# Target Detection using DFC Sequences

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***Abstract:*** This paper mainly focused on the detection of Radar targets using DFC sequences. Since there is no conventional technique available in the literature for the detection of targets using the Binary 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, Binary Sequences, Contour Plots.**

## I. INTRODUCTION

Traditionally, pulse compression sequences are being used to solve the problem of detection and separation of two closely spaced targets in multi-target environment. However, this separation is accomplished at the expense of introducing sidelobes in the matched-filter response, which may mask weak targets and possibly prevent their detection altogether. In the process of designing pulse compression sequences, the Ambiguity Function 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. J. P. Costas [1] suggested the design procedure for the design of frequency-coded waveforms, which ensure high delay-Doppler resolution. In this context, many researchers have been working with different ways of using Costas sequences effectively in the radar signal design [2-7].T.d.Bhatt et.al [8-9] recommended the design of frequency coded waveforms for target detection and high-resolution radar waveforms for multi-radar and dense target environments. Alternatively, H. Deng [10] suggested an innovative way of designing the DFC sequences for netted radar systems using global optimization algorithm. The design of DFC sequences for the sequence lengths of N = 32, N=100, N=128, N=200 and N=500, using PSOCM algorithm [11] are used 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 DFC transmitted signal and the received echo signal to demonstrate the detection of targets in different scenarios.

## II. DISCRETE FREQUENCY CODED SEQUENCES

Consider a Discrete Frequency Coded sequence with N adjacent sub-pulses of time duration 'T' and each is modulated with a distinct carrier frequency. The coding waveform can be represented as

$$S(t) = \sum_{n=1}^{N} A_n(t) e^{j2\pi f_n t} \tag{1}$$

where $f_n$ is the coding frequency of $n^{th}$ sub pulse and $A_n(t) = \begin{cases} \frac{1}{T} & (n-1)T \le t \ge nT \\ 0 & \text{otherwise} \end{cases}$

The resulting coding sequence can be written as $\{f_1, f_2, f_3 ... f_N\}$ for waveform of a DFC sequence, which is a permutation of $\{0, \Delta_f, 2\Delta_f, 3\Delta_f, ..(N-1)\Delta_f\}$. The value of $\Delta_f$ is chosen as $\Delta_f = \frac{1}{T}$. For convenience, when T is selected as 1, given $\Delta_f = 1$ and a DFC sequence is simply represented as {0, 1, 2, 3… N-1} and this sequence is termed as Discrete Frequency Coded sequence (DFC).

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

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 $\tau$ and Doppler shift $\nu$. 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 $x(t)$, $\tau$ is the time delay between waveforms, and $\nu$ 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 $\tau$ and $\nu$.

## IV. TARGET DETECTION SCENARIOS

The DFC sequences of length 32,100 and 200 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 ($\mu$s), $\Delta f$ = Doppler frequency Resolution (m/s), $\Delta R$ = Range Resolution (m), $\Delta V$ =Velocity resolution (m/s). All the simulations are performed considering the pulse width of 133 $\mu$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 $$\Delta R=\frac{c}{2B} \tag{3}$$

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

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

where $f_0$ is the carrier frequency of the waveform.

