Performance Comparison of DFC and Poly Phase Coded Sequences for Target Detection

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***Abstract*—This paper mainly focused on quantifying the effect of additive white Gaussian noise on the detection and resolution performance of DFC and 28-phase sequences. The effect of noise in detecting the targets using DFC and 28 phase coded signals of different lengths with varying signal to noise ratio (SNR) is computed using cross ambiguity function. The PSLR,PSLR-3 are calculated , range resolution and Velocity resolution are computed using contour plots of cross ambiguity function in various scenarios and are compared.**

***IndexTerms*—Cross Ambiguity Function, AWGN, PSLR, PSLR3.**

I. INTRODUCTION

Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal. It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal. At the microwave frequencies usually used for radar, the external noise which enters via the antenna is generally quite low so that the receiver sensitivity is usually set by the internal noise generated within the receiver. If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the desired signal, and if the receiver itself were so perfect that it did not generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction electrons called thermal noise. Most of the studies in the signal design assume an ideal receiver. Since noise is the chief factor limiting receiver sensitivity, it is necessary to identify the deterioration caused by the presence of noise.

Anand K. Ojha et.al have studied the performance of complimentary coded radar signals in Additive White Gaussian Noise (AWGN) environment [1], in terms of the effect of target fluctuations and noise on resolution properties [2] and also the impact of noise and target fluctuation on the performance of binary and Frank radar signals [3-4]. Whereas the signal to noise ratio sensitivity of matched and mismatched radar compression filters are discussed in [5]. Raja Rajeswari. K et.al has studied the performance of matched and post compression filters in the presence of AWGN [6]. In the subsequent sections the additive white Gaussian noise is considered, its effect on DFC and 28-phase coded signals of different lengths with varying signal to noise ratio (SNR) is computed. For the same sequences the PSLR and PSLR 3 in various target detection scenarios are compared.

II. EFFECT OF NOISE ON 28-PHASE CODED SIGNAL

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

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

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.

$$\phi(n) \in \left\{0, \frac{2\pi}{M}, 2\frac{2\pi}{M}, \ldots, (M-1)\frac{2\pi}{M}\right\} = \{\psi_1, \psi_2, \psi_3, ..\psi_M\} \quad (4)$$

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

28-Phase coded signal [7] of length 32, 100 and 200 are considered to study the effect of AWGN in various scenarios. The received signal is added with additive white Gaussian noise for various values of SNR.
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 [8]. The cross-ambiguity function is also related to the cyclic cross-correlation function as discussed in [9].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 .

Cross-ambiguity function $\chi_{xy}(\tau,\nu)$ of the signal $x(t)$ with the signal $y(t)$ is defined as $\chi_{xy}(\tau,\nu)=\frac{1}{T_d}\int_{-\infty}^{\infty} x(t)\, y(t-\tau)e^{j2\pi\nu t}dt$.

CAF is computed between the transmitted and received signal of different lengths. SNR is varied from +20dB to -20dB and the minimum allowable level of SNR in dB for the detection of targets without any ambiguity are computed and listed in table1.

PSLR (Defined as ratio of max side lobe peak to main lobe peak $\text{PSLR(dB)} = 20\log\left\{\frac{\text{Max}(\text{Sidelobe peak})}{\text{Mainlobe peak}}\right\}$)and PSLR3 (Defined as ratio of max side lobe peak over a given $\Delta\tau$ and $\Delta\nu$ limits $\text{PSLR3(dB)} = 20\log\left[\frac{|\text{Max}[\text{Max}(\text{Sidelo be Peak})]^2}{|\text{r}(0)^2|}\right]$) ofand the PSLR3 of binary sequences of length 32, 100,200 and 500 are calculated for different SNR is listed in Table 2. The variation in range and Doppler resolution with noise is calculated from the width of the mainlobe and are shown in table 3. The 2-D plots and contour plot of cross ambiguity function using 28-phase sequence of length 200 with SNR =-18dB in a multi moving target scenario is shown in fig.1 (a-c). From table.1 it is evident that,32 bit 28-phase sequences are not able to detect when more than 2 targets present in all the scenario.100 bit sequences are able to detect the targets when SNR is -12 dB in the multi target environment.200 and 500 bit sequences are able to detect targets in all the scenarios but SNR is limited to -18dBonly.

Table 1 Minimum allowable SNR in stationary and moving target scenario.

