International Journal of Engineering & Technology, 7 (2.6) (2018) 147-152

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research Paper



Poly-phase signal generation and optimization of LPI Radar: A new approach

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Abstract

Low Probability of Intercept (LPI) Radar own certain positive characteristics make them nearly undetectable by Intercept Receivers. In a battle field, this present a considerable strategic problem. New digital receivers required complex signal processing techniques to detect these types of Radar. This paper address the problem of constructing a new hybrid waveform design using Poly-Phase modulation technique to optimize the detection performance of LPI Radar. Phase coded Pulse compression waveforms using Frequency Hopping Spread Spectrum (FHSS) are designed to evaluate the detection performance of LPI radar in terms of Discrimination factor (DF). The difference in DF of the Poly-phase coded and Binary phase coded signals is increasing with the increase in the phase values. The effect of noise on Hybrid Poly-Phase waveforms examined using the signal to noise ratios of -10dB, -15dB and -20dB and extract the parameter necessary for the LPI Radar system.

Keywords: *Discrimination Factor; Low Probability of Intercept(LPI); Poly-Phase signals; Pulse Compression; Phase shift Keying.*

1. Introduction

For easy signal generation and processing, the most commonly used code is Binary code in radar pulse compression. Long pulse is transmitted to achieve large radiated energy and range resolution. This is the conventional method of pulse compression[1].Phase coding and linear frequency modulation are primary radar pulse compression modulation. Pulse modulation provides the advantages of phase coding and LFM method and hence Radar designers like this method [2].But in LPI Radar secrecy is more important and hence traditional method of pulse compression is not preferred. Binary signal and poly-phase signals have large main lobe to peak side lobe ratio of same code length but the structure of poly-phase waveform is more complicated and very difficult to detect and analyze by an enemies Electronic Investigation Measure[3]. Radar waveform design algorithm proposed[4] based on two different applications, target detection and target characterization, where communication signal scattered off the target and considered as an interference in the objective functions.LPI Radar uses a special waveforms proposed to avert a non-cooperative intercept receiver from intercepting and detecting it's emission. LPI Radar and Pulse compression provides a trade-off between high peak power and High range resolution. LPI Radar is not easily detected by Electronic Investigation equipment. Another class of Radar signals, Poly-phase codes are useful for pulse compression applications. Low-range side lobes, compatibility with digital signals, low cross correlations, the Doppler tolerance, compatible with Band Pass limited receiver and ease of implementation are many useful features of Poly-Phase codes[3]. Binary codes have the phase constellation size of 2 and distributed over 2π phase. These codes are used in receiver filter to reduce mismatch loss, mismatch due to range sampling and radiated spectrum trade-off [5]. A Quaternary phase code is one whose sub pulses are phased in one of the four states:0, 90, 180 and 270 degrees or equivalently +1, +j, -1 or -j. This means that odd numbered sub pulses are real (±1) and even numbered sub pulses are imaginary(±j). In this case the magnitude of these sub pulses for Quaternary phase code will be Real-Imaginary. Quaternary phase code with complex magnitude i.e. phase code whose sub pulses are phased in one of the four states 45, 135, 225 and 315 degrees or equivalently 0.7071+j0.7071, -0.7071+j0.7071,- 0.7071-j0.7071 or 0.7071-j0.7071. In this case all the sub pulses are of complex magnitude only. In proposed work, poly-phase signals are constructed using spread spectrum techniques in order to optimize the detection performance of LPI Radar. This results include coincidence detection of LPI waveform with improved detection capability. The poly-phase signal is decoded into a bi-phase signal for the purpose of transmission. However the bi-phase signal is additionally decoded into poly-phase signal at the receiver. The work is structured in this paper as follows. In section 2, poly-phase codes and construction of new family of poly-phase codes are given. Section 3 provide the description of Optimization algorithm used for better performance of LPI radar, effect of noise on the detection performance of Radar in describe in section 4, followed by results and discussion in section5.

