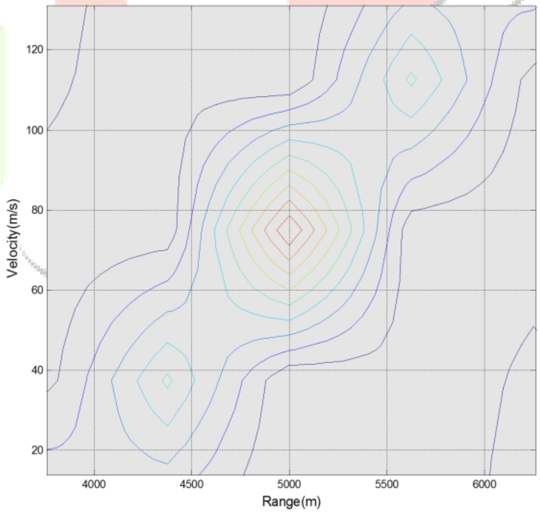


Fig.2d

Fig.2 Single Moving Target Scenario

Contour plots of CAF of the transmitted and received signal for 28-phase sequence.
(R =5000m, v=75 m/ sec)
(a)28-phase sequence of length500 (b) 28-phase sequence of length200
(c)28-phase sequence of length100 (d) 28-phase sequence of length32