Scenario	Number of targets	Length of the 28-phase sequence			
		32	100	200	500
Stationary target	1	-12dB	-18dB	-20dB	-20dB
	2	-10dB	-16dB	-20dB	-20dB
	3	Zero Noise	-12dB	-20dB	-20dB
	4	No Detection	-12dB	-20dB	-20dB
	5	No Detection	-12dB	-16dB	-20dB
Moving target	1	-14dB	-18dB	-20dB	-20dB
	2	-10dB	-18dB	-20dB	-20dB
	3	Zero Noise	-16dB	-18dB	-18dB
	4	No Detection	-12dB	-18dB	-18dB
	5	No Detection	-12dB	-18dB	-18dB

Table 2 PSLR and PSLR3 of 28-phase sequences for different SNRs

N	Zero Noise		SNR=0dB		SNR=-10dB		SNR=-20dB	
	PSLR	PSLR3	PSLR	PSLR3	PSLR	PSLR3	PSLR	PSLR3
32	-26.36	-3.265	-25.27	-3.326	-20.0	-3.51	-13.39	-2.373
100	-31.62	-10.31	-29.89	-10.24	-23.34	-10.66	-16.65	-8.854
200	-31.62	-16.11	-32.39	-16.03	-27.95	-16.36	-19.35	-11.24
500	-36.25	-19.26	-34.7	-14.60	-28.54	-14.53	-22.3	-14.35

Table 3 Range and Doppler resolution

N	Zero Noise		SNR=-10dB		SNR=-20dB	
	ΔR (m)	$\Delta\nu$ (m/s)	ΔR (m)	$\Delta\nu$ (m/s)	ΔR (m)	$\Delta\nu$ (m/s)
32	625	37.5	651	40.25	-	-
100	200	37.5	207	39.12	221.5	41.5
200	100	37.5	113.4	38.75	102.6	43
500	40	37.5	41.5	38.5	42.25	41.3

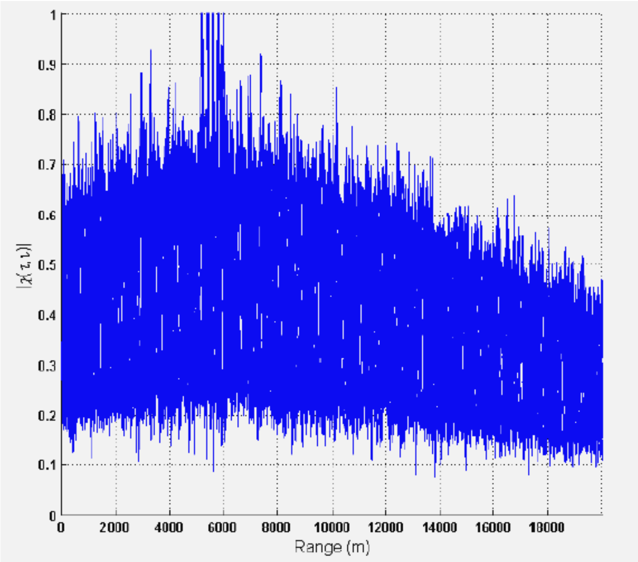


Fig.1a. 2-D plot for measuring the range

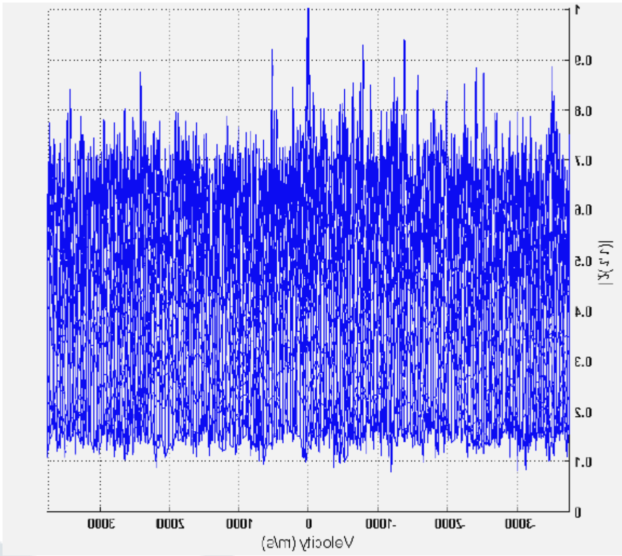


Fig.1b. 2-D plot for measuring the velocity

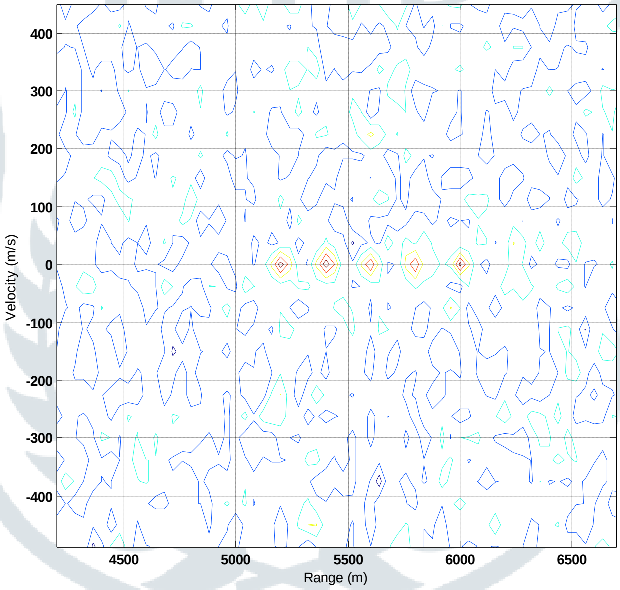


Fig.1cContour plot for the measurement of velocity and range.