2. Poly-phase hybrid code for LPI Radar

Poly-phase coded waveform provide a class of frequency derived phase coded waveforms that can be sampled on reception & processed digitally[6]. Poly-phase codes also address the reality of espionage threat as well as the Electronic attack threat. Programmability and variety are two code characteristics that makes espionage a more difficult task; thus, Poly-phase code will no doubt

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prove to be the LPI waveform of the following decades[7]. Size, cost, performance are the major parameters that are attractive in these Radar systems, because surreptitiously in presence of electronic intelligent system[8].

2.1. Basics strategies for Poly-phase hybrid codes

High data rates with fixed bandwidth is provided by Multi-level modulation techniques. Mathematically M-array phase shift keying (M-PSK) signal is given as

$$S(t) = \begin{cases} A\cos(2\pi fc\, t + \theta i + \theta' & 0 \le t \le T \\ 0 & \text{elsewhere} \end{cases} \quad (1)$$

where $\theta i = \frac{2\pi}{M} i$

for i=0, 1, 2, ...,M-1, A is constant, fc is carrier frequency, θ' is initial phase angle and T is symbol duration. Equation (1) can be expended as

$$S(t) = A\cos\theta i \cos(2\pi fc + \theta') - A\sin\theta i \sin(2\pi fc + \theta') \quad (2)$$

In this paper, Poly-phase signal i.e. Quaternary phase, Octal phase and 16 phase signals are used in pulse compression. To increase the bandwidth of PC signals, spread spectrum technique is used. In spread spectrum, the signal is spread over the multiple carrier frequencies and called poly-phase frequency hopping spread spectrum (poly-phase FHSS). The transmission of such poly-phase FHSS signal with Quaternary phase, Octal phase and 16 Phase becomes complex and difficult to process. Therefore poly-phase FHSS signal are encoded into the Bi-phase coded signals using gray code encoder.

2.2. Quaternary phase shift keying (QPSK)

A modulation technique that transmits two bits per symbol is QPSK. QPSK has twice the bandwidth than BPSK. Here two cases of QPSK i.e. QPSK with real-imaginary constellation and QPSK with complex constellation are considered based on the constellation diagram. The magnitude and symbols in constellation diagram is represents as In-phase and Quadrature phase in terms of sine wave and cosine wave. Mathematically represented as

$$S_{qpsk} = A\cos(2\pi fc + \emptyset(t)) + j\sin(2\pi fc + \emptyset(t)) \quad (3)$$

where $\emptyset(t)$ corresponds to one of the phases of four possible combinations 0, π/2, π, 3π/2. Equation (3) generates four symbols +1, +j, -1, -j for Real-imaginary magnitudes, each symbol transmits as two binary bits. Similarly for complex magnitudes carrier phases chosen as π /4, 3π /4, 5π /4, 7π /4.Table 1 and 2 gives the information of phases chosen, magnitude and corresponding gray encoded signals.

Table 1: Binary encoded codes for QPSK with Real-imaginary constellation

Information bit(Gray encoded)	QPSK Phase (Φ)	Magnitude
00	3π/2	-j
01	Π	-1
10	π/2	+j
11	0	+1

Table 2: Binary encoded codes for QPSK with complex constellation

Information bit(Gray encoded)	QPSK Phase (Φ)	Magnitude
00	5π/4	-0.7071-j0.7071
01	3π/4	-0.7071+j0.7071
10	π/4	0.7071+j0.7071
11	7π/4	0.7071-j0.7071

2.3. Octal phase shift keying (OPSK)

In OPSK, eight different phases are used with real-imaginary and complex magnitudes and these phases are encoded into three bit binary code. Carrier phases chosen as 0, π/4, π/2, 3π/4, π, 5π/4, 3π/2, 7π/2 for real-imaginary magnitudes. Similarly for complex magnitude, carrier phases chosen as π/12, π/6, π/3, 5π/12, 7π/12, 2π/3, 5π/6, 11π/12. Table 3 and 4 mentioned the different phase values and their magnitudes with Gray encoded codes.