**Table.1 Parameters for various target scenarios.**

| Length of DFC Code | $f_c$ (Giga Hz) | $V_{max}$ (m/s) | $R_{max}$ (m) | $t_b$ ($\mu$ sec) | $\Delta f$ (Hz) | $\Delta R$ (m) | $\Delta V$ (m/s) |
|---|---|---|---|---|---|---|---|
| 500 | 30 | 3750 | 20000 | 0.2667 | 7500 | 0.08 | 37.5 |
| 200 | 30 | 3750 | 20000 | 0.6667 | 7500 | 0.49 | 37.5 |
| 100 | 30 | 3750 | 20000 | 1.3333 | 7500 | 1.99 | 37.5 |
| 32 | 30 | 3750 | 20000 | 4.1167 | 7500 | 19.53 | 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 DFC sequence of length 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 DFC sequence of length 200,100 and 32 with an enlargement around the peak point are shown in the fig.1 (a-c) respectively. It is measured from the fig. 1(a-d) that, the range resolution for the sequence length of 200,100 and 32 is 0.5m, 2m and 20m 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-c). 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 DFC sequence of length 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 DFC sequence of length 200,100 and 32 with an enlargement around the peak point are shown in the fig. 2(a-c) 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 200 :($R_1$=5000m, $R_2$= 5001m, $R_3$=5002m, $R_4$=5003m and $R_5$=5004m with $v_1 = v_2 = v_3 = v_4 = v_{5=}$ 0m/s).

Sequence length 100 :($R_1$=5000 m, $R_2$ = 5004m, $R_3$=5008m, $R_4$=5012m and $R_5$=5016m with $v_1 = v_2 = v_3 = v_4 = v_{5=}$ 0m/s).

Sequence length 32 :( $R_1$=5000 m, $R_2$ = 5040m, $R_3$=5080m, $R_4$=5120m and $R_5$=5160m with $v_1 = v_2 = v_3 = v_4 = v_{5=}$ 0m/s).

The transmitting signal is coded with DFC sequence of length 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 200 100 and 32 are shown in fig. 3(a-c) 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. It is evident from fig.3 (a-c) as the sequence length is increased the sidelobe levels are lowered.