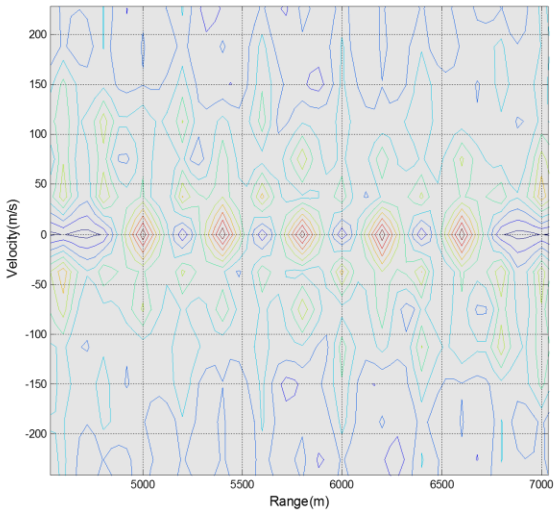


Fig.3a

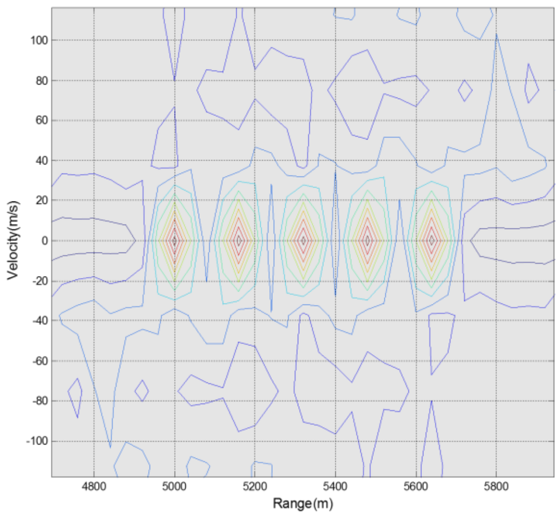


Fig.3b

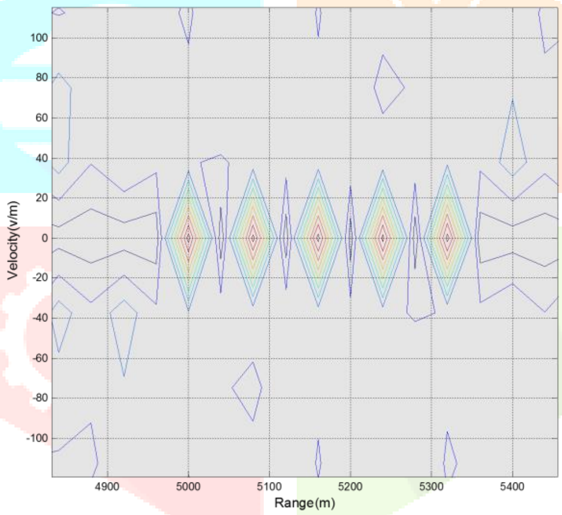


Fig.3c

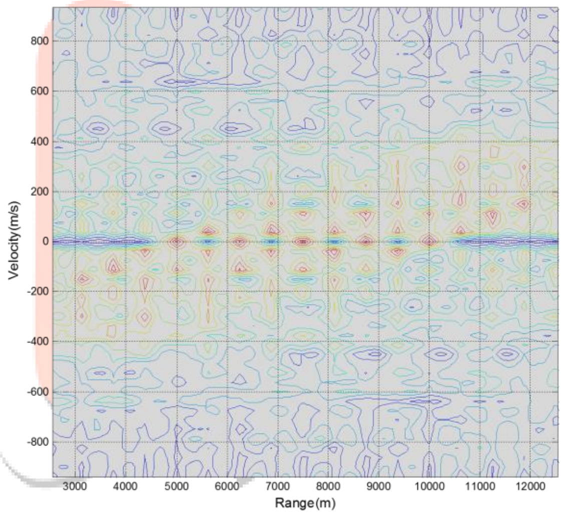


Fig.3d

Fig.3 Multi Stationary Target Scenario

Contour plots of CAF of the transmitted and received signal for 28-phase sequence

(a)28-phase sequence of length500

(R1=5000m,R2 = 5080m, R3=5160m, R4=5240m and R5=5320m with v1 = v2 = v3 = v4 = v5= 0m/s)

(b) 28-phase sequence of length200

(R1=5000m, R2 = 5200m, R3=5400m, R4=5600m and R5=5800m with v1 = v2 = v3 = v4 = v5= 0m/s).

(c) 28-phase sequence of length100

(R1=5000 m, R2 = 5400m, R3=5800m, R4=6200m and R5=6400m with v1 = v2 = v3 = v4 = v5= 0m/s).

(d) 28-phase sequence of length32

(R1=5000 m, R2 = 6250m, R3=7500m, R4=8750m and R5=10000m with v1 = v2 = v3 = v4 = v5= 0m/s).

MULTI MOVING TARGET SCENARIO

In this scenario, five moving targets at a range of 5000m moving with different velocities are considered for simulation. (R1= R2 =R3= R4= R5=5000m with v1 = 0m/s, v2 =75m/s, v3 = 150m/s, v4 =225m/s and v5= 300m/s). The transmitting signal is coded with 28-phase 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 Discrimination Factor of 32 bit 28-phase 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.