Table 3: Binary encoded codes for OPSK with real-imaginary magnitudes

Information bit(Gray encoded)	OPSK Phase (Φ)	Magnitude
000	5π /4	-0.7071-j0.7071
001	π	-1
011	3π/4	-0.7071+j0.7071
010	π /2	j
110	π /4	0.7071+j0.7071
111	0	1
101	7π /4	0.7071-j0.7071
100	3π /2	-j

Table 4: Binary encoded codes for OPSK with real-imaginary magnitudes

Information bit(Gray encoded)	OPSK Phase (Φ)	Magnitude
000	2π /3	-0.5-j0.866
001	7π/12	-0.866-j0.5
011	5π/12	-0.866+j0.5
010	π /3	-0.5+j0.866
110	π /6	0.5+j0.866
111	π/12	0.866+j0.5
101	11π /12	0.866-j0.5
100	5 π /2	0.5-j0.866

2.4. 16-Amplitude phase shift keying (16-APSK)

16-APSK is a method of phase shift keying which encodes 4-binary bits at a time. In this work, 8 different phases used with two level of amplitudes as 1 and 3 . Carrier phases chosen for this method are 0, π /4, π /2, 3π /4, π, 5π /4, 3π /2, 7π /4.

Table 5: Binary encoded codes for 16-APSK with real-imaginary constellation

Information bit(Gray encoded)	16-APSK Phase (Φ)	Magnitude
0000	5π /4	-0.7071-j0.7071
0001	Π	-1
0011	3π/4	-0.7071+j0.7071
0010	π /2	j
0110	π /4	0.7071+j0.7071
0111	0	1
0101	7π /4	0.7071-j0.7071
0100	3π /2	-j
1100	13π/4	-2.1213-j2.1213
1001	3π	-3
1111	11π/4	-2.1213+j2.1213
1110	5π/2	3
1010	9π/4	2.1213+j2.1213
1101	2π	3j
1001	15π/4	2.1213-j2.1213
1000	14π/4	-3j

Table 6: Binary encoded codes for 16-APSK with complex constellation

Information bit(Gray encoded)	16-APSK Phase (Φ)	Magnitude
0000	π /8	-2.1213-j2.1213
0001	7π/8	-0.7071-j0.7071
0011	3π /4	-2.7714+j1.1478
0010	5π /8	-2.1213+j2.1213
0110	π /2	0.7071+j0.7071
0111	5π/8	-0.7071-j0.7071
0101	Π	-0.7071-j0.7071

0100	9 π /8	-1.1478-j2.7714
1100	7π/4	1.1478-j2.7714
1001	3π	2.7714-j1.1478
1111	4/π	0.7071+j0.7071
1110	3π/8	1.1478+j2.7717
1010	π/4	2.1213+j2.1213
1011	π/8	2.7714+j1.1478
1001	2π	2.1213-j2.1213
1000	15π/8	2.1213-j2.1213

3. Analysis of detection performance of LPI Radar

Detection performance of the Radar system can be defined by the parameters such as Discrimination factor, Figure of merit, Signal-to-Noise ratio, Merit factor. Hamming scan Algorithm[4], a traditional method to optimized method to optimize the performance of goodness, which search the neighbourhood of the points in all the directions to reduce the cost function and have fast convergence rate. In this paper, Optimization algorithm is proposed and applied in context of FHSS poly-phase signals by considering Discrimination factor as performance index[8].

3.1. Discrimination Factor(DF)

Discrimination factor is the ability to measure the quality of coded signal. High value of DF results a good code and a poor code results when DF will be of low value. It is defined as the ratio of main peak of autocorrelation function to the magnitude of peak side lobe value of autocorrelation function[4]. It given as