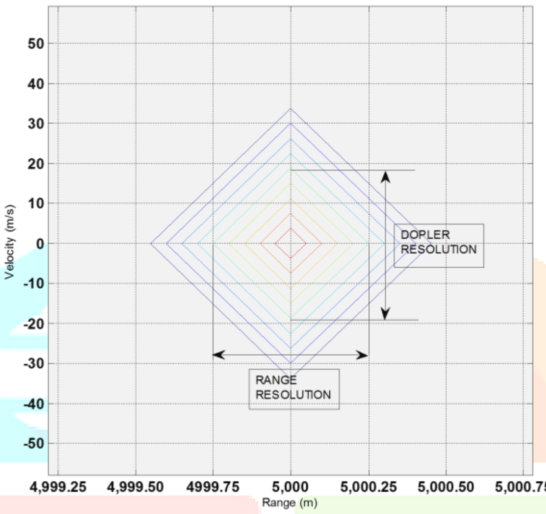


**Fig.1a**

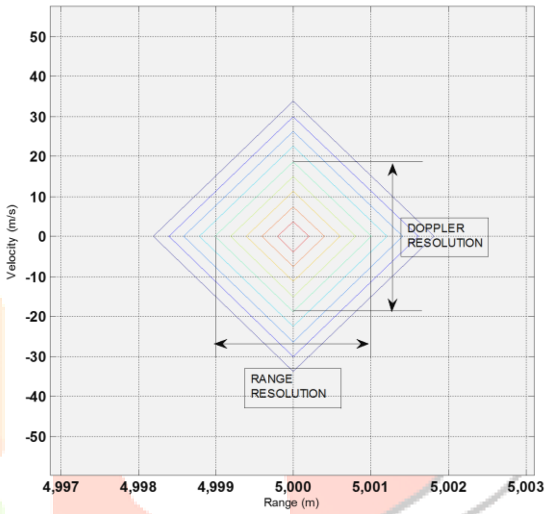


**Fig.1b**

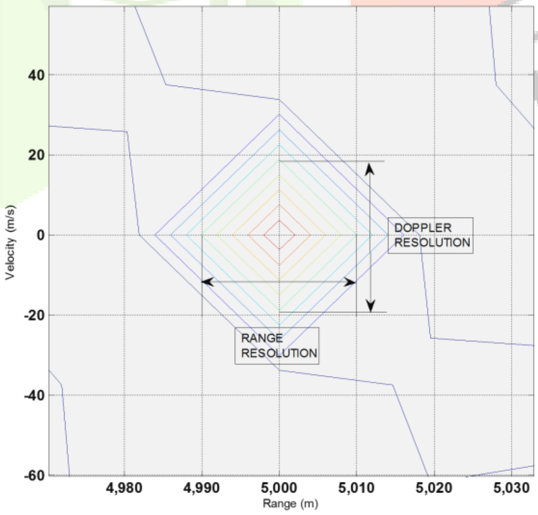


**Fig.1c**

**Fig.1 Single Stationary target scenario.**

**Contour plots of CAF of the transmitted and received signal for DFC sequence.**
(R =5000m, $v$=0 $m$/ sec)
**(a) DFC sequence of Length 200 (b) DFC sequence of Length 100**
**(c) DFC sequence of Length 32**

**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 DFC sequence of length 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 200 100 and 32 are shown in fig. 4(a-c) respectively. It is obvious from fig. 4(a-c) that all the targets are detected at chosen locations without any ambiguity. It is clear from fig. 4(a-c) that as the sequence length is increased the sidelobe levels are lowered. Thus target detection is achieved without any ambiguity.

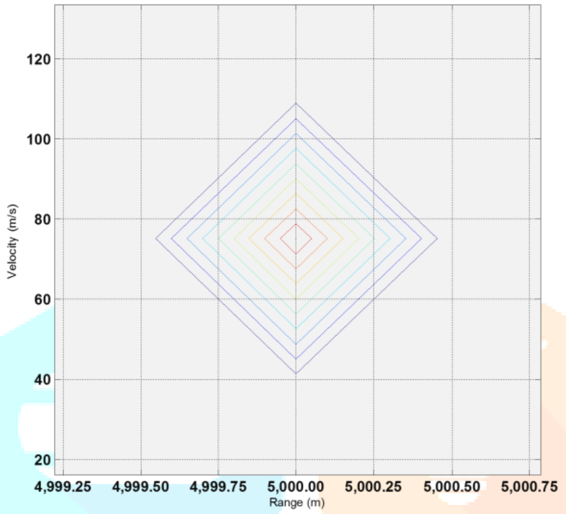


**Fig.2a**

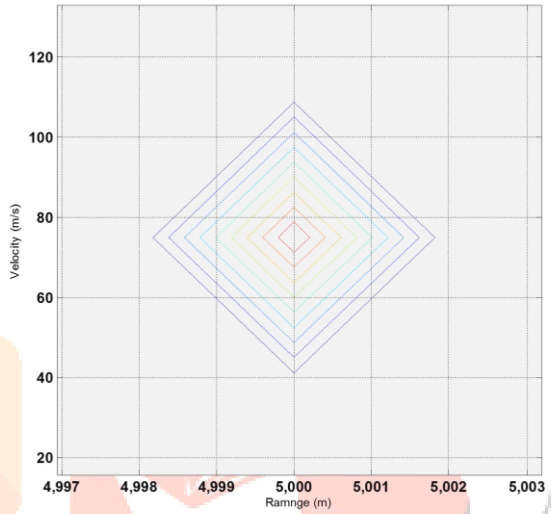


**Fig.2b**

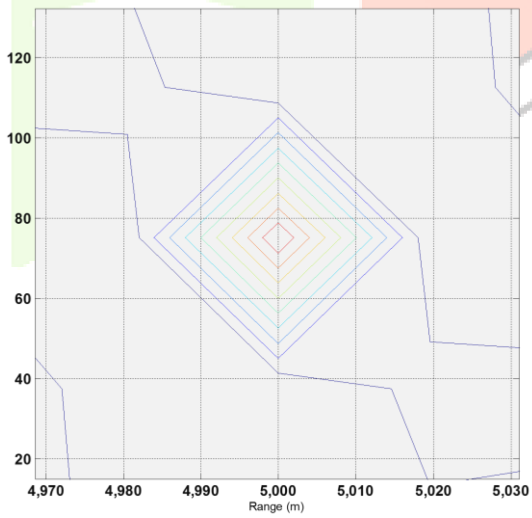


**Fig.2c**

**Fig.2 Single moving target scenario**

**Contour plots of CAF of the transmitted and received signal for DFC sequence.**
(R =5000m, v=75 m/ sec)
**(a) DFC sequence of Length 200 (b) DFC sequence of Length 100**
**(c) DFC sequence of Length 32**

