International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 2 (2018) pp. 1265-1273

Hybrid-PSK/FH (Bi-Alphabetic) waveform for Target Detection in High Resolution, K-Band LPI Radar System

Shaik Maznu
Associate Professor, Department of Electronics and Communication Engineering,
Vidya Jyothi Institute of Technology, Aziznagar, CB post, Hyderabad-75, Telangana State, India.

Dr. I.A. Pasha
Professor, Department of Electronics and Communication Engineering,
B.V.R.I.T, Narsapur, Medak Dist., Telangana State, India.

Dr. P. Chandrasekhar Reddy
Professor, Department of Electronics and Communication Engineering,
JNTUH College of Engineering, Hyderabad, Telangana State, India.

Abstract

The waveforms are specifically designed to make detection process very difficult. Such signals are called as low probability intercept (LPI) radar waveforms. The LPI antenna must use a transmit radiation pattern with low side lobes. One promising approach discussed in this paper is the employment of binary coded transformation of the ternary phase coded sequences generated as a result of spreading the spectrum of binary phase coded signatures. The transmission of binary encoded hybrid ternary spread spectrum signals with low side lobe autocorrelation properties reduce the possibility of interception and detection of the electronic warfare (EW) intercept receiver. This paper applies Hamming Back Track technique to generate hybrid binary-ternary frequency hopping (Hybrid-PSK/FH) spread spectrum for LPI to obtain improved range and Doppler resolution aiming through the framework of a coincidence detection strategy to detect the point targets. The higher order hybrid electromagnetic spread spectrum transmission virtually more invisible to conventional LPI radar waveform. We compared the performance of higher order PSK/FH codes in presence of varying SNR considering additive Gaussian noise.

Keywords: Peak to Side lobes Ratio (PSLR), High resolution, Doppler tolerance, integrated side lobe Level (ISL), coincident detection.

INTRODUCTION

In low probability of intercept (LPI) radar, the characteristics such as low power, larger bandwidth, other frequency hopping design parameters makes difficult to be searched by radar warning receiver (RWR). These special features are desirable due to detecting and tracking of an enemy target without alerting them to the radar's presence. More added characteristics keep the LPI radar find out by novel intercept receivers. Intercept receivers use variety of techniques to discover radars using angle of arrival, scan rate, bandwidth, carrier frequency, modulation period, and polarization etc., and LPI radar features pose a provocation to non-cooperative intercept receiver. In this paper we address the interception and analysis of radar signals, which includes the detection and estimation of LPI radar waveform parameters in a complex environment of high noise interference and Doppler considerations. Randomly changing one or many of these attributes can provide Uncertainty of the intercept receiver [1-2]. The correlated linear frequency waveform set design problems by optimizing these parameters for variant beam patterns. The existing beam pattern matching design methods have a principal problem that the resulted waveform is inconstant waveform and produced from a many alphabets, and thus the waveform cannot be cropped easily. LPI Radar uses continuous wave (CW), wide bandwidth low power signals of the order of few watts making its detection difficult [3]. The correlated LFM signal has few good attribute such as constant envelope, easy formation and fine Doppler tolerance [4-7]. A large pulse compression ratio that provides a wide band and low peak power used in LPI transmission in order to avoid interception by EW intercept receiver [8-9].

A desire sequence is the one with sharp sample-like autocorrelation. In mostly there are two major merits to calculate the resemblance of a sequence with sample: integrated side lobe level (ISL) and peak side lobes ratio (PSLR) [10-14]. To obtain long sequence with peaky autocorrelation is an optimization problem in the field of LPI radar signal design. Earlier research based on ternary sequence for conventional pulse compression radar results into improved performance in terms of achieving high PSL/merit factor (MF) [15-17]. The ternary sequence faces two problems [18]. First problem ternary sequence has low energy efficiency; The Second problem is difficult to have on-off switches at high power in comparison to phase shifting. To overcome these problems, the authors proposed a ternary sequence that can be coded into a binary sequence for transmission purpose [19-20]. In author [21] proposed a Non-linear frequency modulation (NLFM), better performance in terms of PSLR can be achieved by not masking a nearby target and to increase dynamic range. If an adding an approximate amplitude modulation, as occurs in Hybrid-NLFM (HNLFM), the PSLR reach very low values. In this paper A New Hybrid-PSK/FH waveform can be chosen for LPI transmission and thus bi-alphabetic Hybrid PSK/FH waveform pulse compression with good discrimination factor (DF) or PSLR and merit factor. This concept can be applied to the construction of new family of LPI radar signals.

This paper is organized as follow: The system model is described in section-II; The Hybrid-Code transformation is detailed in section-III; the coincidence detection using matched filter is given in a section-IV; Finally Discussions block diagram of Transmitter and receiver and simulation results given in a section-V.

