TARGET DETECTION

IN LOW ENR

By

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In the name of Allah, the most Merciful and the most Beneficent

ABSTRACT

MULTIPLE TARGET DETECTION IN LOW ENR

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The problem of detection and identification of multiple low observable targets in a heavily cluttered environment is the primary focus of this thesis. The work deals with a novel approach for detecting multiple targets i.e. use of higher order statistics for pattern recognition of a possible target. Pulsed radar transmits short burst of electromagnetic energy, in the form of coded sequence after which the receiver is turned on to listen for the echo. . The echo not only indicates that a target is present, but the time that elapses between the transmission of the pulse and the receipt of the echo is a measure of the distance to the target and relative frequency difference between the transmitted echo and received echo is a measure of the Doppler information of the target. In the highly noisy environment, the radar signals are much attenuated when they reach the target and return to the receiver. Secondly in case of close multiple targets side lobes of stronger target affects the detection of weaker target.Thirdly if the length of the coded sequence is small ,then the range resolution of the targets becomes coarse. Complementary-coded pulse radar may be a solution in the sense that it transmits complementary-coded pulses and compresses the received pulses so that highly effective transmitted power, fine-range resolution, and low sidelobes level can be achieved simultaneously.

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Chapter 1

INTRODUCTION

1.1 Background

The basic function of a radar is to detect and to find out range of the target . A train of modulated pulses is transmitted in a specified direction .From the recived reflected pulse the range is found out. Phase coding basically helps to increase the range resolution but is also helpful in to avoid jamming of the radar.

Target detection involves estimation of the time of arrival of received pulse as well as the Doppler shift in the transmitted frequency.The estimate of the time of arrival is used to estimate the distance of the target and Doppler shift estimate is used for estimating the speed of the target.

1.2 Overview of the Thesis

This Thesis is organized into eight chapters. Chapter 2 discusses the need of pulse compression and matched filtering. Pulse compression is a process required to increase the range resolution of the target. This is achived by transmitting a coded pulse and at the receiver matched filtering of it.

Chapter 3 presents the basics of golay codes also known as complementary codes. Complementary codes are used basically for achieving no side lobes after the compression process. This property of these codes is of great significance if the scenario is of low ENR

In chapter 4 higher order statistics is studeied. Higher order statistics of a Gaussian signal do not possess any information in them. 4^{th} order cumulant of a Gaussian signal is zero if the signal length is of infinite length. This property of Gaussian signal is exploited in this thesis. Chapter 5 describes the main problem of the thesis I.e. multi target detection in low ENR . After the pulse compression sides lobe arrive which also affect the detection process . Due to the side lobes some times false alarm arrives and some times false dismissal occur.

In chapter 6 compression results are studied for different coding techniques and for different energy to noise ratios. Comparisons are also made for single and multi target scenarios.

Chapter 7 discusses the problem of moving targets. In moving target environments compression results behave in different manners. In this chapter performance of golay codes is discussed.Chapter 8 concludes the thesis and recommends for the future work.

Chapter 2

PULSE COMPRESSION AND MATCHED FILTERING

Time delay estimation (TDE) or time of arrival (TOA) is a basic tool in statistical signal processing. Applications of TDE follow from the simple relationship given by

$$R = v * t / 2$$

where

R, is the distance of the object,

v, the velocity of the wavefield sent to the object, and

t, time taken for the wave to reach the object .

For example, in range measurements for radar or sonar, v is assumed known and the targets' range is determined by measuring t , the time required for the transmitted signal to propagate to a target and be reflected back to point of transmission. Also for velocity measurements, like in biomedical or nuclear engineering applications, where R is assumed known and t the time required for a signal to travel the distance , R is measured.

$x_1(t)$ and $x_2(t)$ correspond to the transmitted and received signals, respectively, it is apt to assume that $n_1(t) = 0$ and that s(t) is a known deterministic signal. It is well known that for the nominal active scenario where $n_2(t)$ is a realization of a white, Gaussian random process, the (asymptotically optimum) maximum likelihood time delay estimation (ML TDE) processor is the matched filter, which cross correlates $x_1(t)$ and $x_2(t)$. The estimate t'' is the time that corresponds to the maximum of the matched filter output.

2.1Radar overview

An elementary form of radar consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator, a receiving antenna, and an energy detecting device or receiver. A portion of the transmitted signal is intercepted by a target, and reflected in all directions. The energy that is re-radiated in the direction of the radar is of prime importance. The receiving antenna collects the returned energy and delivers it to the receiver, where it is processed to detect the presence of a target and to determine its position and its relative velocity. The distance of the target is determined by measuring the time taken for the signal to travel to the target and back. The direction, or angular position, of the target may be determined by the direction of arrival of the reflected wave-front.

The most common radar waveform is a train of narrow rectangular shaped pulses modulating a sine wave carrier. The distance is measured as a function of the time taken by the transmitting pulse to travel to the target and back. Since electromagnetic waves travel at the velocity of light, the distance is given by

$R = c\ T/2$

where

R is the range of the target,

T is the time take by the Tx pulse to travel to target and return,

c is the velocity of the radar signal in space.

2.2. Radar Receiver Operations

Broadly the Radar problem can be given as:

- Detection: To detect the presence or absence of a target signal in the presence of background noise.
- Estimation: To determine the parameters of the target -mainly range, azimuth, elevation, velocity and acceleration. The maximum range detection capability of a radar is directly dependent on transmitter power and duty cycle of transmitter wave as given in the equation below,

Maximum range = $k * P_{avg}$

where

$P_{avg} = P_p$ * duty ratio

$= P_p * t / T$

$= P_p * t * F$

where

P_p is the peak transmitted power,

t is the sub pulse width of the Transmitted wave,

F is the peak repetition frequency (PRF)

Hence the maximum detectable range can be improved by increasing P_p, t or F. Let us consider the three possibilities in detail.

- Increasing Pp: High voltages cause insulation breakdown and also complicate transmitter design.
- Increasing t: The echo of two targets separated by a time delay is proportional to the distance between the two targets. When the targets are closely placed it would result in the merging of the two echoes and confusing the dual targets as one. The resolution or ability to detect two closely spaced targets could be improved by decreasing t but this would in turn decrease the maximum detectable range. Therefore improvement of range at the cost of resolution is an unacceptable proposition.
- Increasing PRF: PRF has an inverse relation with maximum unambiguous range. Thus doubling of PRF frequency would decrease the maximum unambiguous range by half. Hence increase of PRF is of no help as far as improving the range of radar goes.

Thus researchers from all over the world, based on their research work, evolved a universal solution to the problem of improving the detection range without sacrificing range resolution or putting undue constraints on Transmitter peak power. This solution involved sending out a coded signal, the coding being done with the help of Pulse Compression.

2.3. Principle of Pulse Compression

2.3.1Nature of waveform

Pulse compression involves the transmission of a long coded pulse and processing of the received echo to obtain a relatively narrow pulse. A long pulse may be obtained from a narrow pulse. Narrow pulses contain a large number of frequency components with a precise phase relationship between them if the relative pulses are changed by a phase distorting filter, the frequency components combine to produce a stretched or expanded pulse. The expanded pulse is then transmitted. The received echo is processed in the receiver by a compression filter. The compression filter readjusts the relative phases of the frequency components so that a narrow or compressed pulse is again produced.

An example of a pulse compression radar is phase coded pulse compression. In pulse coded waveform the long pulse is sub-divided into a number of shorter subplulses of equal duration. Each is then transmitted with a particular phase in accordance with a phase code (usually binary coding). Phase of the transmitted signal alternates between 0 & 180 degrees in accordance with the sequence of elements: 1s and 0s (+1s & -1s) in the phase code. The phase code used is generally a standard code, which has proved to provide the best resolution and least ambiguity in determining the target parameters. The codes used can be either Barker (which is given below) or some form of pseudo random code. The former is restricted to a maximum of 13 bits while the latter can be of any length. Commercial radars use codes of length nearly 50 to 60 bits.

Code Length	**Code Elements**	**Sidelobe level**
2	10, 11	-6.0

3	110	-9.5
4	1101,1110	-12.0
5	11101	-14.0
7	1110010	-16.9
11	11100010010	-20.8
13	1111100110101	-22.3

Table -1 Barker Codes

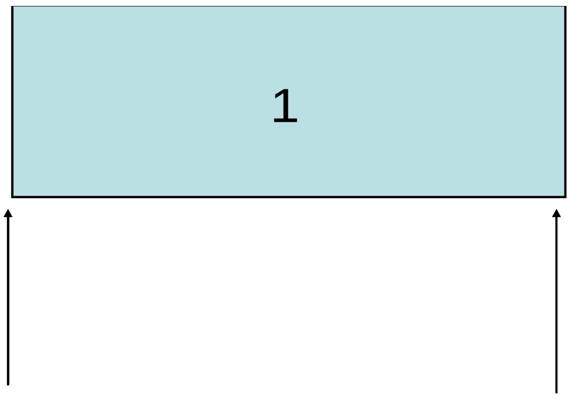

Figure -1 Uncoded Transmitted Pulse

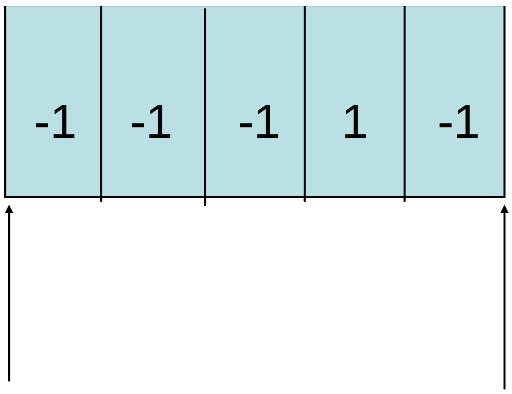

Figure -2 Pulsecoded(Barker) Transmitted Pulse

2.3.2 Correlation : Detection of the waveform

This brings up the question of how the time of arrival of the reflected signal is determined. The basis of this determination involves the computation of the correlation between the two signals, the outgoing and incoming. Correlation is a measure of the similarity or relatedness between two waveforms. For two waveforms v_1 and v_2 the correlation is mathematically given by the following equation

$$r(\tau) = \int_{-T/2}^{T/2} v_1(t')v_2(t+t')dt$$

If they have the same fundamental period T_0, then T can be replaced by the same and the average cross correlation can be computed. It should be noted that the correlation depends on the time shift, t given to the waveforms. This shift results in a maximum correlation at some points and zero at others. Two waveforms are considered to be coherent if they are related while they are uncorrelated or incoherent if there is no match between them at any given time. Auto correlation is the measure of the coherence of a waveform with itself. It is noted that in the case of auto correlation it would be maximum when the time shift would be zero or a multiple of its time period. In radar signaling the received and sent signal are basically the same so it is the auto correlation that is computed. The two signals i.e. the one broadcast and the one received are matched continuously. The instant when they match or the auto correlation is the maximum is the point at which the signal is considered to have arrived. This computation is done with the help of a matched filter.

2.4. Matched Filter

A pulse compression radar is a practical implementation of matched filter system. A matched filter is part of the receiver that is specifically designed to maximize the output signal to noise ratio. Block diagram of matched filter is shown in figure1.2.

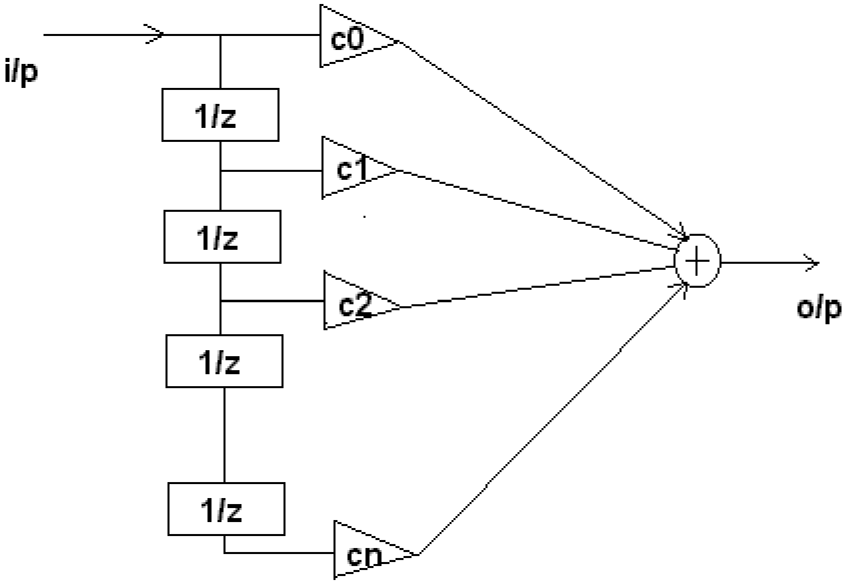

Figure -3: Matched Filter

The Length M or length of the sequence is equal to the number of subpulses in the sequence. The sequence is incorporated into the signal by means of phase coding.