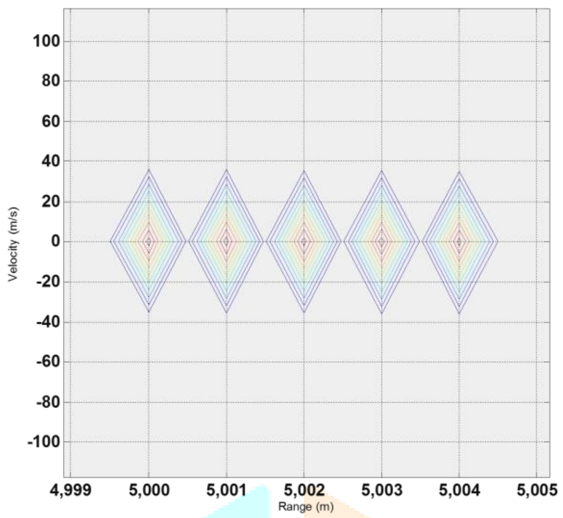


**Fig.3a**

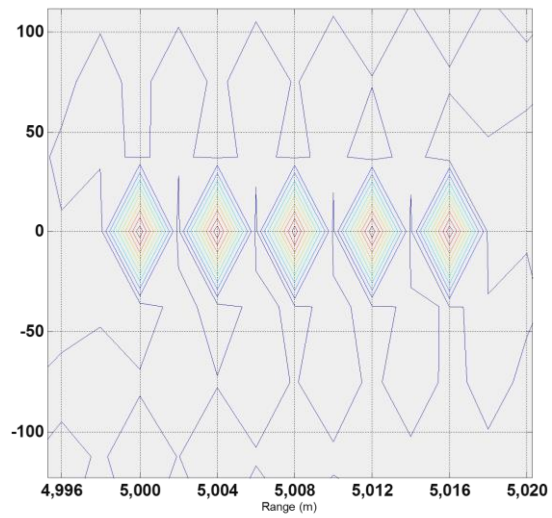


**Fig.3b**

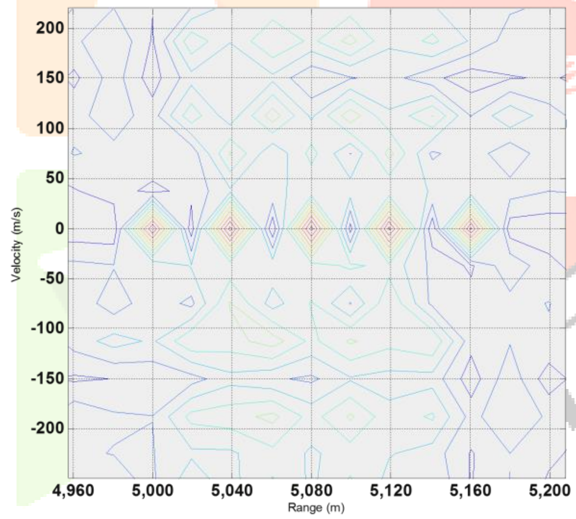


**Fig.3c**

**Fig.3 Multi Stationary Target Scenario**

**Contour plots of CAF of the transmitted and received signal for DFC sequence.**

**a) DFC sequence of Length 200**

$R_1$=5000m, $R_2$= 5001m, $R_3$=5002m, $R_4$=5003m and $R_5$=5004m with $v_1 = v_2 = v_3 = v_4 = v_5 =$ 0m/s).