SYSTEM MODEL

A. Binary Phase Shift (PSK) Signal

Increasing the number of elements or phase changes in the sequence allows the design of longer sequences, to result in a pulse compressed radar waveform with low time side lobes and higher range resolution waveform with greater processing gain in the receiver [9].The Binary phase shift signal with phase code, l= {-1, +1), the code (+1) indicate 0 phase and (-1) indicate π radians. Consider a CW radar waveform of Period T which is a train of 'V' equal length pulses with each pulse width t_b. In order to generate binary phase shift signal (PSK) consider a carrier frequency f_c, the sampling frequency f_s, the W number of code periods to generate, W samples of phases 0, π/2, π, 3π/2, 2π, and 5π/2 are the cycles per subcode. In this process, the sequence S (n) generated a randomly as a {11-1111 -11-11-1-1 11-11-11}. The resultant PSK signal is given by

$$B(t) = \sum_{n=1}^{v} S(n) * fc \quad (1)$$

B. Frequency Hop (FH) Spread Spectrum Signal

FSK radar using frequency hopping (FH) techniques hops or varies the transmitting frequency in time over wide bandwidth in order to prevent an un-wanted receiver from intercepting the waveform. The radar frequency slots are chosen from an FH sequence {f1, f_2 …f_{Nf}} of the available frequencies for transmission at a set of consecutive time intervals {t_1, t_2 … t_V}. This improves the radar processing gain. Each frequency is used random method based on good DF or PSL values of the sequence. Since the frequency sequence appears random to the intercept receiver, the possibility of following the varying in frequency is impossible. This prevents a jammer from reactively jamming the transmitted frequency. To generate FH spread signal, consider M carrier frequencies with W samples within the carrier cycle 2π, where M is integer. For the generation of carrier signal we consider the multiplicative group consisting of five phasors $\{w_5^n; n = 0,1,2,3,4,5; w_5 = \exp(\frac{j2\pi}{4})\}$; 0, π/2, π, 3π/2, 2π and 5π/2. The resultant FH signal is phase as ternary. The expression for frequency hop (FH) spread signal is done on random selection basis corresponding to the binary time-frequency matrix. The FH Spread signal is given by

$$\mathbf{P(t) =} \quad Ae^{j2\pi\, fj\, t} \quad (2)$$

The FH waveform has N_f random frequencies within a band B, with each frequency lasting time t_b s in duration. In FH spread signal, frequencies allocated has phase as ternary fj Є (+1, 0,-1) and P (t) of length N_t.

C. Hybrid Phase Coded Frequency Hop Spread Signal (Hybrid-PSK/FH)

In Hybrid-PSK/FH spread spectrum signal design the PSK signal B(t) of phases is multiplied with frequency hop Spread signal P(t) of phases. In this procedure the FH spread signal is modulated with BPSK signal i.e. each carrier frequency for allotment of FH spread signal which is relieved during a specific period of time is combined with BPSK. For this procedure with multiplicative group consisting of five phasors$\{w_5^k; k = 0,1,2,3,4,5; w_5 = \exp(\frac{j2\pi}{4})\}$; 0, π/2, π, 3π/2, 2π, 5π/2 considered for generation of carrier frequencies for FH signal such that the resultant signal phase as ternary. That ternary representation is modulated with BPSK to obtain mixed ternary representation. The ternary representation length is N_t. A correlation receiver with a phase mismatched reference signal is used to receive the echo wave of target instead of a perfectly phase matched reference. This allows radar to generate signals that can match targets spectral response in both magnitude and phase. The Combined Hybrid signal (BPSK coded FH spread spectrum signal) is given by

$$Q(t) = B(t)*P(t) \quad (3)$$

The ternary phases Q(t) is further encoded into binary phase sequence by using binary bigrams for the purpose of transmission, viz:+1→+1+1, -1→-1-1, 0→+1-1 or -1+1. The length of the binary bigram sequence Q (b) will be double the length of ternary representation ($2N_t$) when coded into binary bigrams i.e. is N_b. Hence the pulse compression ratio will increase. This gives confuse when electronic warning (EW) receiver attempts to characterize, classify and detect LPI radar transmitted waveform [1-2]. The transmitted Hybrid-PSK/FH signal is given by

$$S(t) = Ae^{j2\pi fjt+\Phi k} \quad (4)$$

Where Φ_k is one of N_b PSK code and f_j is the one of the N_f FH frequencies.