$$D = \frac{r(0)}{\max\limits_{k\neq 0}|r(k)|} \quad (4)$$

3.2. Design steps of algorithm and Flowchart

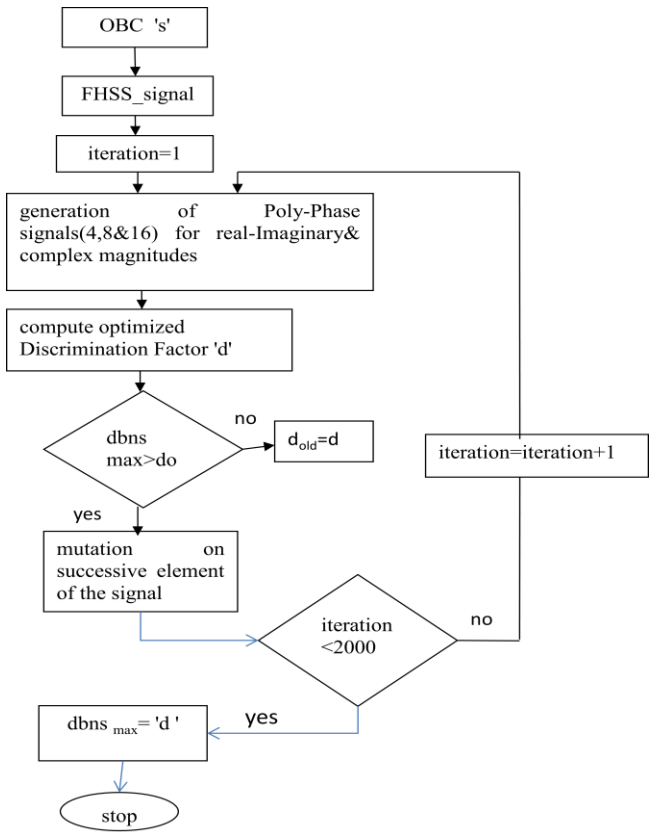


Fig. 1: Optimization algorithm for generation of Poly-phase signals and evaluation of detection performance of LPI Radar

Optimization algorithm is used to generate the poly-phase coded signals and evaluate the DF. To obtain good performance measure, poly-phase sequences should go through the optimization by considering Discrimination as requisite. The procedure used for generating the poly-phase coded signals is starts with choosing the optimized binary code (OBC) of length 'N'. A prescribed number 'W' called span and time slot 't' is considered. Different phases are chosen and perform the first level of modulation to generate the poly-phase coded signals of length '6N'. By choosing three carrier frequencies second level of modulation is performed by using the technique called as Frequency Hopping Spread Spectrum (FHSS).Among the three carrier frequencies, one of the carrier frequency is chose randomly and the modulated signal is spread over the entire band of frequency. This modulation generates poly-phase FHSS signal of length'6N'. Mutation is apply on neighbouring sequences in optimization algorithm to select the best sequence. If Optimization is succeed in improving the Discrimination Factor, the search can be resume. Finally poly-phase FHSS signal of length '6N' is encoded into bi-phase signal using Gray code encoder. The length of this signal is '12N'.

4. Performance evaluation of Poly-phase sequences.

To evaluate the noise performance, the poly-phase sequences, which are disturbed by Gaussian noise at different SNR (η) and standard deviation (σ) are considered. The detection performance of LPI Radar is evaluated under noisy condition by obtaining the optimized DF. In figure no. explains the effect of noise on the performance of LPI Radar. In this work, the optimized DF is evaluated at 0.3, 0.5, 0.7, 0.9, 1 values of standard deviation and noise level added -10dB, -15dB and -20dB. The effectiveness of the poly-phase signals on the detection performance has been improved with the increase in the standard deviation and noise level.

5. Results and discussion

Detection performance of PLI Radar has been evaluated using poly-phase coded waveforms. The analysis of poly-phase signals, in this paper QPSK, OPSK and 16-APSK schemes are discussed for two cases. One is with real-imaginary magnitudes and other with complex magnitudes of phase coded signals. From the simulation results it has been observed that phase coded signals with real-imaginary magnitudes have high discrimination factor and shown in the figure 3-8.Quaternary phase coded signal results in high discrimination factor as compared with the Octal phase code and 16 phase coded signals given in table 7. This table shows the comparison of DF for all the three phase coded signals with respect to D, D_{PSK}, $D_{bi\text{-}phas}$ and variation in D_{PSK} and $D_{bi\text{-}phas}$ (Δ). The percentage of variation in D_{PSK} and $D_{bi\text{-}phas}$ is increases with increase in phase values. The reason for the increase in variation is, in QPSK, 4 phase coded signal in converted into 2 phases (bi-phase signal) but in 8- phase and 16-phase coded signals, 8-phases and 16-phases are converted into bi-phase signals respectively. The observations shows that the detection performance of LPI Radar improved with increase in phase value for real-imaginary magnitudes with W=6 and t=3.16 phase coded signal is more noise affected signal and hence the performance of the Radar system using this waveform is degraded as compared with four phase and eight phase coded signals. Poly-phase code waveforms sampled at the receiver and process digitally. The detection effectiveness of phase coded signals with noise (σ and SNR) and with signal (without noise) are done and shown in figure 9-14.