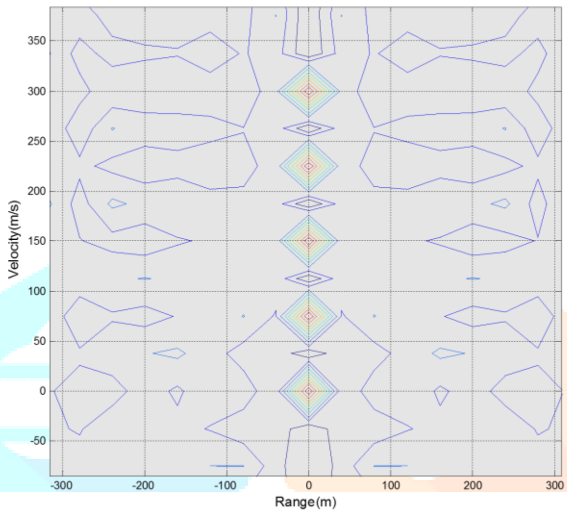


Fig.4a

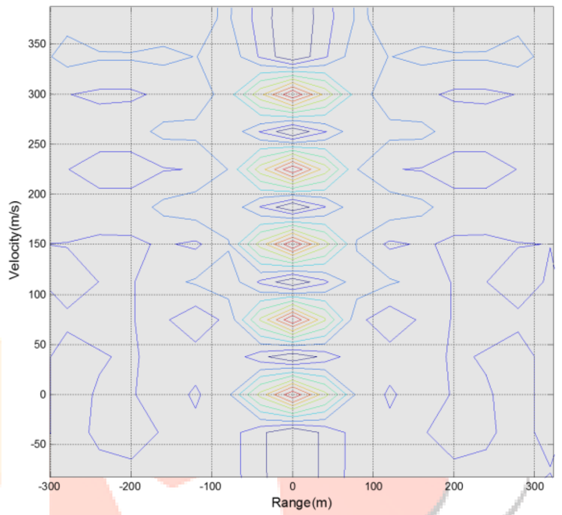


Fig.4b

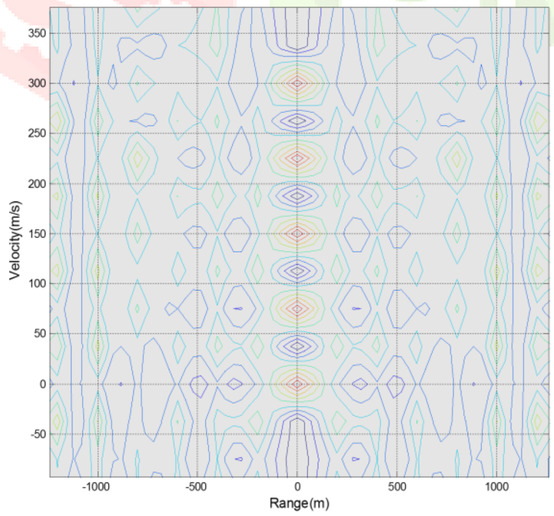


Fig.4c

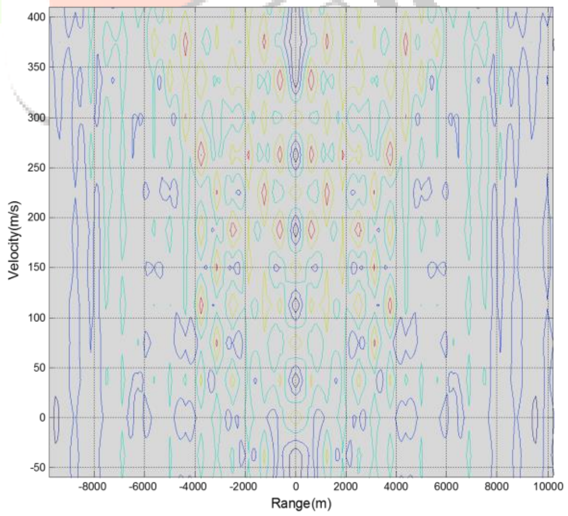
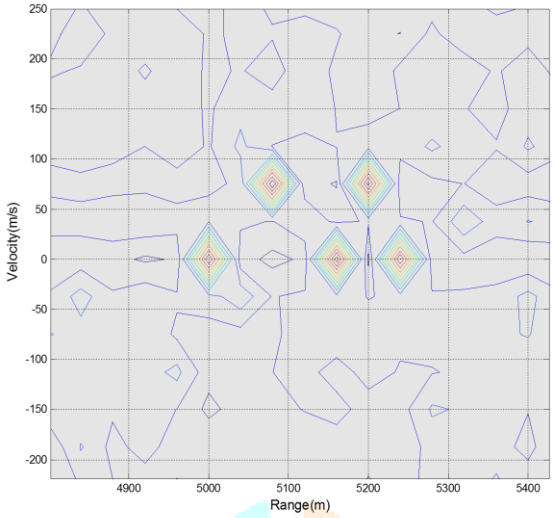


Fig.4d

Fig.4 Multi Moving Target Scenario

Contour plots of CAF of the transmitted and received signal for 28-phase sequence
(R1= R2 =R3= R4= R5=5000m with v1 = 0m/s, v2 =75m/s, v3 = 150m/s, v4 =225m/s and v5= 300m/s).

(a)28-phase sequence of length500 (b) 28-phase sequence of length200
(c)28-phase sequence of length100 (d) 28-phase sequence of length32



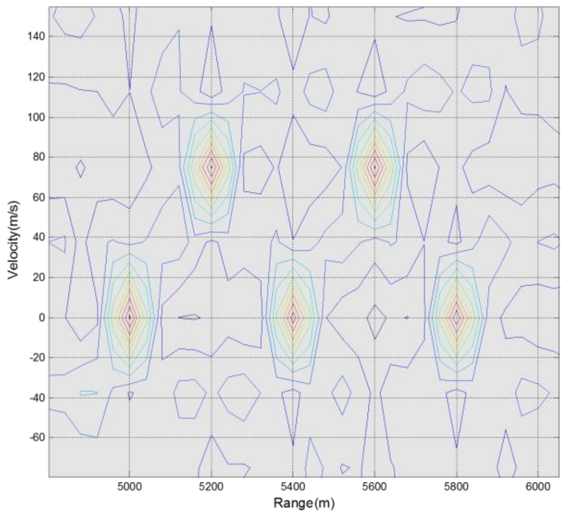
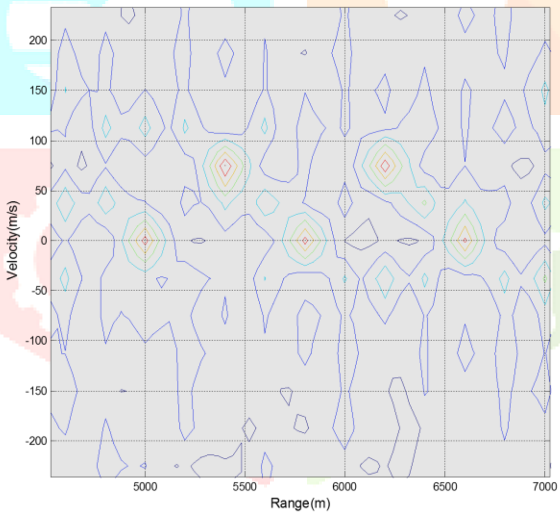