D. Design Algorithm of System Model

The notation for design algorithm of bi-alphabetic representations of ternary representations obtained from BPSK signal combined with FH spread signal is

$$\mathbf{Q(n) = [Q_0, Q_1, Q_2, \dots, Q_{r-2}, Q_{r-1}]} \quad (5)$$

N_t is the length of the combined ternary representation is taken as r, where the element Q_j is one of the alphabet [+1, 0, -1].

$$\rho(r) = \sum_{i=0}^{m-1-r} Q_i * Q_{i+r} \quad (6)$$

ρ (r) is called the aperiodic autocorrelation function of the ternary phases representation.

$$D = \frac{\rho(0)}{\mathrm{Max}|p(k)|k=0} \quad (7)$$

Where D is the DF or PSLR

$$\mathrm{ISL}=10\log(\frac{1}{M})\mathrm{dB} \quad (8)$$

$$M= \frac{\rho 2(0)}{\sum_{k=-r+1}^{r-1}\rho 2(k)} \quad (9)$$

Where ISL is integrated side lobe level

The matched filter output ρ (k), k = -r+1, -r+2 ….r-2, r-1, is the aperiodic autocorrelation can be represented mathematically as

$$\rho\ (k) = \frac{1}{M}\sum_{i=1}^{M-K} Qi\ Qi + k \quad k=-r+1,r+2,\ldots r-2,\ r-1 \quad (10)$$

The binary phase represented Hybrid-PSK/FH waveform obtained by binary bigrams method applies to ternary phase representations of Hybrid-PSK/FH spectrum signal which is a good DF or PSLR. Here $PSLR=PSLR_b+PSLR_t$ is taken as objective function, $PSLR_b$ is values of binary phase sequences and $PSLR_t$ is values of ternary phase sequences. When such a binary bigram is transmitted they can be subjected to bi-alphabetic representations at the receiver. The proposed Hamming Scan (HS), Hamming Back Track (HBT) and Degree Of Freedom (DOF) algorithms are used to design an optimized ternary-binary alphabetic representation of hybrid BPSK/FH signal. In [19] authors proposed Hybrid-Nonlinear Frequency Modulation (HNLFM), the PSLR or DF can reach very low values (e.g., PSLR< -60dB) with increasing length. The proposed Hybrid-PSK/FH waveform would be performing well in increasing length and more noise environment. The PSLR or DF values of Hybrid-Nonlinear frequency modulation (HNLFM) and Hybrid-BPSK/FH waveform, as shown in Table 1&2 and Figure 1&2. In Hybrid-PSK/FH waveform got good PSLR values for increasing compression ratio. Because, we applied HS and selective HBT algorithm to PSK and FH spread signal to generated good ternary phased waveform. Further these ternary phases are converted to binary phases with the help of binary bigram method and its length become double. This intra pulse modulated code with doubling of length and good PSLR or DF values is selected based on DOF algorithm. In this way we achieved good PSLR or DF values of proposed Hybrid-PSK/FH waveform. The optimized ternary-binary alphabetic representations are good PSLR/ Merit Factor (MF) in an additive white Gaussian noise (AWGN) environment, SNR and high resolution with Doppler environment of LPI Radar. The ternary-binary alphabetic sequence attains good PSLR values at increasing length, various SNR and noise standard deviation (N_{sd}). Due to AWGN channel PSK coded FH spread spectrum waveform converted to ternary phase coded FH spread spectrum waveform. In poly-gram reading, it can also be represented as binary ternary representation. These two sequences are notation ally transmitted and received. They can be processed separately at the receiver to set up coincidence detection.

Table 1. Effect of the compression ratio on the peak-to-sidelobes ratio (PSLR), HNLFM (optimum and sub-optimum) and Millet signals.

Length of the compression ratio	HNLFM optimum DF or PSLR (dB)	HNLFM sub-optimum DF or PSLR (dB)	Millett waveform DF or PSLR (dB)
32	-30	-30	-25
64	-50	-50	-28
128	-75	-65	-30
256	-80	-63	-32
512	-82	-62	-33
1024	-85	-60	-34

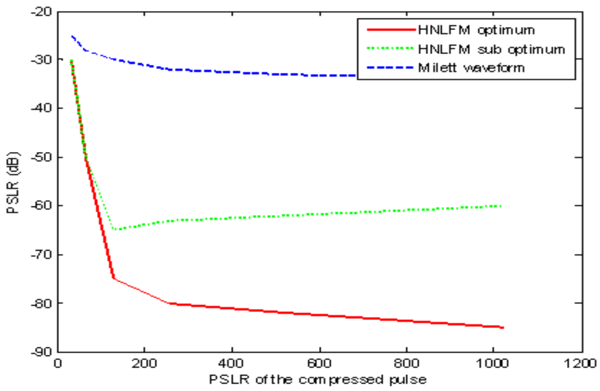

Figure 1. Effect of the compression ratio on the peak-to-side lobes ratio (PSLR), HNLFM (optimum and sub-optimum) and Millet signals.

Table 2. Sum of DF values of bi-alphabetic representations using HBT Algorithm with degree of freedom.