The phase coded received signal enters the taps one by one. The signal is unchanged of the coefficient of the tap is 1 and inverted in phase if it is -1. The coefficients of multiplication are the code in reverse form. The products are summed and the output obtained has maximum signal to noise ratio.

2.5. Sidelobes and Different Sequences

Side lobes arrive in almost every sequence after compression.Barker codes have the quality that their side lobes are of low intensity. All the side lobes are positive and of equal lengths.Main constraint of barker code is their length i.e. if the compression of higher order (more than thirteen) is required barker code is not feasible. In those situations some other sequence is required for the compression purpose. Unlike barker codes other sequences give better compression but the maximum side lobe to main lobe ratios are much higher than the barker code. In this thesis other sequences which are also used are

- PN Sequence
- Kasami Sequence
- Gold Sequence

are hiIn High ENR(Energy to Noise ratio) , side lobes of the compressed pulse do not affect the detection process , but if it is a low ENR system or multi target detection problem , side lobes affect seriously the detection process.They can create false alarms and false dismissal as well. Barker codes have low side lobe to main lobe ratio if the length of the coded sequence increases. But maximum 13 chip barker code is available which again is a serious constraint. PN sequence has no limitation on the coding length but maximum side lobe to main lobe ratio is high.

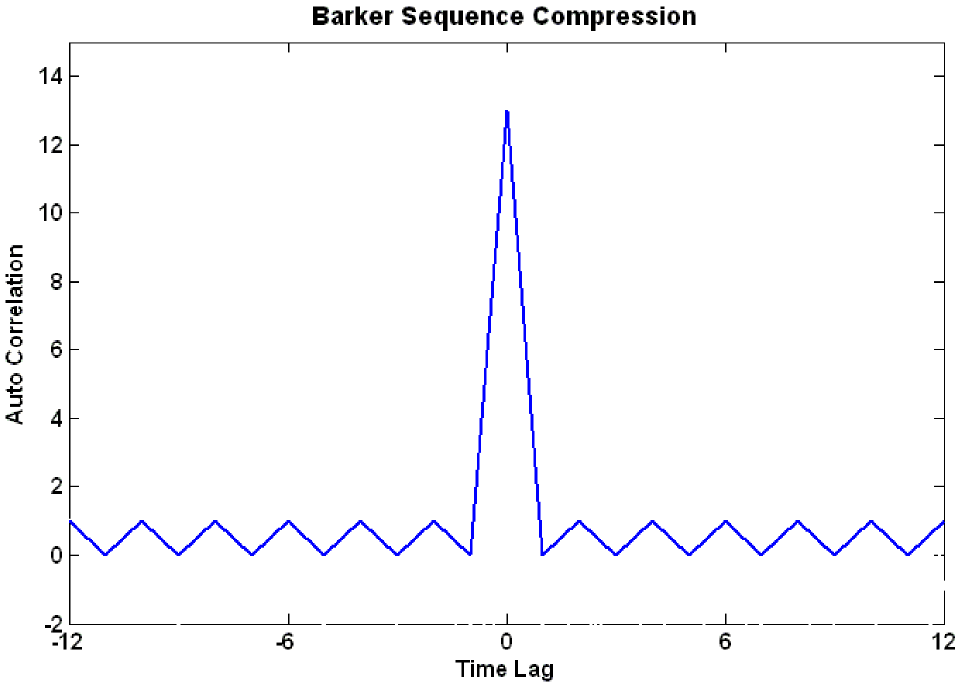

Figure -4: Compression of Barker sequence coded signal

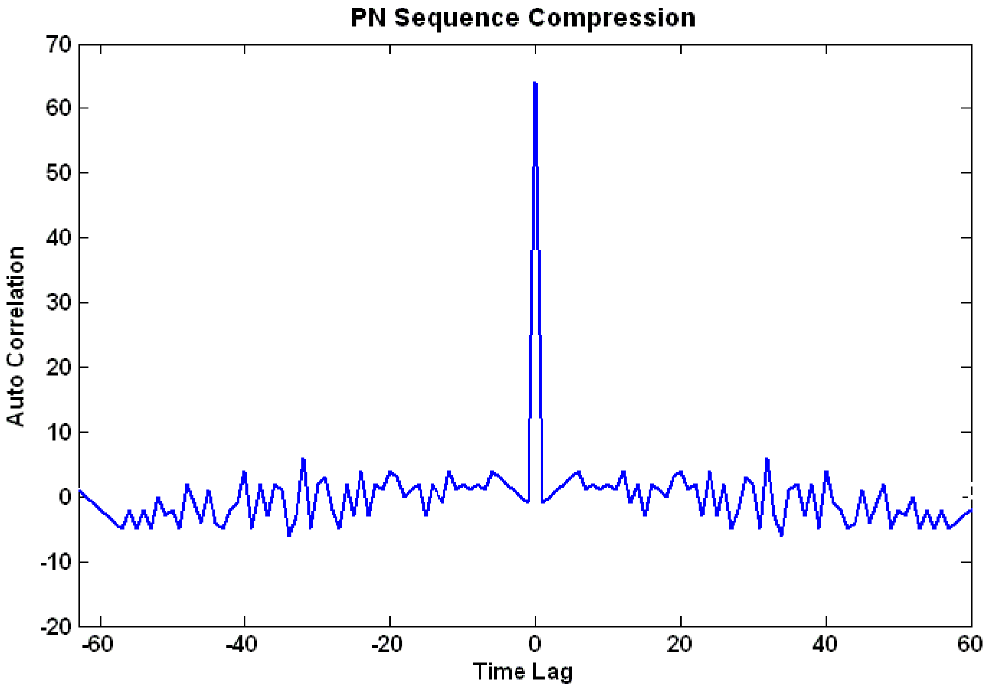

Figure -5: Compression of PN sequence coded signal

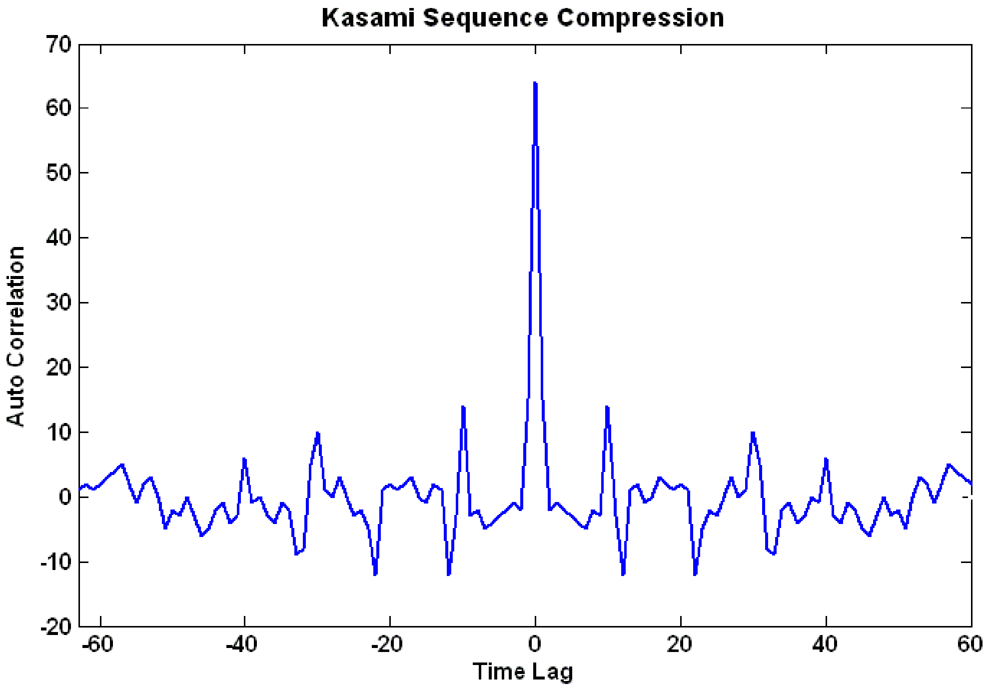

Figure -6: Compression of Kasami sequence coded signal

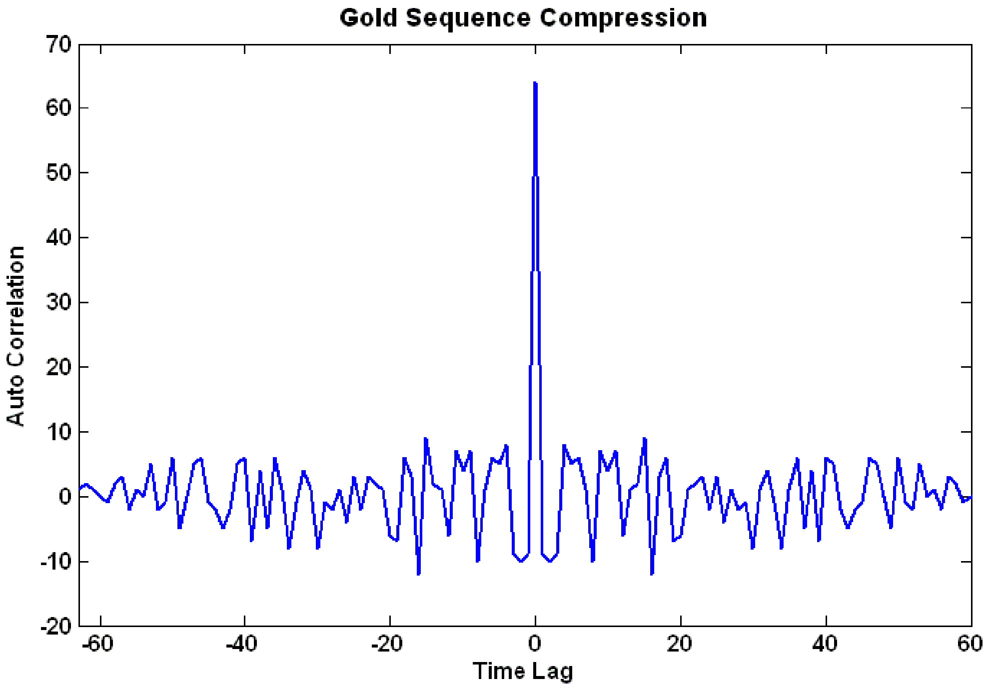

Figure -7: Compression of Gold sequence coded signal

2.6. Conclusion

In active radar scenario, matched filtering is the best technique for the detection purpose because transmitted pulse is known hence easy to be detected by matched filtering.But matched filtering produce sidelobes after compression which can be problematic in different conditions. Different sequences give different type of side lobe pattern after compreesion. For most of the time kasami sequence is near to zero unlike gold code. But where its value has significant magnitude (positive or negative) it is much higher than its gold counterpart.So either there should be some compromise or some other technique should be used.

Chapter 3

COMPLEMENTARY CODES

3.1 Complementary Codes

Complementary codes were first studied comprehensively by Marcel J. E. Golay in 1960; they are therefore also called Golay codes. In his paper [11], Golay created the definition of complementary codes, and studied their properties and synthesis methods. Golay defined a pair of complementary codes as two equally long finite sequences of two kinds of elements, which have the property that the number of pairs of like elements with any given separation in one sequence is equal to the number of pairs of unlike elements with the same separation in the other sequence. Figure 1 shows a pair of complementary codes, code I (00010010) and code II (00011101), to help clarify the definition. Each code has a length of 8 bits, and the two kinds of elements are 1 and 0. In the figure, L is used to denote a pair of like elements and U a pair of unlike elements in code I or code II. For the given separation of 2, it is shown that code I has one pair of unlike elements and four pairs of like elements, and code II has four pairs of unlike elements and one pair of like elements. Any other separations (0, 1, 3, and so forth) can be used to check out the property of the pair of complementary codes.