Fig. 1 Multi stationary target scenario (five targets) with SNR=-18dB

III. Effect of noise on DFC coded signal

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

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

wheref_n is the coding frequency of n^{th}subpulse 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 Δ_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).

Discrete frequency coded signal [10] is considered in this section to quantify the effect of additive white Gaussian noise on the detection and resolution performance. The performance characteristics of DFC codes of lengths 32,100 and 200 are considered for.The received signal is added with additive white Gaussian noise for various values of SNR .To check the detection and resolution capabilities, CAF is computed between the transmitted and received signal of different lengths. SNR is varied from +20dB to -20dB and the minimum allowable level of SNR in dB for the detection of targets without any ambiguity are computed and listed in table 4.

The PSLR and the PSLR3 of DFC sequences of length 32, 100 and 500 are calculated for different SNR is listed in Table 5. The variation in range and Doppler resolution with noise is calculated from the width of the mainlobe and are shown in table 6. The 2-D plots and contour plot of cross ambiguity function using DFC sequence of length 200 with SNR = -20dB in a multi moving target scenario is shown in fig 2(a-c).

From table.1 it is evident that, 32 bit DFC sequences are able to detect the targets in all the scenarios. But in multi target environment SNR is limited to -10 dB only.100 and 200 bit DFC sequences are able to detect the targets even SNR is -20 dB in the multi target environment.

Table 4 Minimum allowable SNR in stationary and moving target scenario.

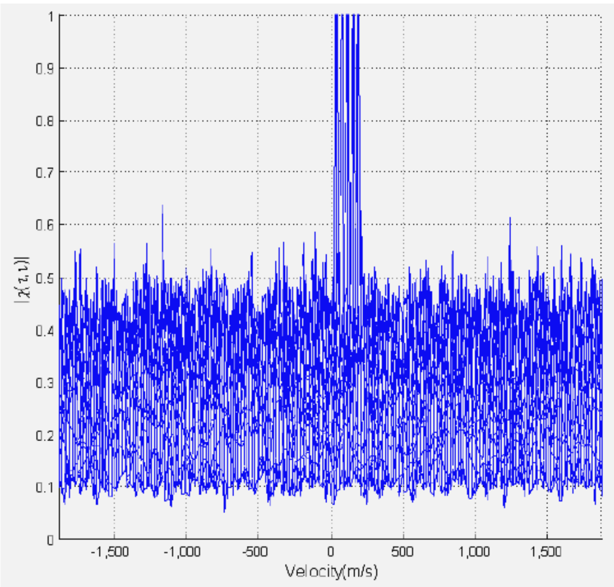
Scenario	Number of targets	Length of the DFC sequence		
		32	100	200
Stationary target	1	-20dB	-20dB	-20dB
	2	-18dB	-20dB	-20dB
	3	-15dB	-20dB	-20dB
	4	-10dB	-20dB	-20dB
	5	-10dB	-20dB	-20dB
Moving target	1	-20dB	-20dB	-20dB
	2	-18dB	-20dB	-20dB
	3	-16dB	-20dB	-20dB
	4	-12dB	-20dB	-20dB
	5	-12dB	-20dB	-20dB

Table 5 PSLR and PSLR3 of DFC sequences for different SNRs.

N	Zero Noise		SNR=0dB		SNR=-10dB		SNR=-20dB	
	PSLR	PSLR3	PSLR	PSLR3	PSLR	PSLR3	PSLR	PSLR3
32	-26.10	-15.80	-28.4	-15.40	-18.96	-15.32	-11.05	-5.71
100	-34.51	-30.45	-27.95	-27.83	-24.43	-21.19	-13.23	-9.22
200	-42.85	-33.97	-33.97	-33.72	-27.95	-26.45	-16.89	-16.15

Table 6 Range and Doppler resolution

N	Zero Noise		SNR=-10dB		SNR=-20dB	
	ΔR (m)	$\Delta \nu$ (m/s)	ΔR (m)	$\Delta \nu$ (m/s)	ΔR (m)	$\Delta \nu$ (m/s)
32	20	37.5	20.72	37.75	22	44
100	2	37.5	2.12	38.25	2.08	41.5
200	0.5	37.5	0.532	41.5	0.51	39.5