Discrimination Factor (DF)values			
Length of Ternary phasesN_t	DF values of Ternary phases d_t(dB)	DF values of Binary phases d_b(dB)	Sum of DF values(Object function)$d=d_b+d_t$(dB)
180	18.38	21.025	39.4
240	18.73	20.59	40.02
300	20.06	20.12	40.184
360	20.43	19.62	40.02
420	20.512	19.763	40.215
480	21.6028	19.8727	41.42
540	21.786	20.3103	42.29
600	22.29	20.7143	42.71
660	22.55	20.5462	43.47
720	22.994	20.96	43.8

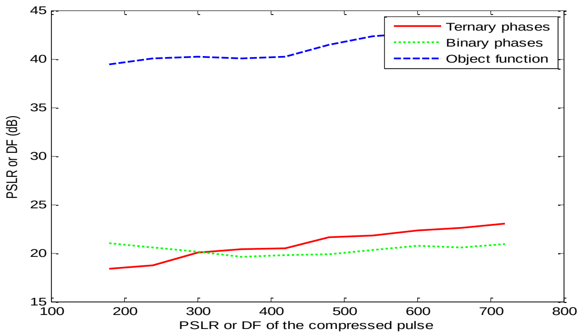

Figure 2. Effect of the compression ratio on the peak-to side lobes ratio (PSLR) of Hybrid-PSK/FH waveform.

HYBRID CODE TRANSFORMATION

In the Hybrid-PSK/FH signal, the FH signal phases (+1, 0, -1) modulated with PSK signal phases (+1, -1). The combined signal may be (-1, 0, +1) or (+1, 0, -1). The element +1 in the ternary representation can be encoded as +1 +1 , the element -1 can be encoded as -1 -1 and the element 0 can be encoded as +1 -1 or -1 +1 by the binary bigram method . This increase in length of the sequence helps in achieving larger pulse compression ratios in LPI radar transmission. Such LPI radar transmitted waveform will be difficult to characterize by the EW intercept receiver [3]. The signal design for LPI radar, the ternary representations obtained during binary phase coded sequence combined with frequency hop spread signal will be utilized to improve PSLR values of LPI radar. When such a ternary-binary, bi-alphabetic representation is subjected to hamming scan (HS) for recursive search, the sum of the discrimination factors $d=d_t+d_b$ can be considered as an objective function to maximize. Here d_t is the DF or PSLR of ternary representation obtained from Hybrid-PSK/FH spread spectrum signal and d_b is the DF or PSL of binary bigrams.

The ternary representation Q (t) is substituted by binary-bigram to obtain Q (b). This is equivalent to two representations with good autocorrelation properties being transmitted in the form of Q (b). At the transmitter we designed phases of the hybrid waveform with the consideration of AWGN channel. While designing we adopted HS algorithms for optimization. On the receiver, the detection of LPI waveform is very difficult process [1-2]. The matched filter's (MF) is optimal when complete knowledge of the signal's parameters is available, resulting they received waveform is maximize the SNR of received noisy waveform. Further improve detection process Author's [16-19] proposed the bi-alphabetic signals with coincide detection by MF. The decoded waveform R(t) is cross correlated at the receiver with pre deigned phased waveforms Q (t) and Q (b). The cross correlated coincident detection values of different levels of noise are shown in table. The cross correlated coincident values of DF or PSLR is decreasing for increasing levels of noise, but new Hybrid-PSK/FH signal improved the performance in a low SNR and larger noise strength standard deviation. When AWGN noise perturbed to Hybrid-PSK/FH signal, the phases differ with the transmitted waveform at the matched filter receiver. In a new Hybrid-PSK/FH signal we designed consideration of noise channel with the help of HS and DOF algorithm. In that process we achieved matched phases with transmitted waveform at the matched filter coincidence receiver. The DF or PSL values increases as increase length of the representations. The coincidence detection of ternary binary phase waveforms plots for various SNR with sub-pulse delays apart (SPDA) are shown in figures.

COINCIDENCE DETECTION FOR LPI RADAR

A K-band 25GHz LPI radar is considered for transmitting an degree of freedom (DOF) code length 1440 of Hybrid-PSK/FH waveform with pulse interval of 0.5µs. The sub-pulse time interval τ is 0.3ns (signal band width 3.33GHz) and range resolution is 4.5cm. At the receiver the resultant waveform is multiply interpreted as binary and ternary phase coded Hybrid-PSK/FH waveform. The bi-alphabetic phase's sequences are simultaneously processed through the two digital matched filters and absolute values of output waveforms are taken for coincidence detection. Figures 4 to 8 shows that the output waveforms of bi-alphabetic binary and ternary phases of Hybrid-PSK/FH waveforms when two targets are at 18 SPDA and noise strength, N_{sd}=0.9, SNR=-5,-3,0,3 &5dB. Loss in peak values of target occurs due to multiple cross correlation peaks appears in the waveform at targets time lag. Table.1and 2 shows that the amplitude levels of cross correlation peaks of binary and ternary phases of length 1200 and 600 respectively, when two targets are at different SPDA in Gaussian white noise environment and with and without Doppler environment.