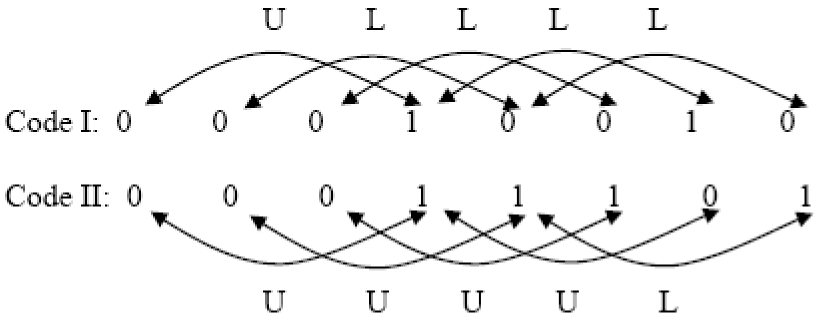

Figure 1: A Pair of Complementary Codes

The properties of complementary codes can be used to generate new complementary codes once a pair of complementary codes is known. A pair of complementary codes remains complementary after the following operations:

- Operation 1: Either code or both codes are reversed.
- Operation 2: The two kinds of elements in either code or both codes are interchanged.
- Operation 3: The kind of elements at even order in both codes is altered to the other kind.

Appending and interleaving operations can be used to synthesize longer complementary codes. Assuming codes $A = a_1 a_2 \ldots a_N$ and $B = b_1 b_2 \ldots b_N$ are a pair of complementary codes of length N bits, and $B' = b'_1 b'_2 \ldots b'_N$ is the altered version of B where the prime of a bit denotes the change of the element kind from one to the other, then

- Operation 4: $C = AB = a_1 a_2 \ldots a_N b_1 b_2 \ldots b_N$ and $D = AB' = a_1 a_2 \ldots a_N b'_1 b'_2 \ldots b'_N$ results in a pair of complementary codes of length $2N$ bits. And
- Operation 5: $E = a_1 b_1 a_2 b_2 \ldots a_N b_N$ and $F = a_1 b'_1 a_2 b'_2 \ldots a_N b'_N$ also results in a pair of complementary codes of length $2N$ bits.

3.2 Principle of Complementary-Coded Pulse Radar

A pulse radar detects objects by measuring the time delay between transmitted and reflected pulses. As illustrated in Figure 2 [12], the maximum unambiguous range R_u and the range resolution ΔR are determined by

$$R_u = \frac{cT}{2} = \frac{c}{2PRF}$$

$$\Delta R = \frac{c\tau}{2}$$

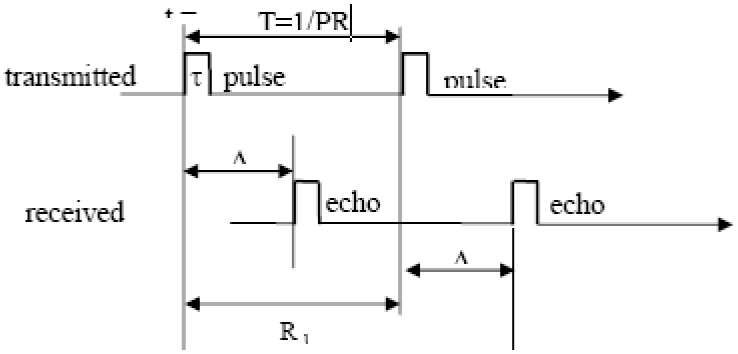

Figure 2: Unambiguous Range and Range Resolution of Pulse Radar

where c is the travel speed of electromagnetic waves in medium, T is the period of transmitted pulses, and its reciprocal is known as pulse repeat frequency (PRF). τ is the pulse width.

According to radar equation, the maximum radar range $R_{\max}$ is

$$R_{\max} = [\frac{p_t G\sigma A_e}{(4\pi)^2 S_{\min}}]^{1/4}$$

where P_t is the power of the transmitted pulse, G is the antenna gain, σ is the radar cross section (RCS), A_e is the antenna's effective aperture, $S_{\min}$ is the minimum detectable signal power and

$$P_t = P_{\max} \tau PRF$$

From equation (2), it is seen that fine-range resolution (small ΔR) requires short pulses (small τ), and from equations (3) and (4) for the detection of distant targets, the high pulse peak power $_{\max}P$, long pulse (bit τ), or high PRF are required once G , σ , A_e, and $S_{\min}$ are set. But high PRF reduces the maximum unambiguous range according to equation (1). Thus short pulses with high peak power are needed for both long-range detection and fine-range resolution. However, it is difficult to generate high-peak power pulses, and high-peak power pulses may result in dielectric breakdown of transmission lines. For this reason, the technique of pulse compression is used, in which frequency- or phase-coded long pulses are transmitted, and received pulses are decoded to obtain short pulses with high-pulse peak power.

The pulse compression is implemented by matched filter. As illustrated in Figure 3, a pulse with magnitude of 1 is coded with an 8-bit binary code. At the output of the matched filter, the waveform is compressed into a main lobe and symmetric sidelobes on each side. The magnitude of the main lobe is increased from 1 to 8, and its width is 2/8 of the original pulse length.

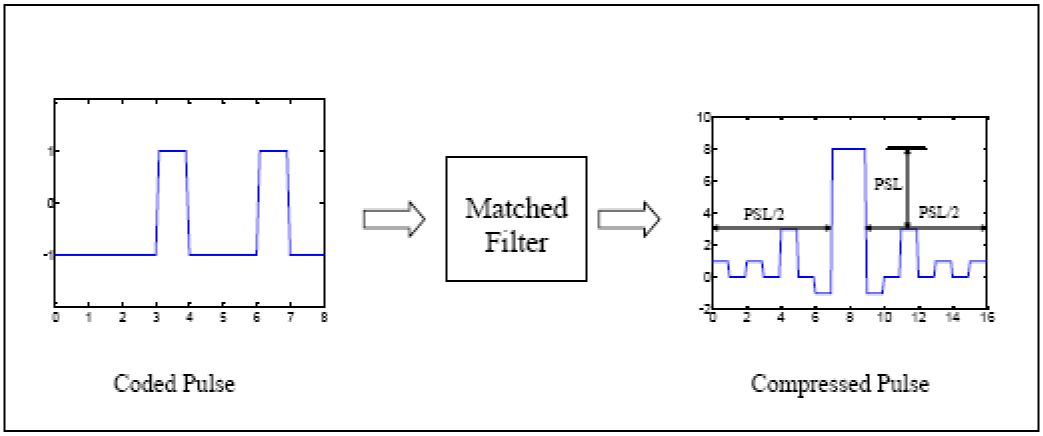

Figure 3: Pulse Compression

The following parameters describe the property of pulse compression [13]:

$$PSL = 10\log[Max(x_i^2)/x_o^2]$$

$$ISL = 10\log[\sum_{i=o}^{N} x_i^2 / x_o^2]$$

where x_i represents the magnitude of all sidelobes and x_0 is the magnitude of the main lobe. *PSL* , the peak sidelobe level, is a measure of the largest sidelobe as compared with the main lobe. *ISL* , the integrated sidelobe level, is a measure of the total power in the sidelobes as compared with the main lobe power.

Sidelobes are an undesirable outcome of pulse compression either in range or time. Since the sidelobes of a strong target may mask weak returns from a nearby target, it is preferable to delete or reduce the sidelobes. Complementary codes discussed in the previous section are therefore employed for this purpose. For a pair of complementary codes with elements either 1 or –1, the sidelobes of the compressed waveform from one code is the inverse of the ones from the other code. When the compressed waveforms from two codes are added together, the sidelobes will be totally canceled in the ideal case, and the magnitude of the main lobe will double. This property of complementary codes can be explained in terms of their autocorrelation functions. The autocorrelation function of codes *A* and *B* is defined by equations (7) and (8), respectively:

$$R_A(j)=\sum_{i=1}^{N-1} a_i a_{i+j}$$

$$R_B(j)=\sum_{i=1}^{N-1} b_i b_{i+j}$$

where *N* is code length in bits and $-(N-1)\le j\le (N-1)$. If codes *A* and *B* are a pair of complementary codes and the elements in the codes are either 1 or –1, then

$$R_A(j)+R_B(j)=\begin{cases}2N & j=0\\ 0 & j\neq 0\end{cases}$$

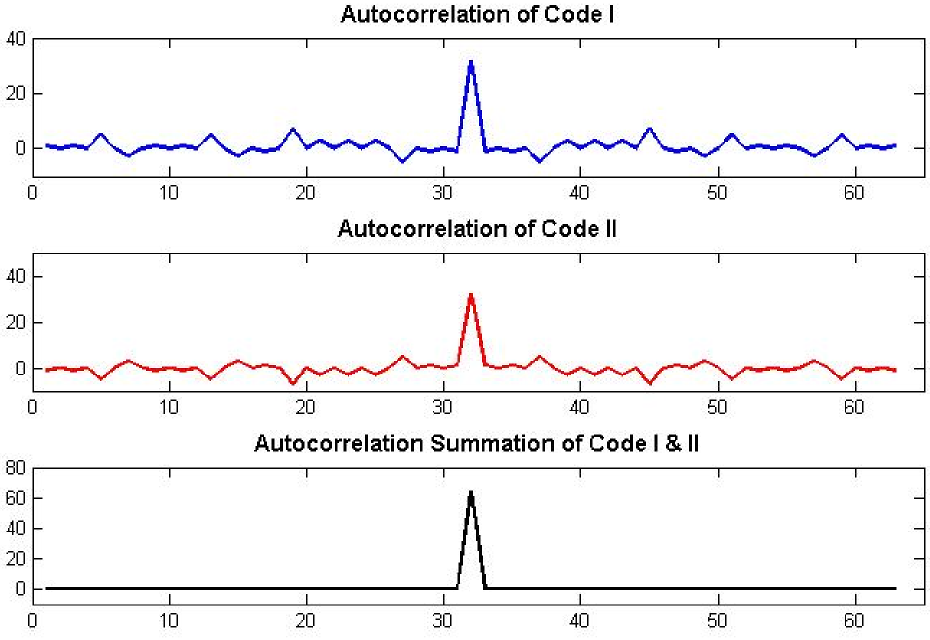

Figure 4: Autocorrelation Functions ${}_{I}R$ (red), ${}_{II}R$ (blue), and ${}_{I\,II}R+R$ (black)

For example, after the 0s in codes I and II are replaced with –1s, their autocorrelation functions are calculated and illustrated in Figure 4, in which the blue plot is the autocorrelation function of code I, the red plot is the autocorrelation function of code II, and the black plot is the sum of the two autocorrelation functions. Figure 4 shows that the waveform of each code has a main lobe located at the center with a magnitude of 32,

which is the code length, and the sidelobes of two codes are opposed to each other so that when summed together the sidelobes are canceled and the peak of the main lobe is increased to 64, which is twice the code length.

3.3 Application Limitations

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There is a application limitations considered in this thesis i.e. what is called the Doppler phase shift. Since the radar is to be carried on an airplane, after it transmits the first pulse coded by the first code in the complementary pair, it will move to a different place when transmitting the second pulse coded by the other code. The moving radar results in what is called the Doppler phase shift between the two pulses. Also because hardware cannot be built perfectly, any imperfection may cause signal amplitude or phase imbalances. For example, different charging and discharging characteristics of capacitors make it impossible to get exactly the same amplitude when generating one positive volt and one negative volt.

Chapter 4

HIGHER ORDER STATISTICS

HOS,"Higher Order Statistics" or "Higher Order Spectra." is a field of statistical signal processing which has become very popular in the last 15 years. It makes use of information extra to that usually used in 'traditional' signal processing measures such as the power spectrum and autocorrelation function. This extra information can be used to get better estimates of parameters in noisy situations, or to shed light on nonlinearities in the signal's production mechanism.

To date virtually all practicable digital signal processing techniques have been based on second order statistics. Consequently, the assessment of signals is often based on an examination of the signal spectrum. The conclusion is drawn that if a signal has a flat or near-flat spectrum then the quality of any prediction will be poor. This line of reasoning while useful for linear predictive systems which only exploit the first and second order statistics of the signal, is not true in general since it ignores the higher order statistics of the signal. The last two decades have seen a growing interest, within the signal processing community, in the use of higher order statistics in a variety of applications.