**b) DFC sequence of Length 100**

$R_1$=5000 m, $R_2$ = 5004m, $R_3$=5008m, $R_4$=5012m and $R_5$=5016m with $v_1 = v_2 = v_3 = v_4 = v_5 =$ 0m/s).

**c) DFC sequence of Length 32**

( $R_1$=5000 m, $R_2$ = 5040m, $R_3$=5080m, $R_4$=5120m and $R_5$=5160m with $v_1 = v_2 = v_3 = v_4 = v_5 =$ 0m/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 200:
Stationary targets ($R_1$=5000m, $R_2$ = 5001m and $R_3$=5002).Moving targets ($R_4$=5000.5m and $R_5$=5001.5m with $v_4$ = $v_5$ = 75m/s).
Sequence length 100:
Stationary targets ($R_1$=5000m, $R_2$ = 5004m and $R_3$=5006m).Moving targets ($R_4$=5002m and $R_5$=5008m with $v_4$ = $v_5$ = 75m/s).
Sequence length 32:
Stationary targets ($R_1$=5000m, $R_2$ = 5040m and $R_3$= 5060m) and two moving targets ($R_4$=5020m and $R_5$=5080m 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-c). It is observed that in all the cases, the targets are detected exactly at the assumed locations without any ambiguity.

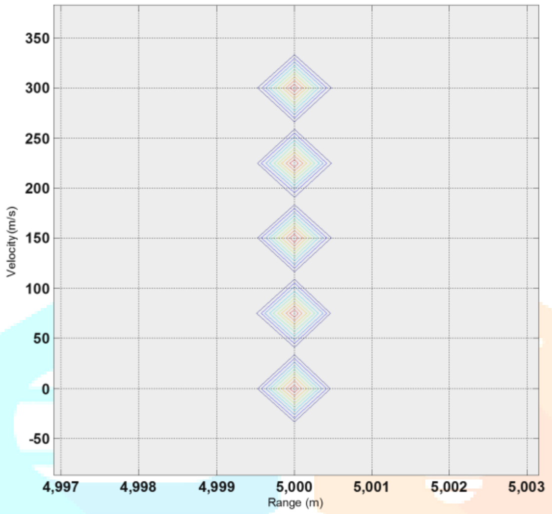


Fig.4a

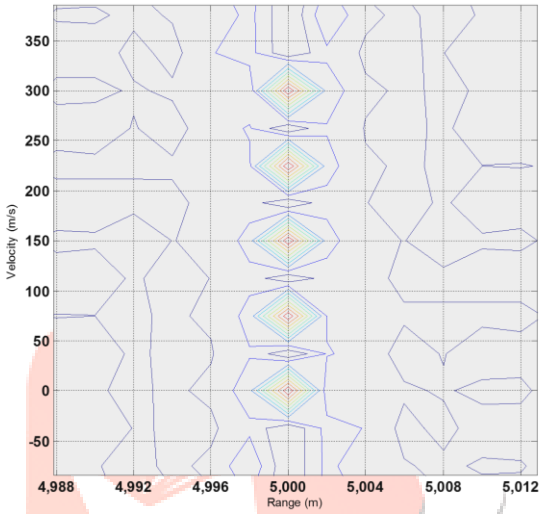


Fig.4b

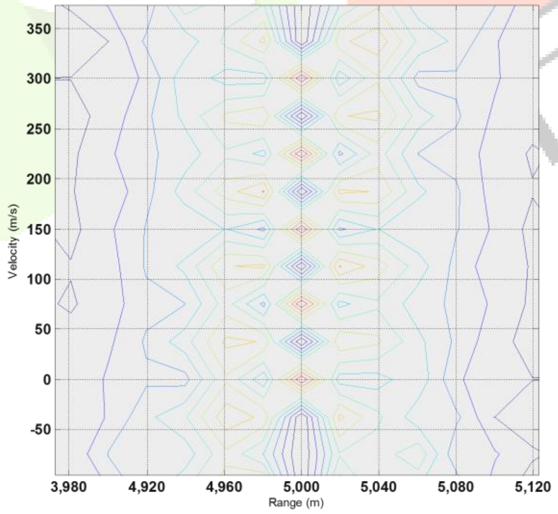