DISCUSSIONS

As the length of the sequence and number of frequencies increases we found that the PSLR values are increases as shown in Figure 2. The increase of PSLR values is due to the increases of spread spectrum and increase of intra pulse modulation. So that more random frequencies are generated. As the randomness of spread spectrum increases the PSLR values are improved. In order to improve PSLR values we applied one more technique is that apply Hamming scan (HS) algorithm to randomly generated frequency hopped (FH) signal. So that we selecting random frequencies with good PSLR values of FH spread spectrum, in that order it become a sub optimal of FH spread spectrum signal.

There are two cases one for waveform design for LPI radar for transmission at the transmitter end as shown in Figure 2. The second case is waveform detection of LPI radar at the receiver as shown in Figure 2. In that procedure we consider an optimized binary signal and then combined the carrier frequencies are encoded with ternary phases (+1, 0, -1). So that the combined Hybrid-PSK/FH spread signal encoded as ternary phases. These ternary phases are encoded into binary phases with double length. The ternary phases of length N_t, and then the encoded binary phases of length would be $2N_t$. In the optimization procedure of a signal is based on the mutation in the original binary signal so that the PSLR values of ternary as well as binary signal is optimized, like that optimized waveform is designed for LPI radar. In that process we observed that the ternary phases have the more PSLR values than the binary as shown in table.3, because the established phases of the hybrid waveform is ternary. At the transmitter end we transmitted is binary phase encoded Hybrid-PSK/FH waveform of length $2N_t$. There are two advantages here, first one is we are transmitting binary sequence so that these phased waveform has good energy efficiency compared to ternary phased waveform, because in ternary phases along with +1 and -1 there is '0'. Second one is we are transmitting binary phased waveform with double length of ternary phased waveform. This is nothing but widening of the spread spectrum signal so that there by suppressing the power that is the basic requirement of LPI radar. Another advantage is that we are transmitting sub optimal binary phase coded waveform length 2N, which is low PSLR, but binary phase coded waveform itself ternary phase coded waveform with good PSLR values. At the receiver we receiving binary phase coded waveform and we are processing the binary phase coded waveform as we received and we also extracting ternary phase coded waveform from binary phase coded waveform i.e. the binary phases of +1 +1 is decoded to +1, -1-1 is decoded to -1 and +1-1is decoded to 0. Then we processing ternary phase coded waveform separately that means as if we are hiding the ternary phase coded waveform within the binary phase coded waveform for the purpose of transmission. At the receiver we are taking out the ternary phase coded waveform of good PSL for the purpose of detection. This is the advantage in a waveform design. Figure 4 shows that the results obtained by maximizing the objective function PSLR of bi-alphabetic phase sequence of HBT and DOF phase codes when coincidence detection at different SNR and noise standard deviation. This optimized phase coded waveform has been applied at transmitter end for detecting two targets at 18 SPDA, N_{sd}=0.9 & SNR=-3,-5, 0 and 3dB as shown in Figure 5 to 8. At the larger SNR the peak level from two targets are more compare to low SNR because protection of phase coefficient of hybrid BPSK/FH waveform at matched filter coincident detector. Ternary phase sequences have with PSLR values (20.4dB at length 360 and 23.26dB at length 760) compared to binary phase sequence (19dB and 20.5dB). At higher lengths ISL is less (2.6dB) for ternary phase sequence compared to binary (2.8dB). It is noticed that, at higher lengths there is a small variation of PSLR/ISL values compared to PSLR/ISL values at lower length. Figure 4 shows that in noise and Doppler free environment, when there is only one target, output yields high PSLR values (40.06dB at length 360 and 44dB at length 720 and low ISL values (6.7dB at length 360 and 4.88dB at length 720), but when two targets are very near at 6SPDA, PSLR values degrade to 33.8dB and 37.55dB, respectively and ISL values increase to an average value of 8.5dB.

In Table 3and 4 shows that the cross correlation peak values of binary and ternary phase sequences at varies SPDA, SNR, noise strength and Doppler. Displayed the cross correlation peak values ternary and binary phase sequences at length 600 and 1200 respectively. If the distance between the two targets increases, the peak values increases. Figure 5 to 8 shows that the basic idea of coincidence detection at various SNR, noise strength, Doppler and at SPDA=18. The cross correlation peaks in the waveforms concurrently indicate the presence of targets. The target is detected if any two cross correlation peaks in the waveform are synchronized. The side lobes do not concur in the two waveforms. It is also observed that the amplitude levels of the side lobe are smaller than the amplitude levels of cross correlation peaks in the waveform. The binary phase sequences has larger peak values compared to ternary due to double length of binary phase sequences.