4.1.Moments and Cumulants:

Moments and cumulants are widely used in scientific disciplines that deal with data, random variables or stochastic processes. They are well known tools that can be used to quantify certain statistical properties of the probability distribution like location (first moment) and scale (second moment). Their definition is given by,

$$\mu_n = E[x^n]$$

where E[.] denotes the average over the probability distribution $p(x)$. In practise we have a set of samples from the probability distribution and compute sample estimates of these moments. However, for higher order moments these estimates become increasingly dominated by outliers, by which we will mean the samples which are far away from the mean. Especially for heavy tailed distributions this implies that these estimates have high variance and are generally unsuitable to measure properties of the distribution. An undesirable property of moments is the fact that lower order moments can have a dominating influence on the value of higher order moments. For instance, when the mean is large it will have a dominating effect on the second order moment,

$$E[x^2] = E[x]^2 + E[x - E[x]]^2$$

The second term which measures the variation around the mean, i.e. the variance, is a much more suitable statistic for scale than the second order moment. This process of subtracting lower order information can be continued to higher order statistics. The resulting estimators are called centralized moments or cumulants. Well known higher order cumulants are skewness (third order) measuring asymmetry and kurtosis (fourth order) measuring "peakedess" of the probability distribution. Since cumulants are functions of moments up to the same order, they also suffer from high sensitivity to outliers.

Many statistical methods and techniques use moments and cumulants because of their convenient properties. For instance they follow easy transformation rules under affine transformations

A formal definition of the relation between moments and cumulants to all orders can be given in terms the characteristic function (or moment generating function) of a probability distribution,

$$\varphi(t) = E[e^{ixt}] = \sum_{n=0}^{\infty} \frac{1}{n!} \mu_n (it)^n$$

where the last expression follows by Taylor expanding the exponential. The cumulants can now be defined by

4.2.kurtosis

Kurtosis is the degree of peakedness of a distribution, defined as a normalized form of the fourth central moment μ_4 of a distribution. There are several flavors of kurtosis commonly encountered, including the kurtosis proper, denoted by α_4 and defined by:

$$\alpha_4 = \frac{\mu_4}{\mu_2^2}$$

where μ_i denotes the ith central moment (and in particular, μ_2 is the variance). The kurtosis "excess" is denoted by γ_4 and is defined by :

$$\gamma_4 = \frac{c_4}{c_2^2}$$

where c_4 is the 4th order cumulant and c_2 is the 2nd order cumulant. Kurtosis excess is commonly used because γ_4 of a normal distribution is equal to 0, while the kurtosis proper is equal to 3. A distribution with a high peak $\gamma_4 > 0$ is calledleptokurtic, a flat-topped curve $\gamma_4 < 0$ is calledplatykurtic, and the normal distribution $\gamma_4 = 0$ is called mesokurtic.

Distribution	**kurtosis excess** γ_4
Bernoulli Distribution	$\frac{1}{1-p} + \frac{1}{p} - 6$
Bionomial Distribution	$\frac{6p^2 - 6p + 1}{np(1-p)}$
Chi-squared Distribution	$\frac{12}{r}$
Exponential Distribution	6
Gamma Distribution	$\frac{6}{a}$
Geometric Distribution	$5 - p + \frac{1}{1-p}$
Maxwell Distribution	$-\frac{4(96-40\pi+3\pi^2)}{(3\pi-8)^2}$
Poisson Distribution	$\frac{1}{r}$
Rayleigh Distribution	$\frac{6\pi(4-\pi)-16}{(\pi-4)^2}$
Uniform Distribution	$-\frac{6}{5}$
Log Normal Distribution	$e^{4s^2} + 2e^{3s^2} + 3e^{2s^2} - 6$
Laplase Distribution	3

Fisher Tippett Distribution	$\frac{12}{5}$
Half Normal Distribution	$\frac{8(\pi-3)}{(\pi-2)^2}$
Normal (Gaussian) Distribution	0

Table 4.1

From table 4.1 it can be deduced easily that it is only normal distribution for which kurtosis of this type is zero . This property of kurtosis is exploited in the thesis as for the noise plus signal condition when a non Gaussian signal is embedded in Gaussian noise, when the test of kurtosis excess is applied all those instances where only noise resides converge to zero while the instances where signal plus noise resides,show a significant non zero kurtosis excess value.

A low SNR signal is received from two different target. Signal is QPSK modulated. After applying Kurtosis Excess property noisy signal gets a considerable non zero value as shown in figure 4.2. Only noise has converged to zero.

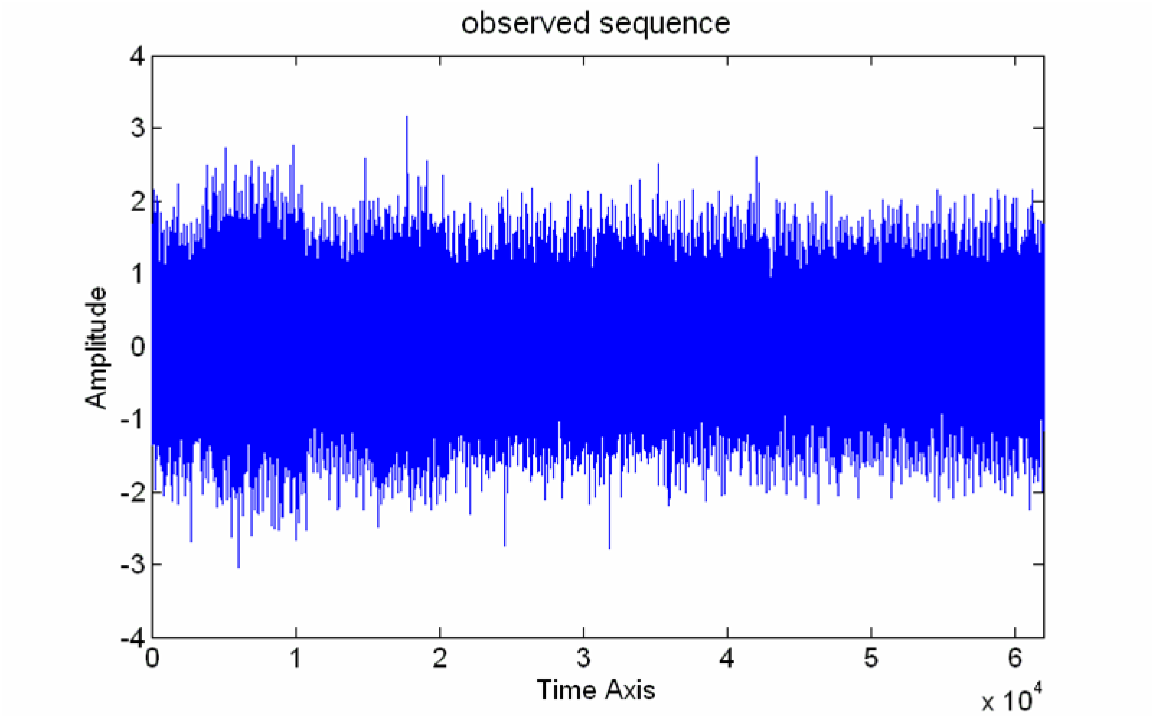

Figure 4.1

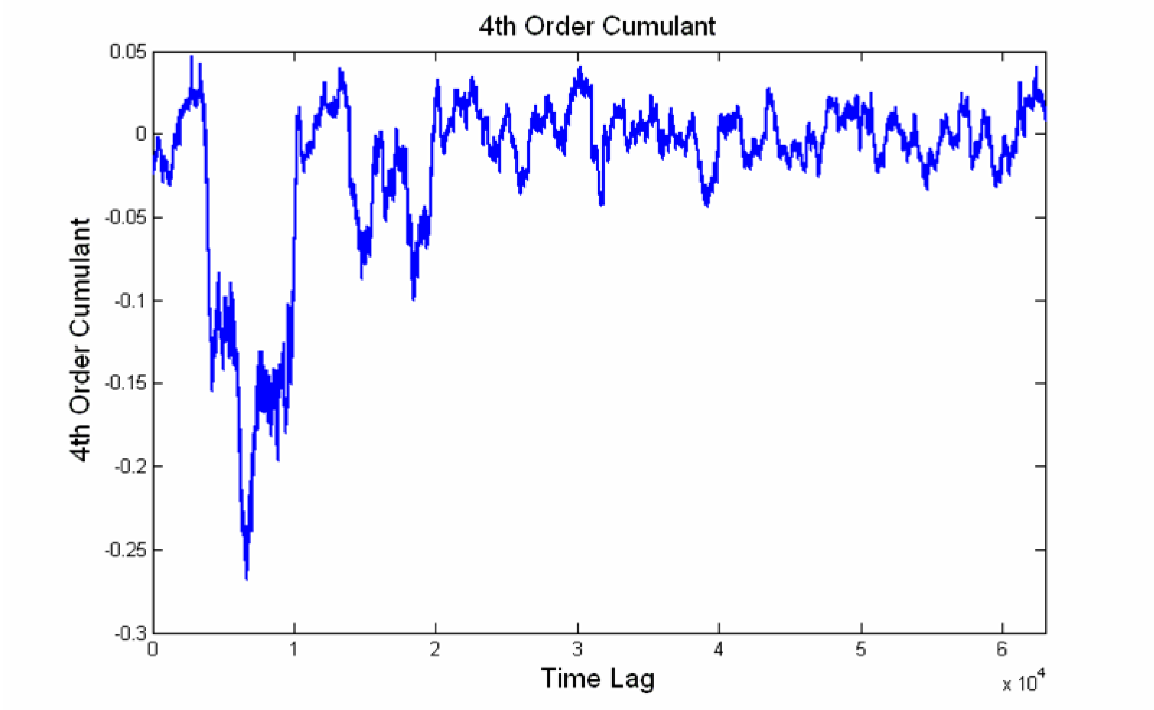

Figure 4.2

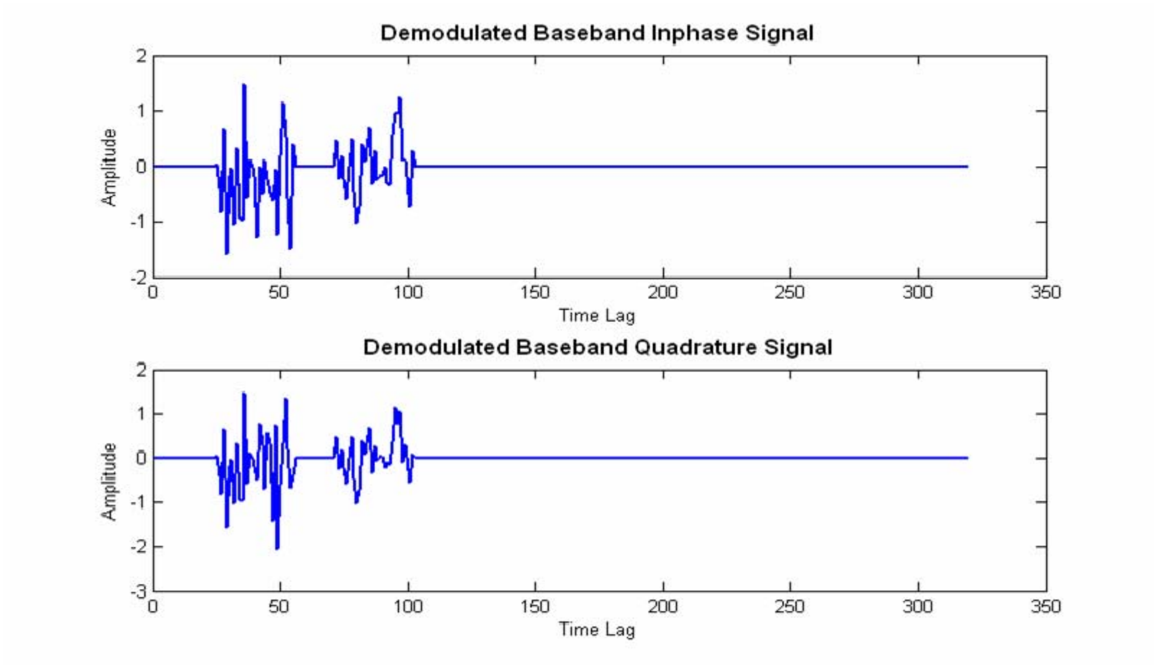

Figure 4.3

4.3 Conclusion:

After applying kurtosis excess property, it is now possible to find a crude location of a low ENR signal upto 5 dB. Only those chunks where there is possibility of targets exists, are considered and the rest where kurtosis has converged to zero are discarded. After demodulaton only small chunks are available for matched filtering hence there xould be very low probability of false alarm even the threshold is applied for a higher value of fals alarm.