Fig.5a **Fig.5b**



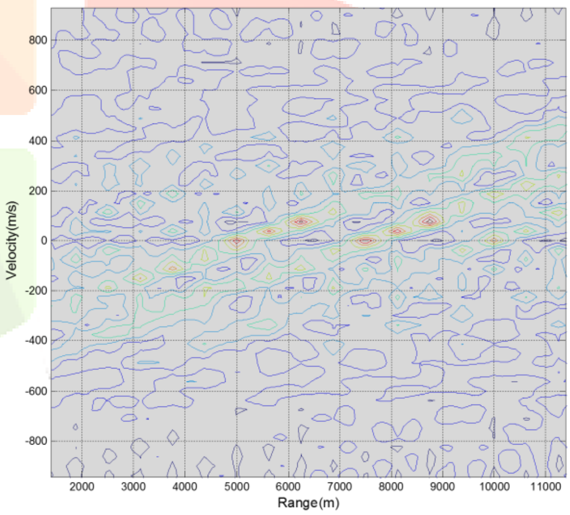


Fig.5c **Fig.5d**

Fig.5 Multi Stationary and Moving Target Scenario

(a) 28-phase sequence of length500
Stationary targets (R1=5000m, R2 = 5160m, and R3=5320m).
Moving targets (R4=5080m and R5=5240m with v4 = v5 = 75m/s).
(b) 28-phase sequence of length200
Stationary targets (R1=5000m, R2 = 5400m and R3=5800m).
Moving targets (R4=5200m and R5=5600m with v4 = v5 = 75m/s).
(c) 28-phase sequence of length100
Stationary targets (R1=5000m, R2 = 5800m and R3=6600m).
Moving targets (R4=5400m and R5=6200m with v4 = v5 = 75m/s).
(d) 28-phase sequence of length32
Stationary targets (R1=5000m, R2 = 7500m andR3= 10000m)
Moving targets (R4=6250m and R5=8750m with v4 = v5 = 75m/s).

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 (R1=5000m, R2 = 5160m, and R3=5320m). Moving targets (R4=5080m and R5=5240m with v4 = v5 = 75m/s). Sequence length 200: Stationary targets (R1=5000m, R2 = 5400m and R3=5800m).Moving targets (R4=5200m and R5=5600m with v4 = v5 = 75m/s).

Sequence length 100: Stationary targets (R1=5000m, R2 = 5800m and R3=6600m).Moving targets (R4=5400m and R5=6200m with v4 = v5 = 75m/s).Sequence length 32: Stationary targets (R1=5000m, R2 = 7500m andR3= 10000m) and two moving targets (R4=6250m and R5=8750m with v4 = v5 = 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.

The contour plots are drawn between delay and Doppler frequency for all the scenarios and the targets are detected exactly at the assumed locations.

V. CONCLUSIONS

Since there is no conventional technique available in the literature for the detection of targets using ployphase signals, the CAF technique is considered as an alternative and the detection procedure is described , in which single and multi-targets in various scenarios such as stationary, moving and mixed(stationary and moving) are presented. It is evident from the contour plots shown in figs. 1to 5 using the 28-phase sequences of length 500, 200 and 100, the targets are detected successfully even in complex situations such as - (i) five targets at same distance from the radar but moving with different velocities (ii) five stationary targets at different ranges. As the sidelobe suppression of 32 bit sequence is less compared to the higher length sequences, in turn 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.1 to 5 that as the sequence length increases the resolution as well as detection performance also increases.

It can also be concluded, that in complex scenarios, especially, in multi target environments, the detection capability of a radar system can be improved by using sequences of very high discrimination factor. It is also emphasized that the CAF technique can be used as an alternative technique for target detection in the polyphase coded continuous wave radar in all the scenarios.

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