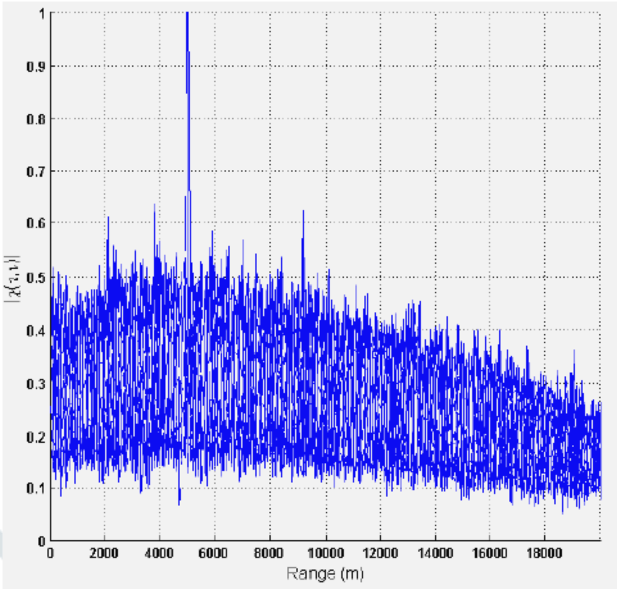


Fig.2a. 2-D plot for measuring the velocityFig.2b. 2-D plot for measuring the range

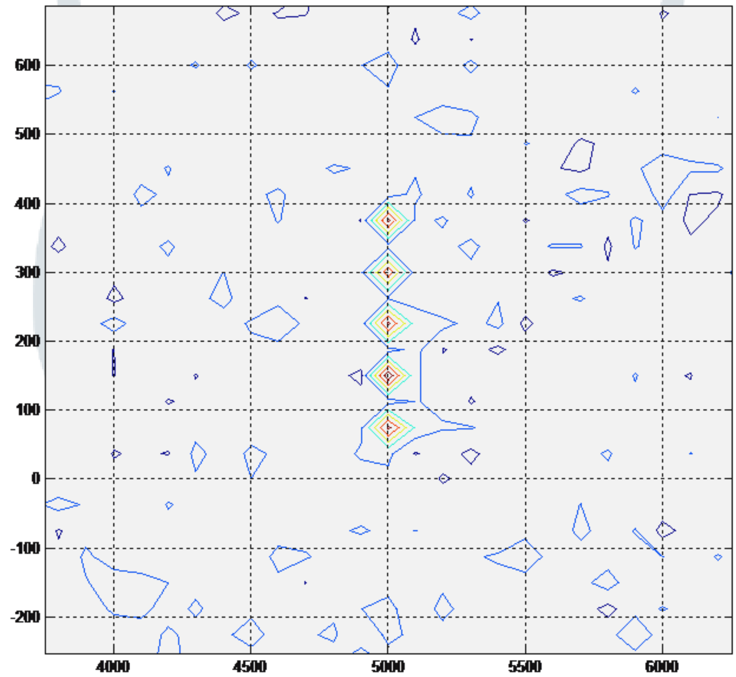


Fig.2c. Contour plot for the measurement of velocity and range.

Fig. 2.Multi moving target scenario (five targets) with SNR=-20dB
(b)

IV. CONCLUSIONS

This paper mainly focused on quantifying the effect of additive white Gaussian noise on the detection and resolution performance of DFC and 28-phase coded sequences of lengths 32, 100, 200 and 500. It is evident from table 1 and 4 that,32 bit 28-phase sequences are not able to detect the targets when more than 2 targets present in all the scenarios.32 bit DFC sequences are able to detect the targets in all the scenario, however, in multi target environment targets are detected when SNR is limited to -10 dB only.100 bit 28-phase sequences are able to detect the targets in all the scenarios and not able to detect when SNR is beyond -12 dB in the multi target environment.200 and 500 bit 28-phase sequences are able to detect targets in all the scenarios but SNR is limited to -18dBonly.100 and 200 bit DFC sequences are able to detect the targets when SNR is varied upto -20 dB in the multi target environment.

It is evident from the table 2 and 5 that, as the sequence length is increased, PSLR as well as PSLR3 are decreased. The, DFC sequences of all lengths have lesser PSLR and PSLR3.

From table .3 and 6 it is concluded that, as the SNR is decreasedthe range and Doppler resolution decreases in all the 28 –phase and DFC sequences but the variation is less using DFC sequences.Hence, DFC sequences are highly recommended for multi target noisy environment to avoid ambiguity of distinguishing the targets for the desired range/Doppler resolution.

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