Chapter 5

THE DETECTION PROBLEM

5.1 Introduction

Detection problem is to deside whether signal is present or not.A received signal is always embedded in noise.Decision has to be between two hypotheses, signal and noise present versus noise only present. This is term as binary hypothesis testing problem. Goal is to use the received data as efficiently as possible in making the decision.There are two hypotheses

- Null Hypothesis
- Alternative Hypothesis

Null Hypothesis says that target is absent while alternative hypothesis says that target is present.Say there is a signal 'A' embedded in white Gaussian noise of zero mean and variance σ^2.Decesion has to be made between $x[0]=w[0],$(noise only) and $x[0]=A+w[0]$(Signal embedded in noise) .The probability density function (PDF) of a noise of variance σ^2 is

$$p(w[0])=\frac{1}{\sqrt{2\pi\sigma^2}}e^{(-\frac{1}{2\sigma^2}w^2[0])}$$

In the detection problem, performance of detector depends upon how different the PDF of received data x[0] under each hypothesis. PDF under Null Hypothesis is

$$p(x[0],H_o)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{(-\frac{1}{2\sigma^2}x^2[0])}$$

and under alternative hypothesis is

$$p(x[0],H_1)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{(-\frac{1}{2\sigma^2}(x[0]-A)^2)}$$

If the ratio of (A^2/σ^2) is low then the PDFs of both the conditions would significantly over lap each other.A decision rule has to be applied along with two types of error that are

- False alarm

i.e. Alternative hypothesis is selected when target is not present

- False dismissal

  i.e. Null hypothesis is present when target is present.

5.2 Neyman Pearson Criterion

To apply the the decision rule on the detection problem, Neymen pearson approach applies a threshold on the basis of false alarm It is desired to maximize probability of detection $P_D = P(H_1;H_1)$ subject to the constraint probability of false alarm $P_{FA} = P(H_1;H_0) = \alpha$. P_{FA} can be constraint by choosing a threshold γ since

$$P_{FA} = P(H_1;H_0)$$

$$P_{FA} = \Pr\{x[0] > \gamma; H_0\}$$

$$P_{FA} = \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-\frac{1}{2}t^2)dt$$

provided σ^2=1.So, if $P_{FA} = 10^{-3}$,$\gamma = 3$.

If A= 1, i.e. the signal energy, then

$$P_D = P(H_1;H_1)$$

$$P_D = \Pr\{x[0] > \gamma; H_1\}$$

$$P_D = \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-\frac{1}{2}(t-1)^2)dt$$

$$P_D = 0.023$$

This probability of detection is not acceptable because it is very low.To increase this We would have to compromise on probability of false alarm.Say $P_{FA} = 10^{-1}$, then $\gamma = 1$.Even at this threshold probability of detection is equal to 0.5. The best way to increase the power of the test for a specific significant of the test , ratio (A^2/σ^2) is to be increased,i.e. the energy of the signal has to be increased.

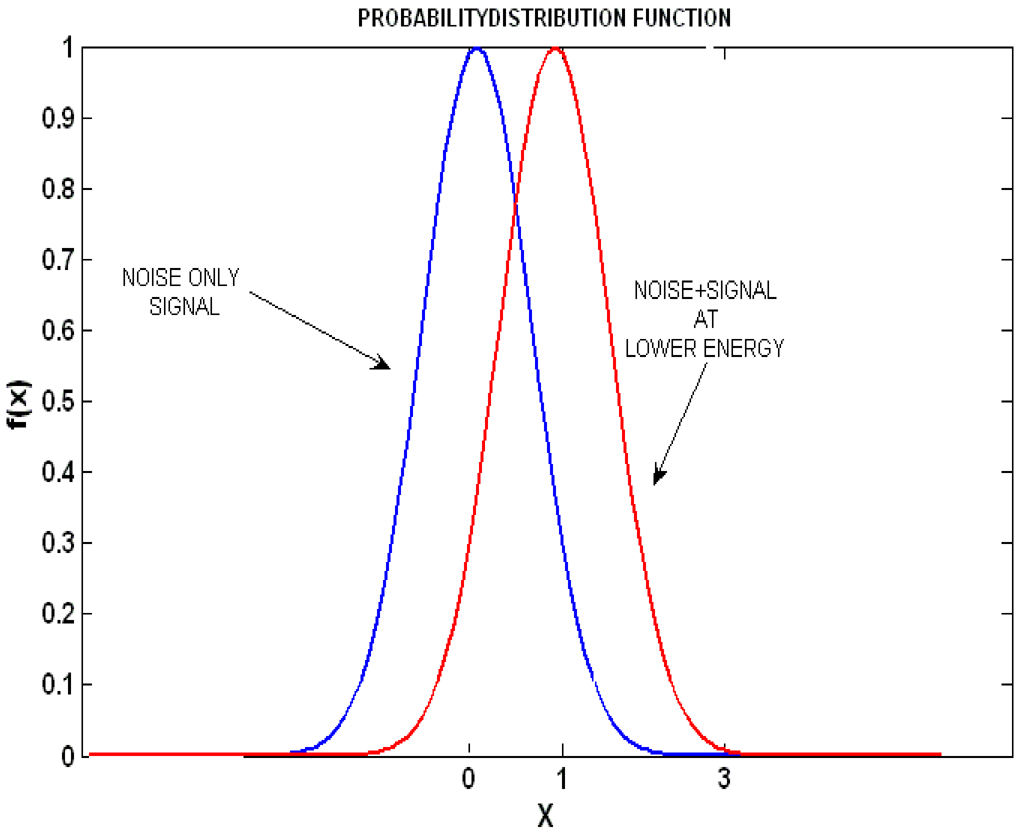

Figure 5.1

In the figure 5.1 when threshold is at line $x = 3$, there is no significant P_D.If the threshold γ lies at $x = 1$, P_D has increased but P_{FA} has also increased .If the signal energy increased then the overlap of the curves of PDFs of both hypotheses decreases which increases the P_D for a particular P_{FA}.

For the white Gaussian noise case, the power of the test P_D for a particular significance of the test P_{FA} by the help of Nyman Pearson (NP)approach is given in the figure5.3.

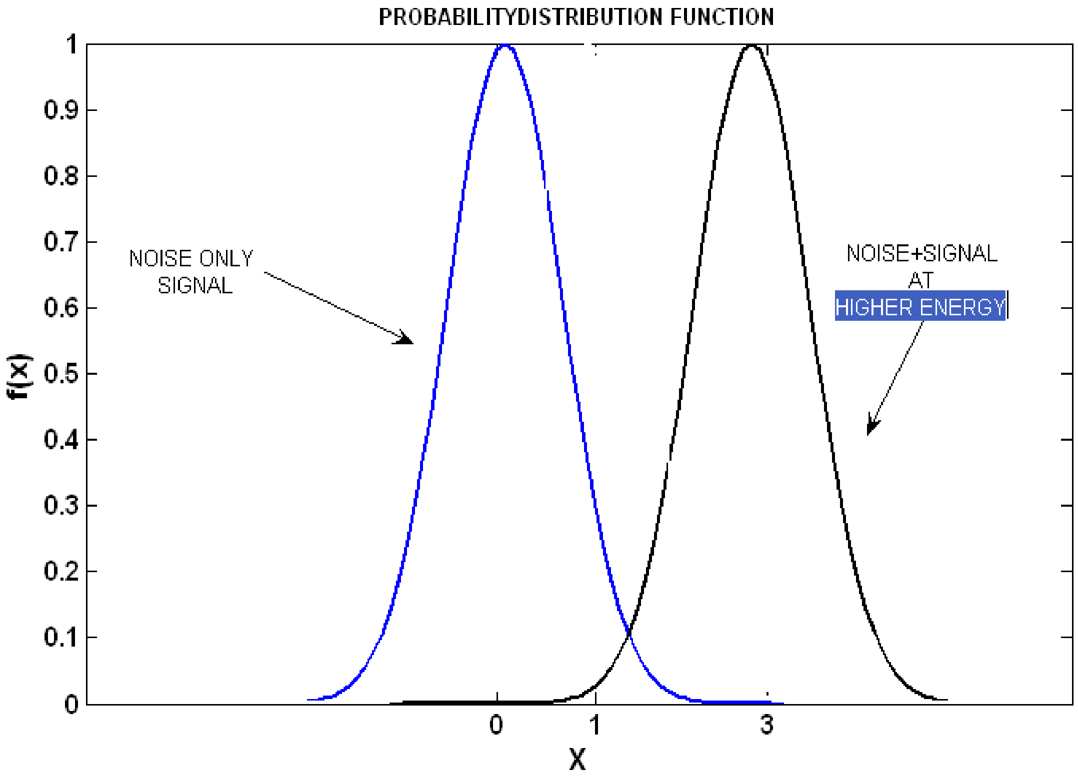

Figure 5.2

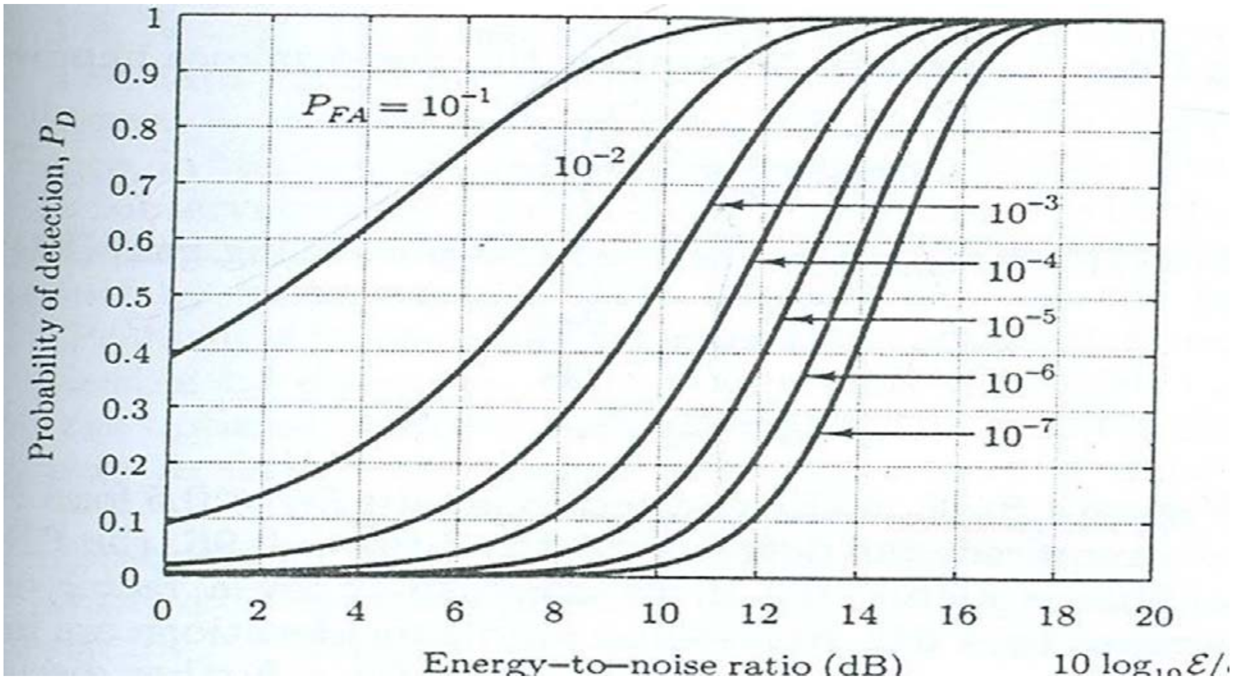

Figure 5.3

5.3 PULSE COMPRESSION AND NP APPROACH

After pulse compression Energy of the pulse increases many folds hence P_D increases for a particular P_{FA}.If the compression technique is pn-sequence or barker sequence side lobes also arrive after compression.Barker codes have low sidelobes of equal intensity but in some other techniques side lobes are of un even amplitude and are positive and negative both. Positive side lobes increase the probability of detection and probability of false alarm both.While negative side lobes increase the probability of false dismissal.In the previous topic it is shown that if the variance of the noise is one , signal energy is alsao one and P_{FA} is adjusted to 10^{-3} then P_D is 0.023. When P_{FA} is adjusted to 10^{-1} then P_D icreases to .55 If the scenario is high ENR and single target detection these sidelobes do not affect the detection process, but if it is a low ENR or multi target environment side lobes severely affect th e detection process. The worst case is the detection of a weaker target in the close vicinity of a stronger target.