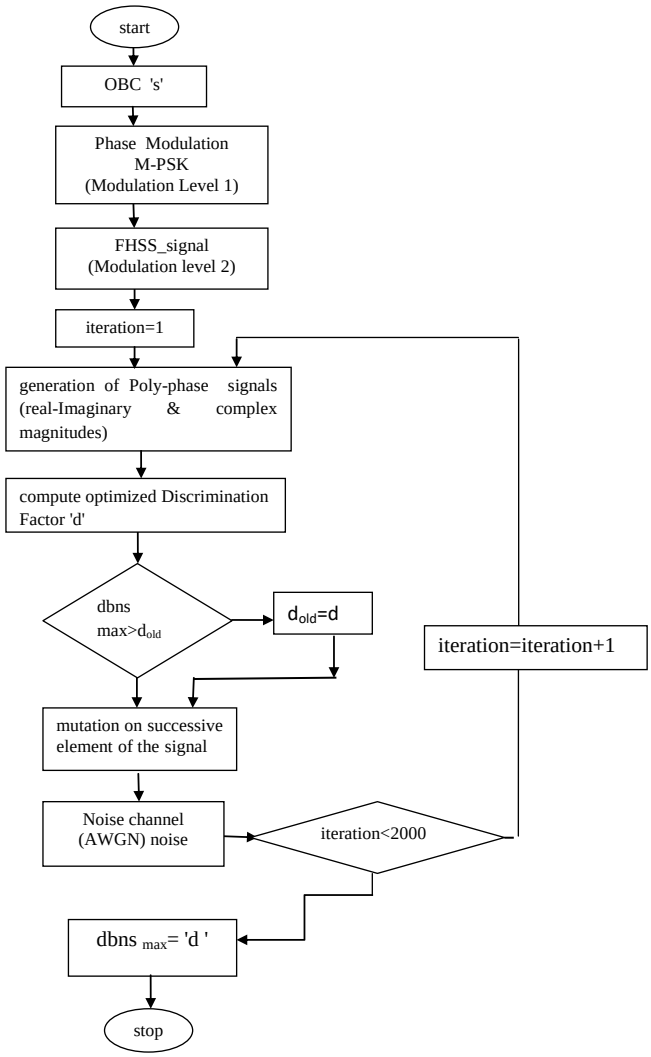


Fig. 2: Evaluation of detection performance of LPI Radar with noise

Table 7: Comparison for QPSK, OPSK and 16-APSK

DF	QPSK	8-PSK	16-APSK
D	18	7.66	10.57
D_{PSK}	12	6.16	9.1
$D_{bi\text{-}phase}$	6	1.49	1.46
$\Delta (D_{PSK} D_{bi\text{-}phase})$ %	33.33	60.96	72.28