CONCLUSION

There are two things done: one is waveform design for LPI at the transmitter end and second case is waveform detection of the LPI at the receiver. At the transmitted end we generated ternary phase Hybrid-PSK/FH waveform with good PSLR values at length 1440 is 20.74dB. This ternary phase code is encoded into binary phase with length double than the ternary phase code and its PSLR value of 23dB. There are two advantages here: one is we are transmitting binary phase sequence with double length so that its energy efficiency is good, second one is widening the length so that suppressing the power this is basic requirement of LPI. At the receiver we receiving binary phase coded waveform and we are processing the binary phase coded waveform as we received and we are also extracting ternary phase coded waveform with good PSLR from binary phase coded waveform. The coincidence detection scheme resulted with significant improvement in the performance of pulse compression system and target detection in the presence of multiple targets with Doppler shift and noisy environment.

Table 3. Details of cross correlation peaks of binary and ternary phase sequence of length 1200 and 600 respectively, when two targets are at different SPDA with and without noise.

Position of two targets	SPDA=6 Peak value(dB), I target/ II target	SPDA=12 Peak value(dB), I target/ II target	SPDA=18 Peak value(dB), I target/ II target
SNR=0dB			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.09	28.09/27.51
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.65/27.55	28.02/27.99	28.09/27.59
ternary	21.81/21.81	21.66/21.64	21.7/21.65
N_{sd}=0.6;binary	27.53/27	27.67/27.3	27.5/27
ternary	21.8/21.55	21.39/21.2	21.7/21.6
SNR=3dB			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.06	28.09/27.59
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.82/27.7	28.05/28.01	28.01/27.4
ternary	21.87/21.7	21.78/21.7	21.78/21.65
N_{sd}=0.6;binary	27.6/27.4	27.83/27.38	27.9/27.13
ternary	21.9/21.58	21.5/21.25	21.5/21.32
SNR=6dB			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.09	28.09/27.59
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.83/27.74	28.09/28.09	27.9/27.13
ternary	21.93/21.93	21.76/21.7	21.5/21.2
N_{sd}=0.6;binary	27.77/27.6	28/27.6	28.08/27.3
ternary	21.9/21.63	21.7/21.4	21.4/21.16

Table 4. Details of cross correlation peaks of binary phase sequence and ternary of length 1200 and 600 respectively, when two targets are at different SPDA with noise and Doppler.

Position of two targets	SPDA=6 Peak value(dB), I target/ II target	SPDA=12 Peak value(dB), I target/ II target	SPDA=18 Peak value(dB), I target/ II target
SNR=0dB;fd=10			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.09	28.09/27.51
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.81/27.6	28.0/27.95	28.0/27.25
ternary	21.81/21.81	21.64/21.64	21.7/21.65
N_{sd}=0.6;binary	27.47/27	27.67/27.3	27.41/27
ternary	21.73/21.13	21.39/21.2	21.7/21.6
SNR=3dB;fd=10			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.06	28.09/27.51
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.82/27.69	28.05/28.0	28.01/27.4
ternary	21.87/21.7	21.73/21.7	21.78/21.65
N_{sd}=0.6;binary	27.6/27.4	27.67/27.35	27.74/27.13
ternary	21.9/21.58	21.5/21.25	21.5/21.32
SNR=6dB;fd=10			
N_{sd}=0.0;binary	27.84/27.73	28.09/28.09	28.09/27.51
ternary	21.93/21.93	21.76/21.76	21.81/21.81
N_{sd}=0.3;binary	27.83/27.74	28.09/28.04	27.9/27.13
ternary	21.93/21.93	21.76/21.7	21.5/21.2
N_{sd}=0.6;binary	27.75/27.5	28/27.6	27.98/27.3
ternary	21.9/21.63	21.68/21.4	21.4/21.16