Let suppose a transmitted pulse is pn sequence coded, the receiver receives first echo from target 1 of higher RCS.Before the dying out of the first echo receiver receives second echo of low RCS . After compression the main lobe of the weaker target arrives at the time lag where the sidelobes of the stronger target are already present. Hence if the sidelobe of the stronger target is positive at that particular instant than it would be constructive for the weaker target and increases the probability of detection but if it is negative at that instant it increases the probability of false dismissal.

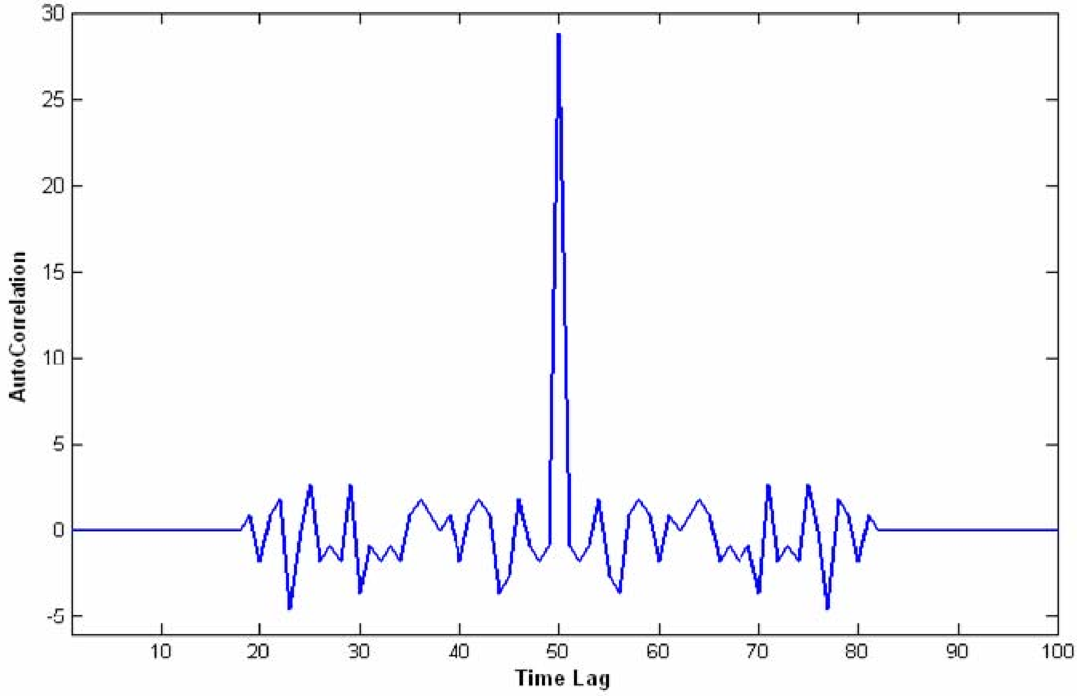

Figure 5.4

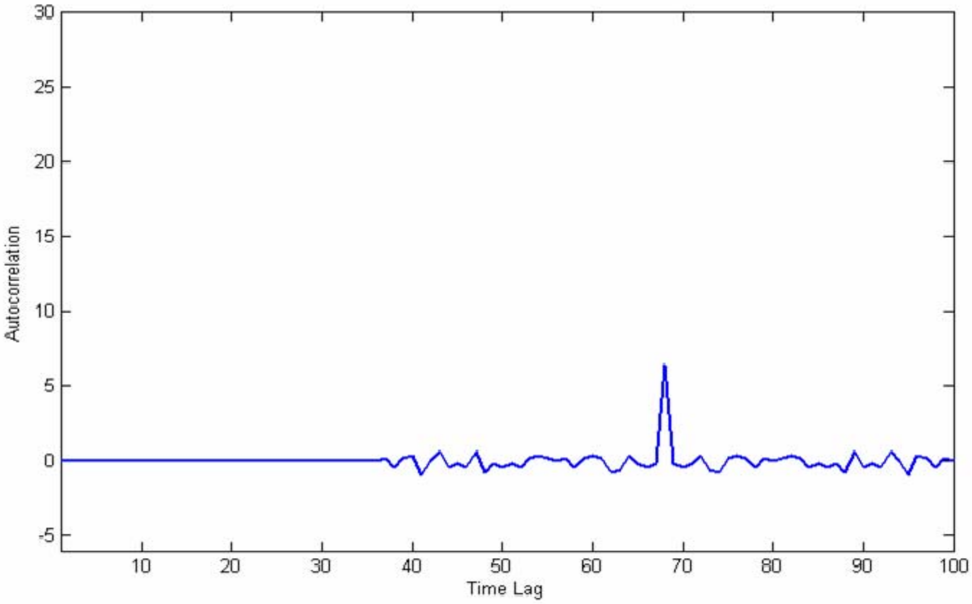

Figure 5.5

In the figure 5.4 there is a compression result of target 1 of stronger radar cross-section bwith out any noise at time lag 50. There is a weaker target at time lag 68 with out any noise as shown in figure 5.5. If low ENR is considered for this weaker target ,this target is still detectable without any false alarm at the particular threshold as shown in figure 5.6. But when this target is in close vicinity of the stronger target this is no more detectable even with the same noise and threshold. In addition there are some false alarm too.

5.4 Conclusin on Side lobes:

It can be concuded from the discussion that if side lobes are present and they are significant too they also affect the detection process and create false alarms and false dismissals on their own. Hence in multi target scenario those compression techniques should be used which do not have side lobes hence detection problem remains confined to noise only and signal plus noise situations and threshold is set according to NP criterion.

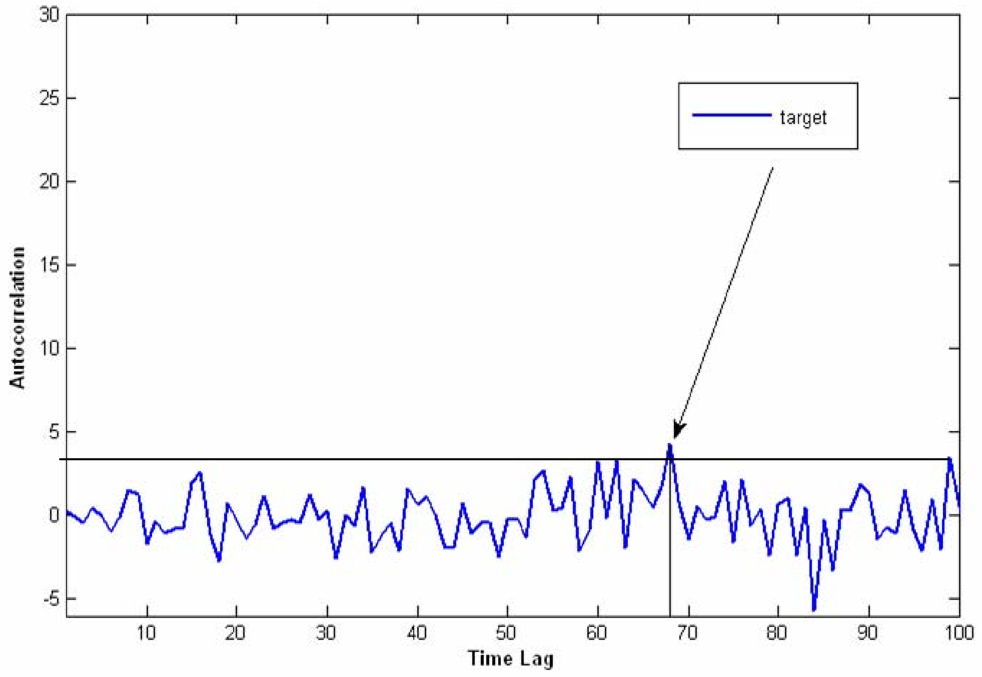

Figure 5.6

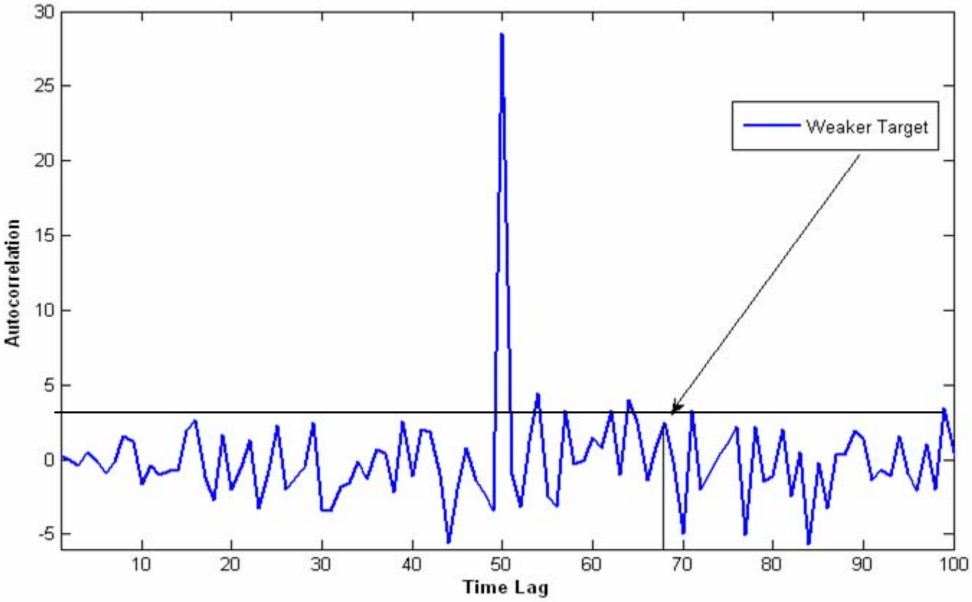
Autocorrelation
Time Lag
Weaker Target
30
25
20
15
10
5
0
-5
10
20
30
40
50
60
70
80
90
100

Figure 5.7

Chapter 6

COMPARISONS OF DIFFERENT SEQUENCES

Performance of Golay codes with several other sequences has been made in the thesis at low ENR which clearly indicatethat the performance of golay code is much better than the other sequences because all the other swequences show the effects of side lobes too in their detection process.

The first case which is considered is of ENR 9.8dB.

6.1 ENR 9.8dB

At 9.8dB a single target is detected when the transmitted pulse is coded with different sequences and the comparison shows that best results are achieved by golay sequences. The noise seed for all the sequences is same.The sequences which are used for the comparisons are