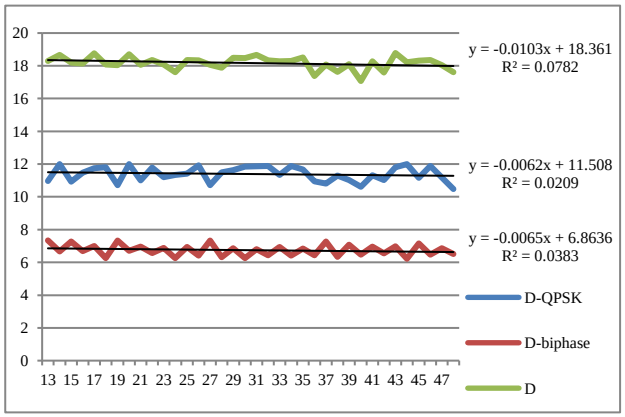


Fig. 3: DF for QPSK and binary encode signals for real-imaginary constellation

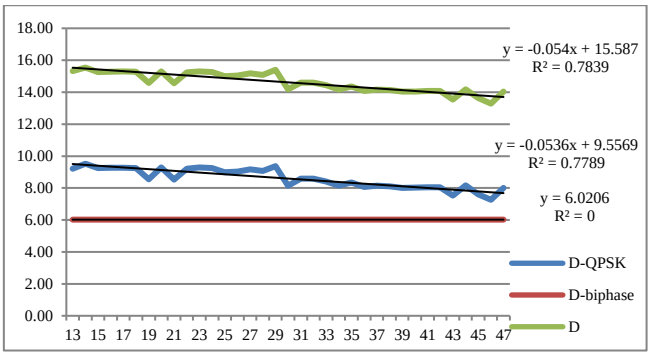


Fig 4: DF for QPSK and binary encoded signals for complex constellation

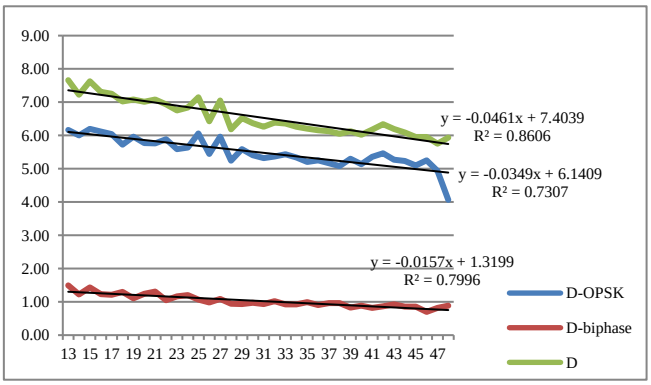


Fig. 5: DF for OPSK and binary encoded signals for real-imaginary constellation

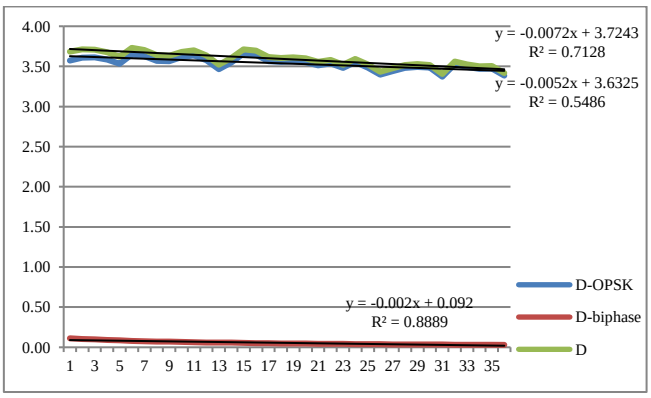


Fig. 6: DF for OPSK and binary encoded signals for complex constellation

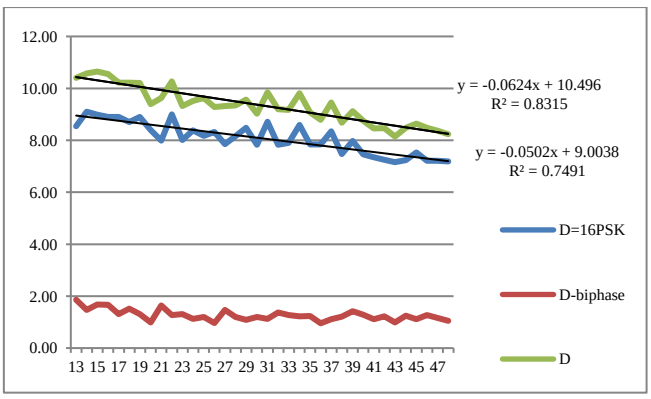


Fig. 7: DF for 16-APSK and binary encoded signals for real-imaginary constellation