Fig.4c

**Fig.4 Multi Moving Target Scenario**

**Contour plots of the CAF of the transmitted and received signal for DFC sequence.**

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

**a) DFC sequence of Length 200** **b) DFC sequence of Length 100**

**c) DFC sequence of Length 32**

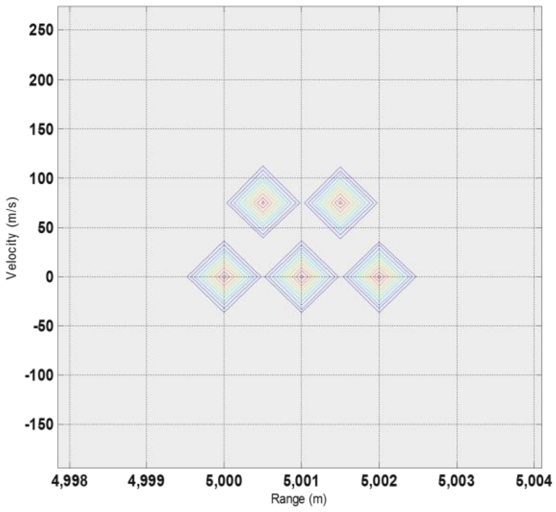


**Fig.5a**

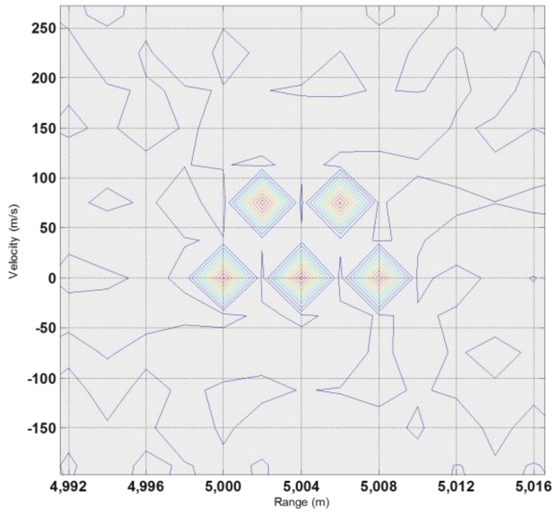


**Fig.5b**

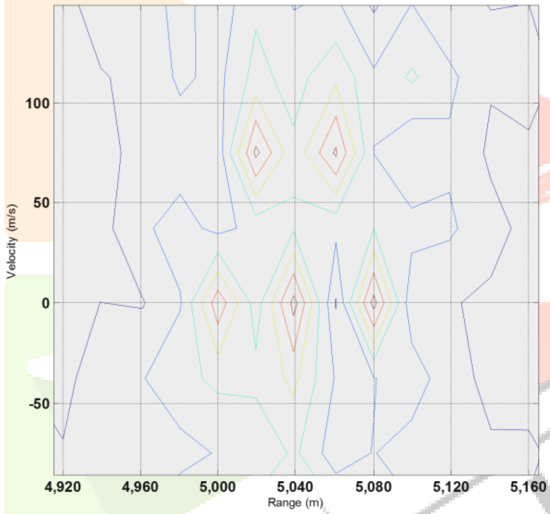


**Fig.5c**

**Fig.5 Multi Stationary and Multi Moving Target Scenario**

**Contour plots of the CAF of the transmitted and received signal for DFC sequence.**

**a) DFC sequence of length 200**
Stationary targets ($R_1$=5000m, $R_2$ = 5001m and $R_3$=5002).
Moving targets ($R_4$=5000.5m and $R_5$=5001.5m with $v_4 = v_5$ = 75m/s).
**b) DFC sequence of length 100**
Stationary targets (R1=5000m, R2 = 5004m and R3=5006m).
Moving targets (R4=5002m and R5=5008m with v4 = v5 = 75m/s).
**c) DFC sequence of Length 32**
Stationary targets ($R_1$=5000m, $R_2$ = 5040m and $R_3$= 5060m)
Moving targets ($R_4$=5020m and $R_5$=5080m with $v_4 = v_5$ = 75m/s).