- PN_sequence
- Kasami Sequence
- Gold Sequence
- Golay Sequence

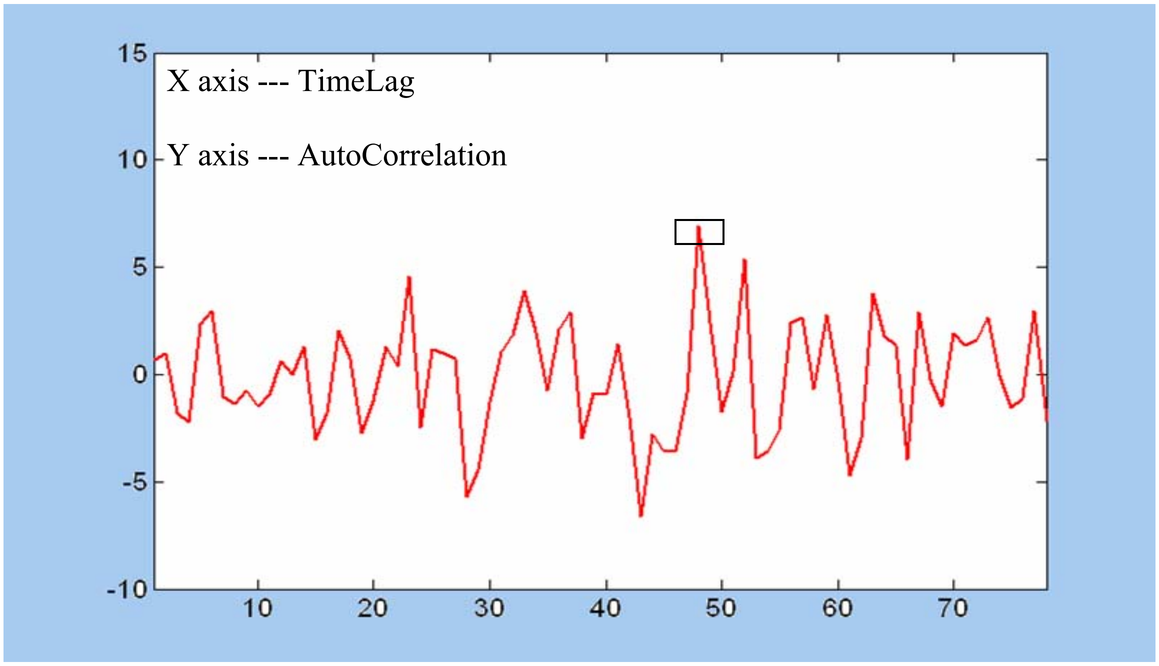

Figure 6.1 PN-Sequence

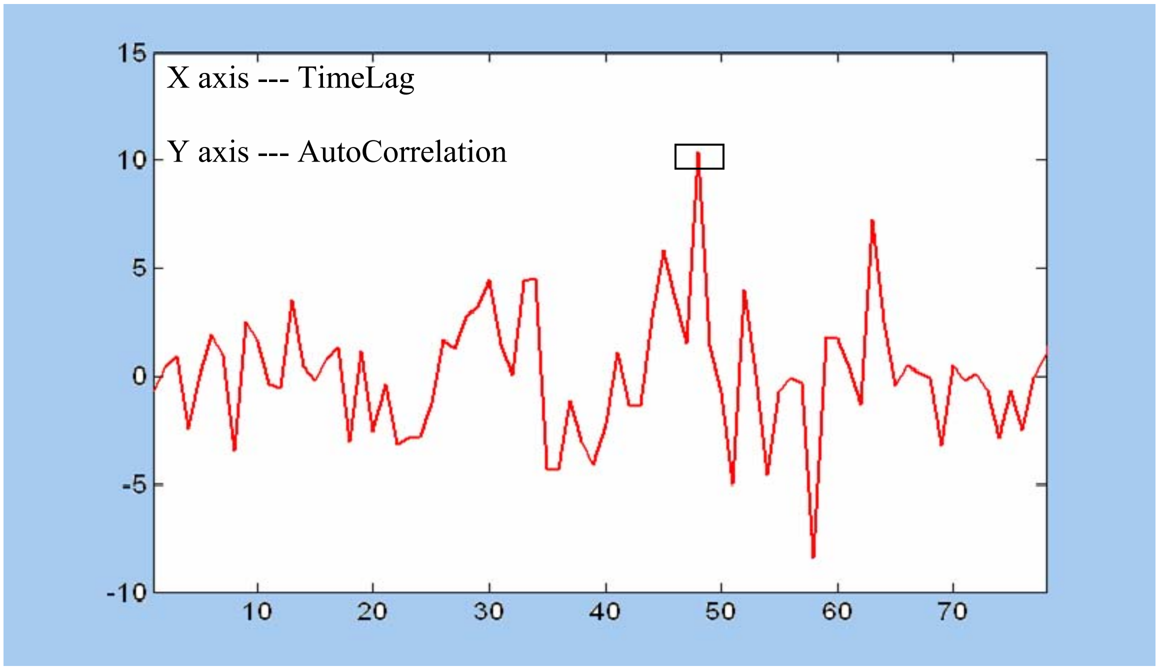

Figure 6.2 Kasami-Sequence

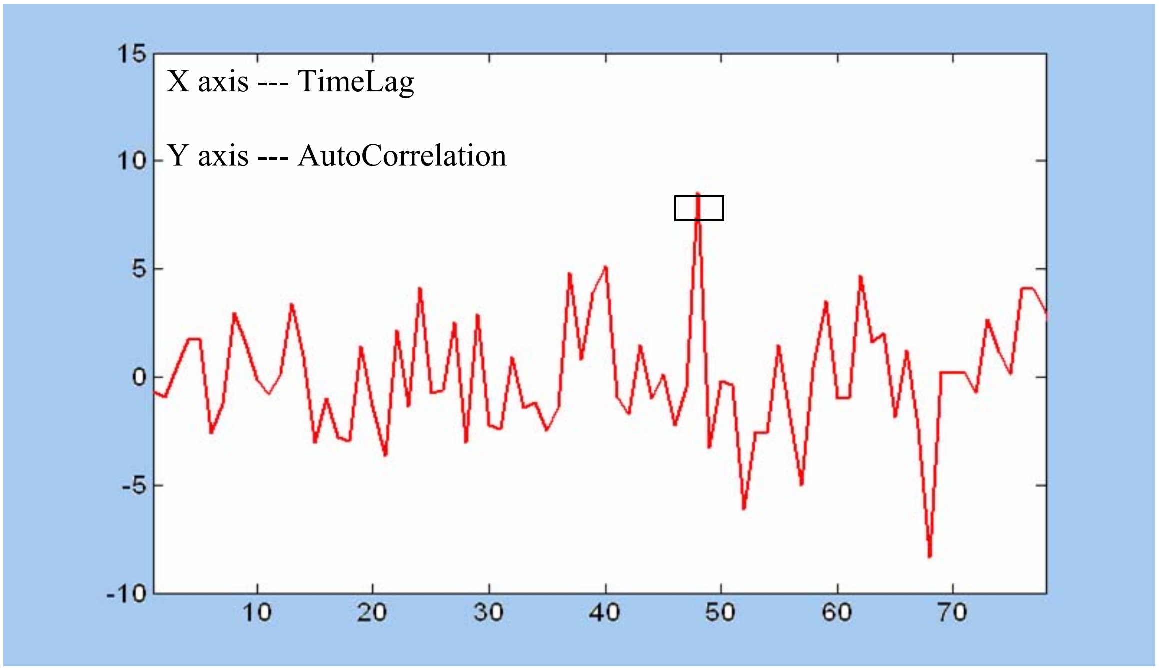

Figure 6.3 Gold-Sequence

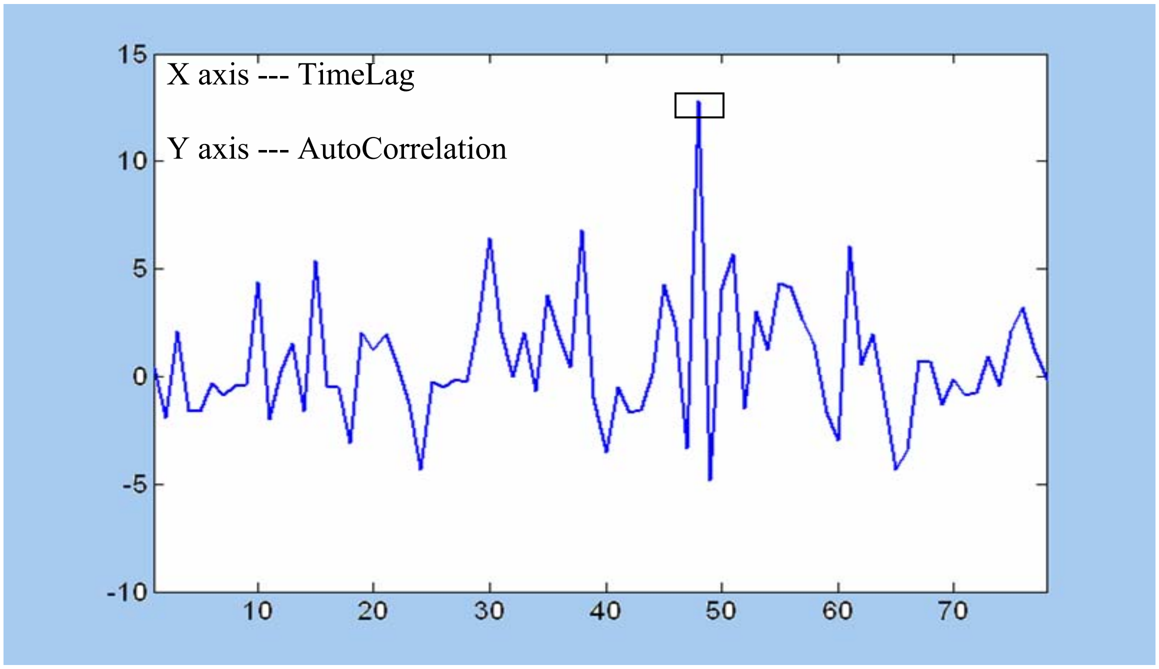

Figure 6.4 Golay-Sequence

6.2 ENR=8.2dB

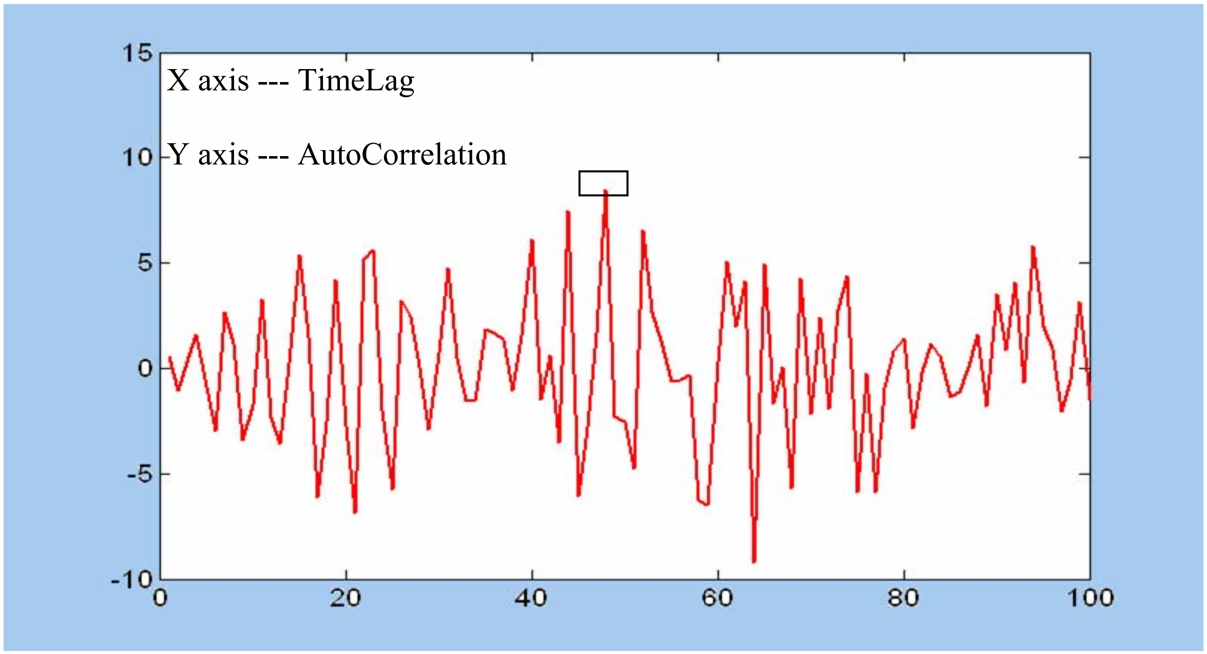

Figure 6.5 PN-Sequence

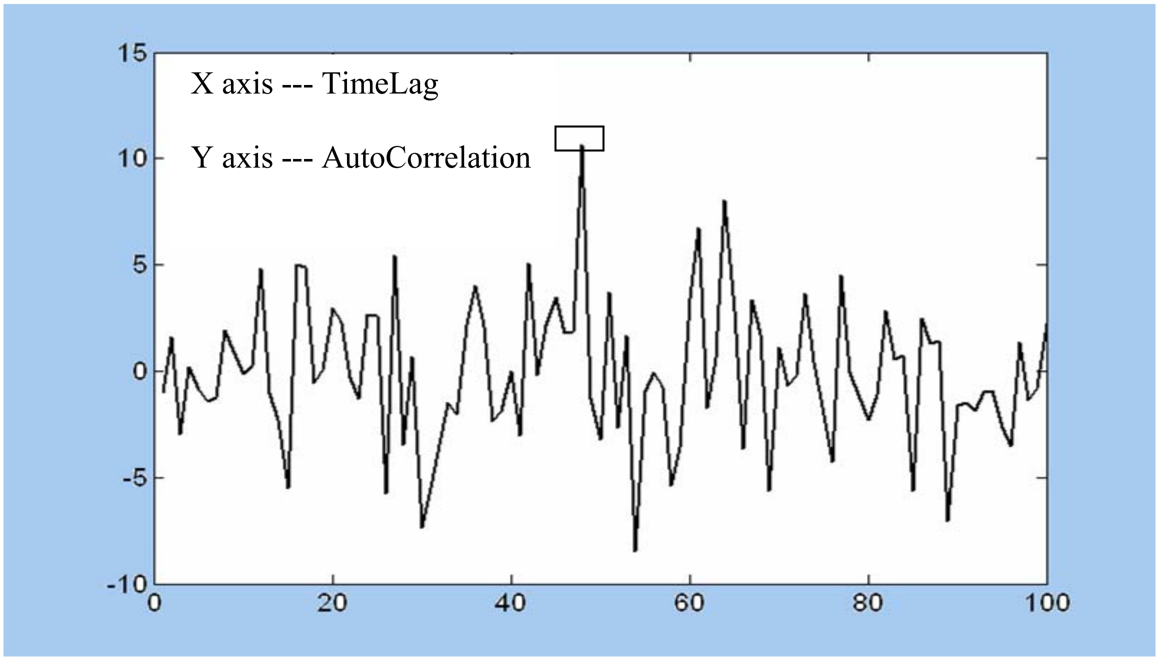

Figure 6.6 Golay-Sequence

6.3 ENR=7.5dB

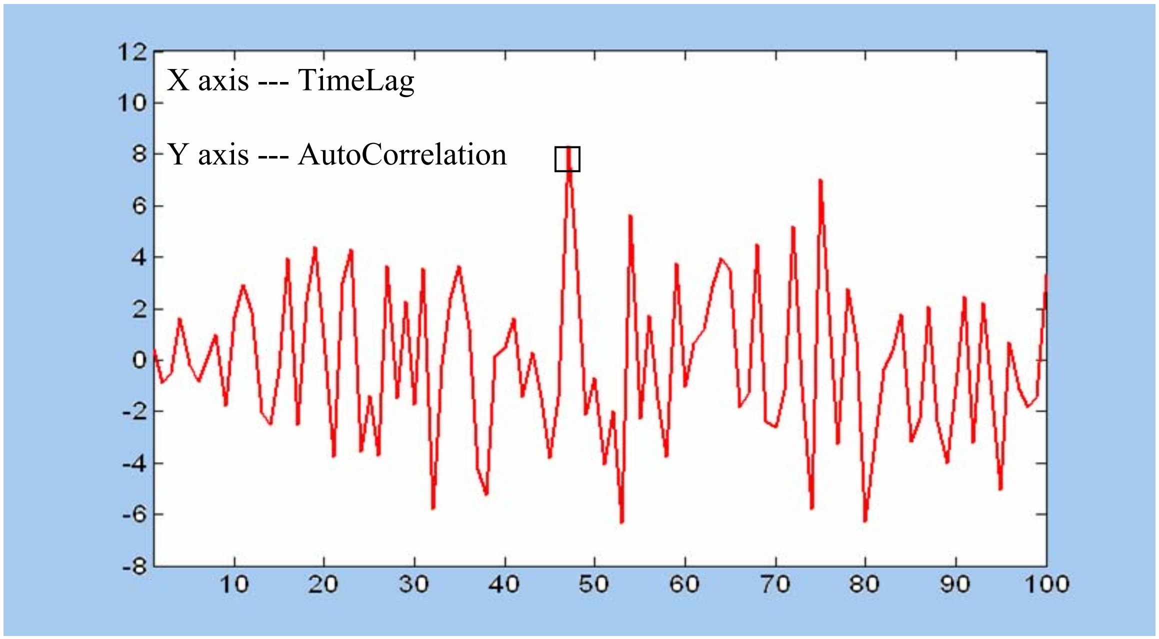

Figure 6.7 PN-Sequence

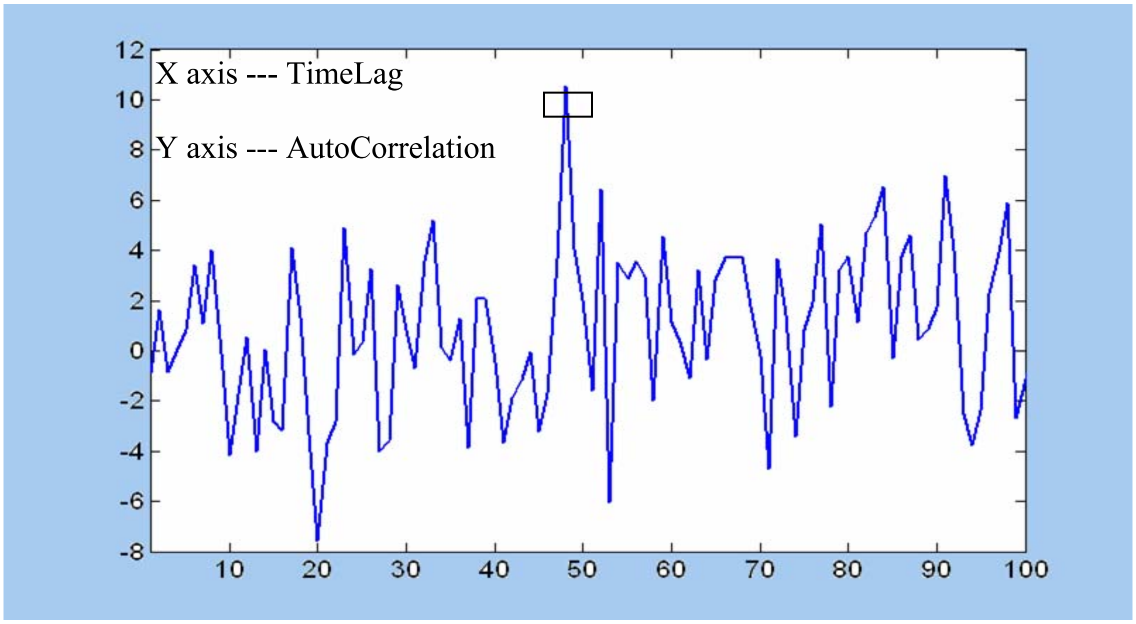

Figure 6.8 Golay-Sequence

6.4 MULTI TARGET SCENARIO