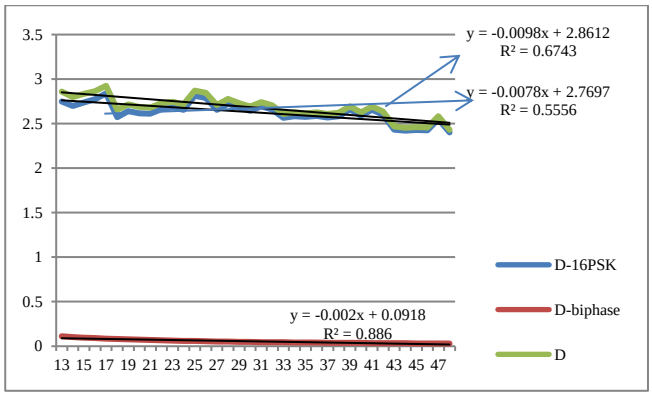


Fig.8: DF for 16-APSK and binary encoded signals for complex constellation

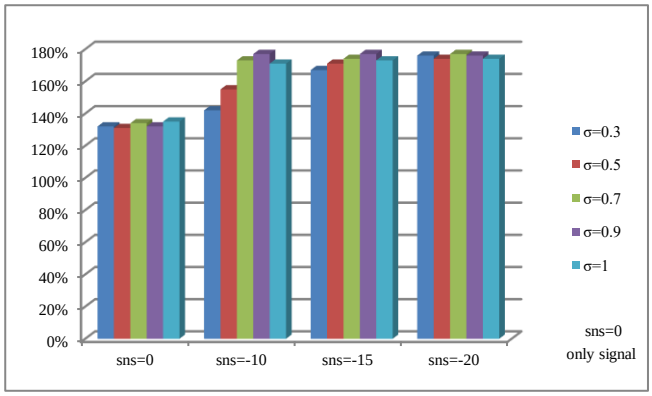


Fig.9: Detection effectiveness of QPSK for real-imaginary constellation

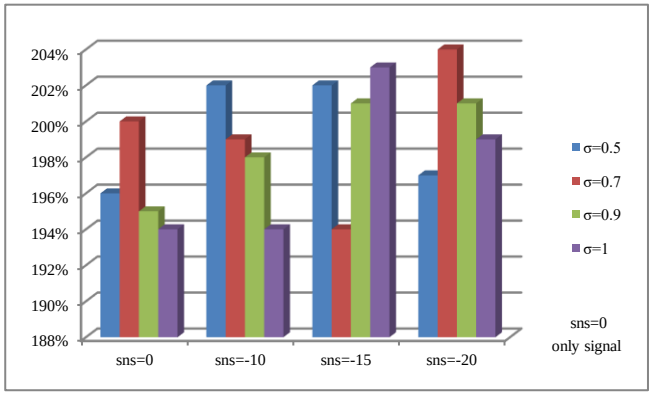


Fig.10: Detection effectiveness of QPSK for complex constellation

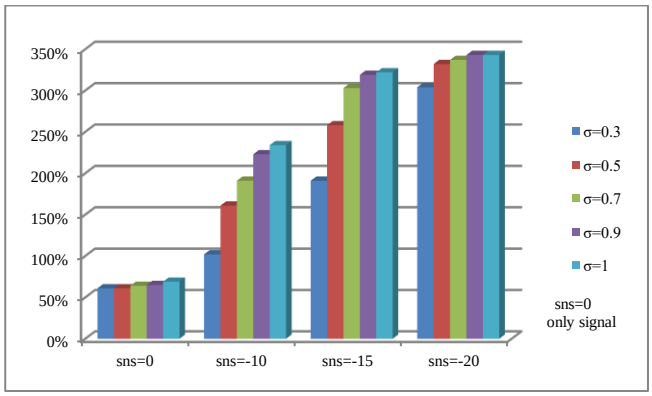


Fig.11: Detection effectiveness of OPSK for real-imaginary constellation

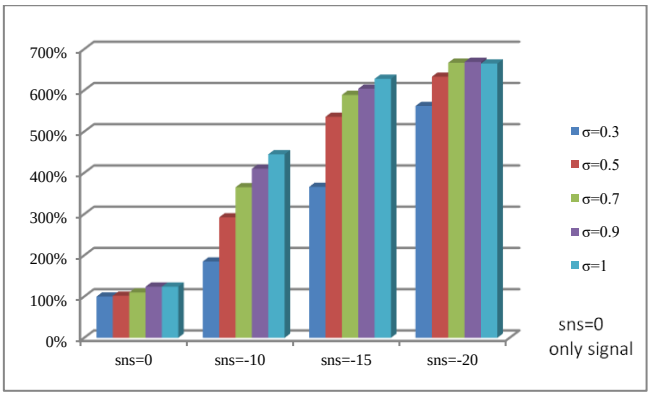


Fig.12: Detection effectiveness of OPSK for complex constellation

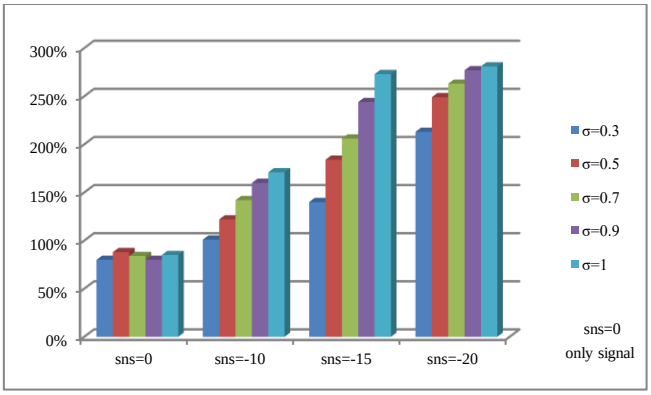


Fig.13: Detection effectiveness of 16-APSK for real-imaginary constellation

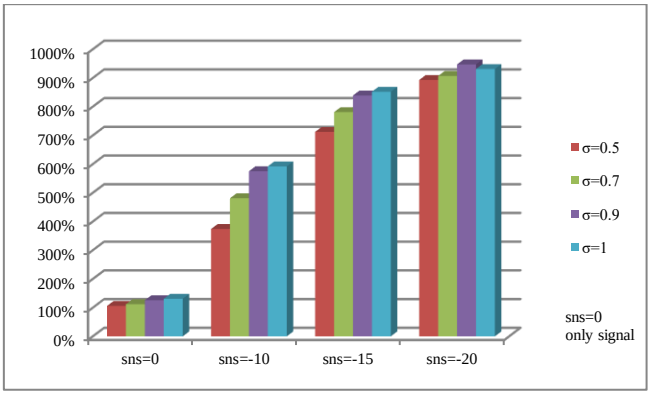


Fig.14: Detection effectiveness of 16-APSK for complex constellation

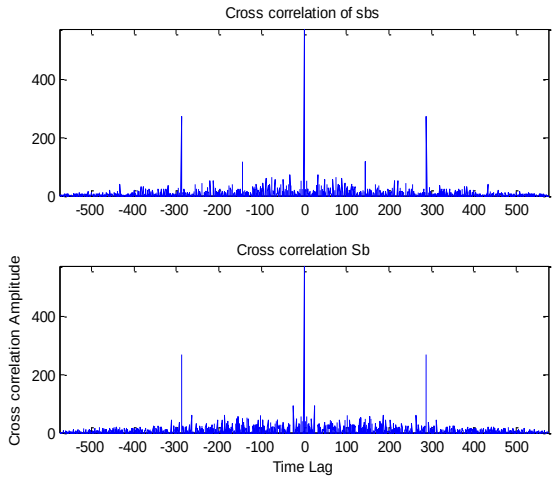


Fig.15: coincidence detection of LPI waveform

6. Conclusion

Three types of phase coded signals i.e. QPSK, OPSK and 16-APSK were considered in this paper. Pulse compression is one of the most effective technique used in Radar for signal processing. In LPI Radar, secrecy and good detection capability are the key characteristics. The Binary encoded signals magnitude is less than phase coded signal, in this work we observed binary encoded magnitude for real-imaginary constellation are 6.2, 0.93 and 0.95, where phase coded signal magnitudes are 12, 6 and 8 for QPSK, OPSK and 16-APSK respectively. In case of complex constellation, bi-phase signal magnitudes are 6.02, 0.03 and 0.033 where as 4-phase, 8-phase and 16-phase coded signal magnitudes are 10, 4 and 3 respectively. This result conclude that bi-phase signal which is embedded in phase coded signals have very less magnitude and hence cannot be detected easily. This provide a very high degree of secrecy in LPI radar. Also the detection effectiveness of the radar system is improved with increase in SNR -10dB, -15dB and -20dB and standard deviation σ = 0.3, 0.5, 0.7, 0.9, 1 as compared with the signal (sns=0dB). Other than signal to noise ratio, analysis of some important characteristics of LPI waveform can be done.

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