## V. CONCLUSIONS

Since there is no conventional technique available in the literature for the detection of targets using DFC coded signals, the CAF technique is considered as an alternative and the detection procedure is explained in this paper, 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 fig. 1 to 5 using the DFC sequences of length 200,100 and 32 , 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. It is clearly evident from the fig.1 to 5 that as the sequence length increases the resolution as well as detection performance increases.

It can also be concluded, that in complex scenarios, especially, in multi target environments, the detection capability of a radar system using DFC coded sequences is very high when compared with all the phase coding techniques available in the literature. It is also emphasized that the CAF technique can be used as an alternative for target detection in the DFC coded continuous wave radar in all the scenarios

## REFERENCES


[1] Costas J.P, “A study of a class of detection waveforms having nearly ideal range Doppler ambiguity properties”, Proc. IEEE, Vol. 72, pp. 996-1099, Aug. 1984.

[2] Golomb S.W. “Algebraic constructions for Costas arrays”, J. Combin. Theory Ser. A,1984, 37, (1), pp. 13–21.

[3] Golomb S.W, Taylor H, “Constructions and properties of Costas arrays”, Proc. IEEE, 1984, 72, (9), pp. 1143–1163.

[4] Drumheller D.M, Titlebaum E.I, “Cross-correlation properties of algebraically constructed Costas arrays”, IEEE Trans. Aerosp. Electron. Syst., 1991, 27, (1), pp. 2–10.

[5] Moreno O, Games R.A, Taylor H, “Sonar sequences from Costas arrays and the best known sonar sequences with up to 100 symbols”, IEEE Trans. Inf. Theory, 1993, 36, (6), pp. 1985–1987..

[6] Jiann-Ching G, Bell M.R, “Diversity waveforms sets for delay-Doppler imaging”, IEEE Trans. Inf. Theory, 1998, 44, (4), pp. 1504–1522.

[7] Beard J.K, Russo J.C, Ericksonk G, Monteleone M.C, Wrightm T, “Combinatoric collaboration on Costas arrays and radar applications”, IEEE Radar Conf., Philadelphia, Pennsylvania, USA, April 2004, pp. 260–265.

[8] T.D.Bhatt, E.G.Rajan, P.V.D.S.Rao “Design of high-resolution radar waveforms for multi-radar and dense target environments”, IET Radar Sonar Navigation. Aug. 2011 – Vol. 5, Issue 7, pp.716–725.

[9] T.D.Bhatt, E.G.Rajan, P.V.D.S.Rao “Design of frequency-coded waveforms for target detection”, IET Radar Sonar Navigation. Oct. 2008 – Vol. 2, Issue 5, pp.388-394.

[10] Hai Deng, “Discrete Frequency - coding waveform design for Netted radar systems Theory and Applications of Netted Radar Systems”, IEEE Signal processing letters, Vol.11, No 2, pp. 179-182, Feb. 2004.

[11] M. V. NageswaraRao, K. Raja Rajeswari, “Design of Discrete Frequency Coded Sequences using PSOCM for Target Detection with CAF”, Radio Engineering, Vol. 20, NO. 1, APRIL 2011. Page No.69-73.

[12] A Gardner, “Statistical Spectral Analysis”, A Nonprobabilistic Theory, Pritice hall Publishing, 1988.

[13] W.A Gardner, “Statistical Spectral Analysis”, A Nonprobabilistic Theory, Pritice hall Publishing, 1988.