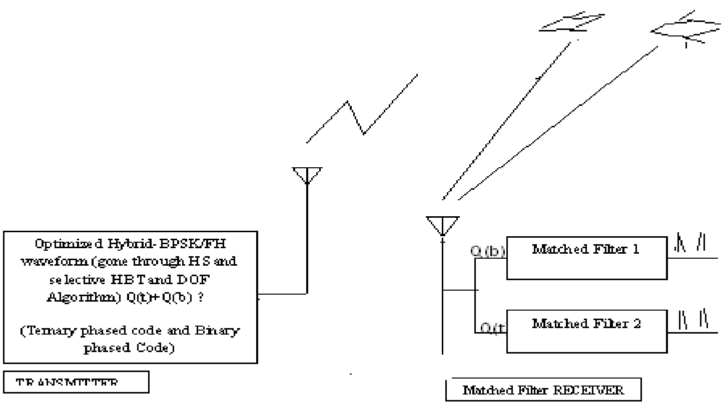

Figure 3. Block diagram of Transmitter and Receiver

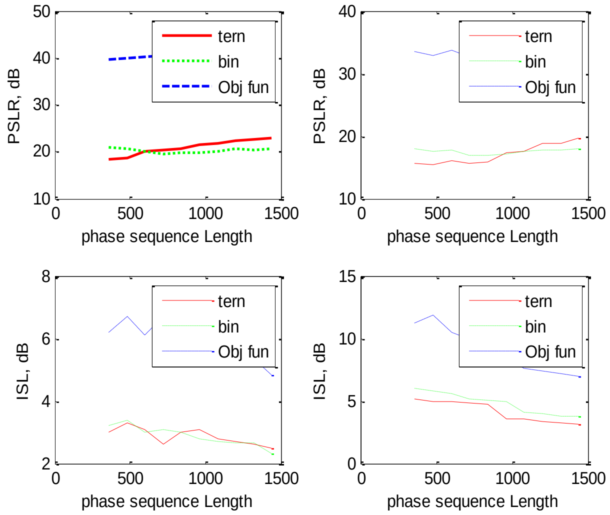

Figure 4. Variations of PSL and ISL for bi-alphabetic phase sequences when single target (0 SPDA) without noise and Doppler and when two targets are at 6SPDA with noise N_{sd}=0.6, SNR=0dB and Doppler fd=10

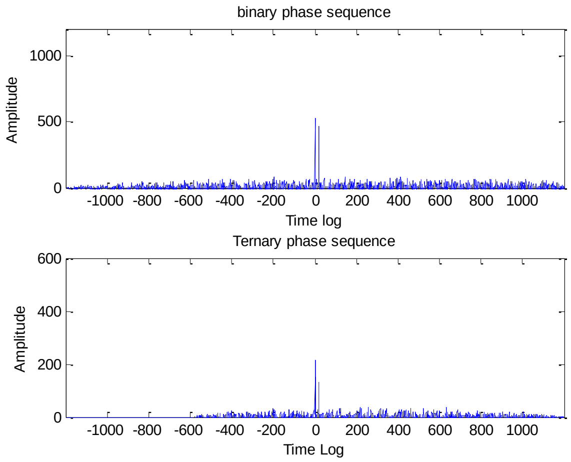

Figure.5. Output waveforms of coincidence detection when two targets at 18 SPDA, SNR=0, N_{sd}=0.9 and fd=10

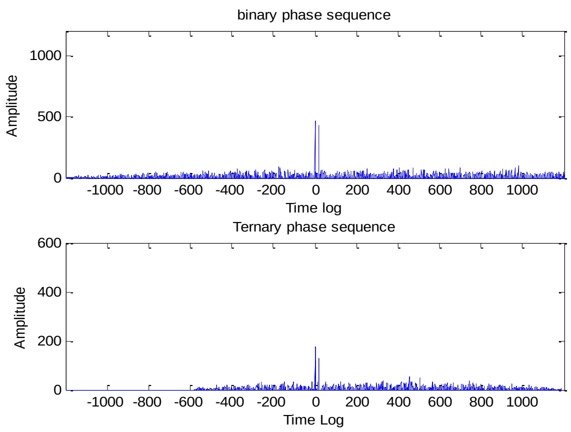

Figure. 6. Output waveforms of coincidence detection when two targets at 18 SPDA, SNR=-3dB, N_{sd}=0.9 and fd=10

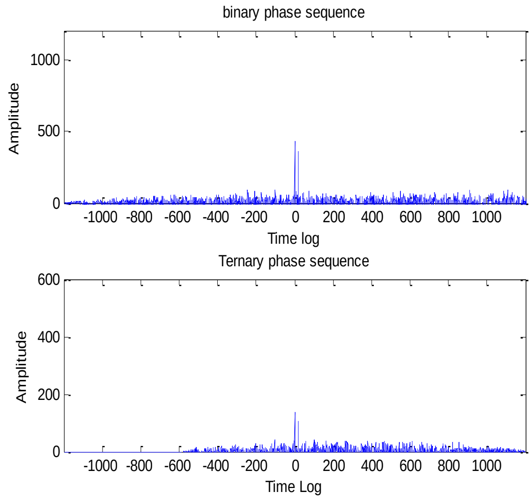

Figure. 7. Output wave forms of coincidence detection when two targets at 18 SPDA, SNR=-5dB, N_{sd}=0.9 and fd=10

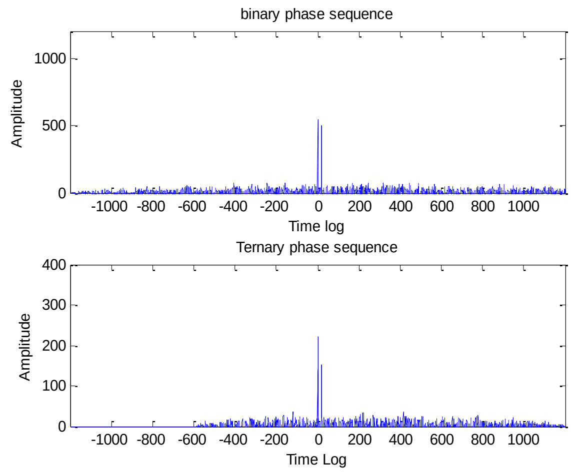

Figure 8. Output waveforms of coincidence detection when two targets at 18 SPDA, SNR=3dB, N_{sd}=0.9 and fd=10

REFERENCES

[1] F.Taboada, P.E.Pace et al: “Intercept receiver signal processing techniques to detect low probability of Intercept radar signals”, Center for joint Services EW, Naval Postgraduate School, CA

[2] Phillip E.Pace., 2003, “Detecting and Classifying LPI Radar”, Artech House, Norwood,

[3] AK Singh, Dr. K. Subba Rao., 2012, “Detection, Identification & Classifying of intra pulse modulated LPI Radar Signal Using Digital Receiver”. International Journal of Emerging Technology and Advanced Engineering, 2(9).

[4] Hui Li, Yongbo Zhao, Zengfei Cheng, and Dazheng Feng., 2016, “Correlated LFM Waveform Set Design for MIMO Radar Transmit Beampattern” , *IEEE Trans. Geosci. Remote Sens.*

[5] W.-Q.Wang., 2015, “MIMO SAR OFDM chirp

waveform diversity design with random matrix modulation", *IEEE Trans. Geosci. Remote Sens,* vol. 53, No. 3, pp. 1615–1625.

[6] C. Y. Chen and P. P. Vaidyanathan., 2008 , "MIMO radar ambiguity properties and optimization using frequency-hopping waveforms" ,*IEEE Trans. Signal Process.*, vol. 56, no. 12, pp. 5926–5936.

[7] G. Hua and S. S. Abeysekera., 2015, "Robust transmit beam pattern design for uniform linear arrays using correlated LFM waveforms" , in *Proc. IEEE Int. Conf. Acoust., Speech Signal Process,* pp.2504–2508.

[8] Daniele Angelosante, Georgios B. Giannakis, Nicholas D.Sidiropoulos., 2010, "Estimating Multiple Frequency-Hopping Signal Parameters via Sparse Linear Regression", IEEE Transactions on Signal Processing, 58 (10).

[9] S. Bourguignon, H. Carfantan, and J. Idier., 2007, "A sparsity-based Method for the estimation of spectral lines from irregularly sampled data", IEEE J. Sel. Topics Signal Process, 1 (4), pp. 575–585.

[10] Alexander Haimovich, Rick Blum, and Leonard Cimini., 2008, "MIMO Radar with Widely Separated Antennas. IEEE Signal Processing Magazine, 25(1), pp.116–129.

[11] He Hao, P Stoica, and Li Jian., 2009, "Designing Unimodular Sequence Sets With Good Correlations; Including an Application to MIMO Radar", IEEE Transactions on Signal Processing, 57(11), pp.4391–4405.

[12] Junxiao Song, Prabhu Babu, and Daniel P Palomar., 2015, "Sequence Design toMinimize the Weighted Integrated and Peak Sidelobe Levels", Accepted in IEEE Trans. on Signal Processing,.

[13] Junxiao Song, Prabhu Babu, and Daniel P Palomar., 2016, "Sequence set design with good correlation properties via majorization- minimization", IEEE Transactions on Signal Processing, 64(11), pp.2866–2879.

[14] Petre Stoica, Hao He, and Jian Li., 2009, "New algorithms for designing unimodular sequences with good correlation properties". IEEETransactions on Signal Processing, 57(4), pp.1415–1425.

[15] Krishnan, S. and Rangayyan, R. M., 1997, "Detection Of chirp and other components in the time-frequency plane using the Hough and Radon transforms", In Proceedings of the IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, 1, pp. 138—141.

[16] Moharir P S, Maru V M, Singh R., 1996 "S-K-H algorithm for signal design", Electron Lett, 32, pp.1648-1649.

[17] R.A Romero, J.Base and N.A Goodman., 2011, " Theory end applications of SNR and mutual information matched illumination waveform" , IEEE Trans. On Aerospace and Electronic Systems, Vol.47, no.2, pp.912-926.

[18] Moharir P S, Subbarao K., 1997, "Non binary Sequences with superior merit factors", IETE J. Res. 1, pp.49-53,

[19] Moharir P S, Maru V M, Singh R., 1998, "Simonization for signal Design", Sadhana, 23, pp. 351-358.

[20] Shaik Mazunu, I.A.Pasha, P.Chandra sekhar Reddy., 2014, "Phase Coded Hybrid Waveform Design for LPI Radar", IJRTET, 11, pp. 75-82 .

[21] Gaspare Galati, Gabriele Pavan, Francesco De Palo., 2017, " Chirp Signals and Noisy Waveforms for solid-state Surveillance Radars". Aerospace 2017, 4, 15.