The main aim of the thesis was to design a technique which is most suitable for the multi target environment. There can be many situations of the multi target detection scenario, but the most critical case is to detect a weaker target in close vicinity of a stronger target. Only this case is considered in the thesis .Figure 6.9 shows the time instants of the main lobes of the compression o the two received echos of the two weaker and stronger targets. From Figure 6.10 to 6.13 show the detection process if different coding techniques were used.

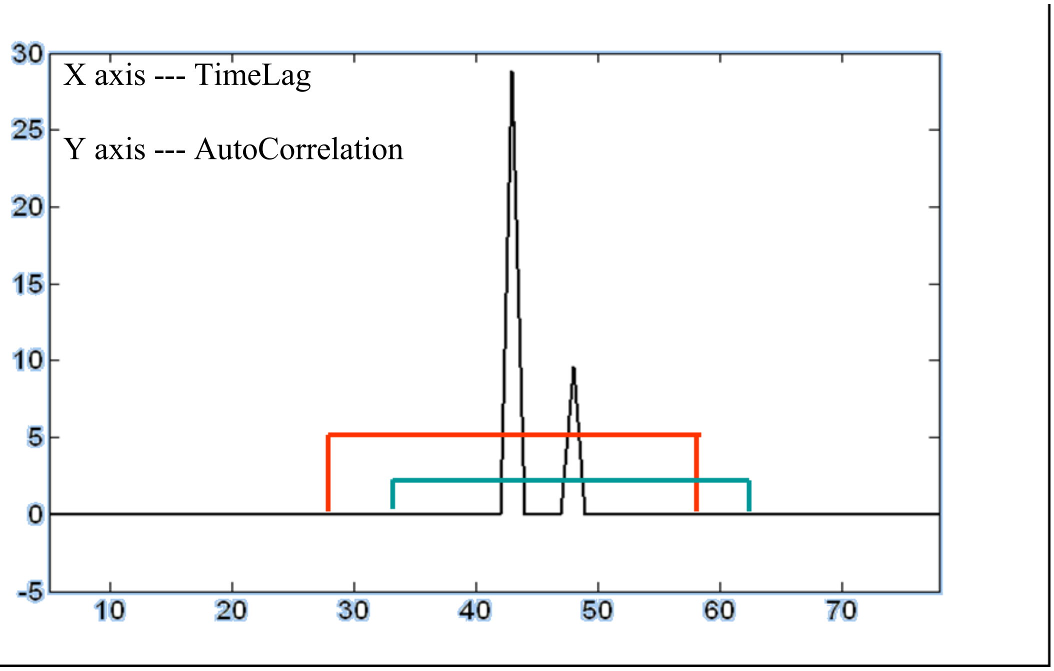

Figure 6.9 Target Location and Intensities

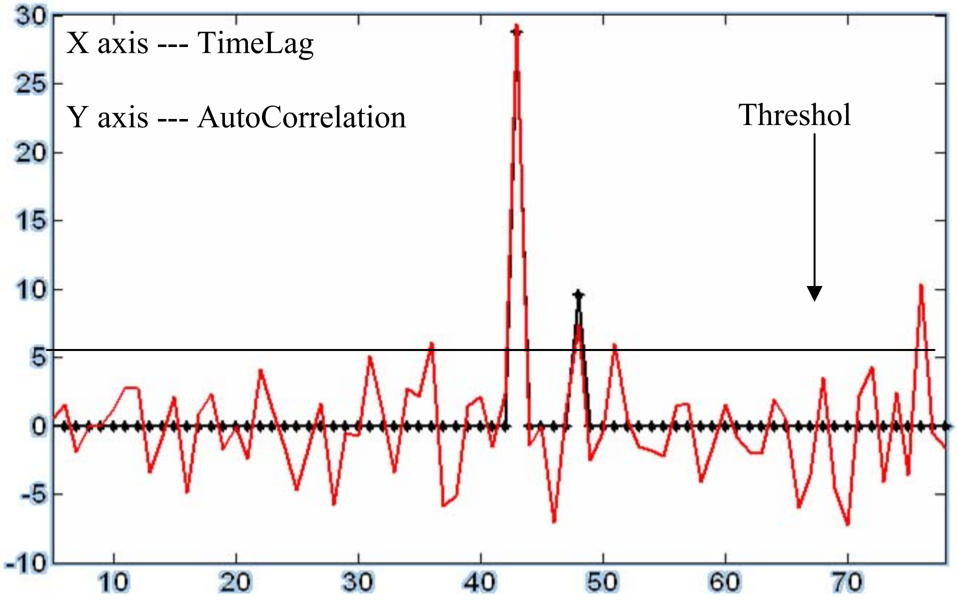

Figure 6.10 PN-Sequence

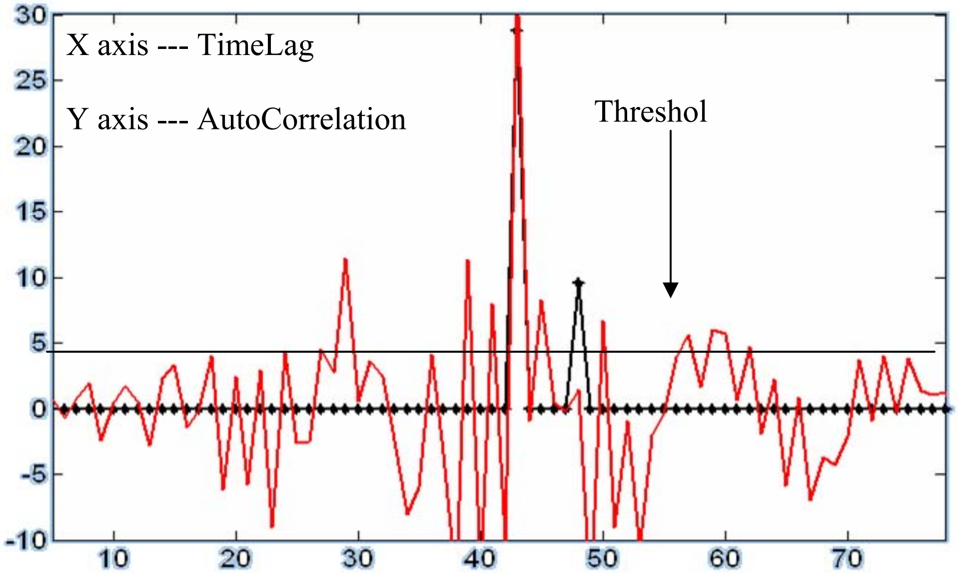

Figure 6.11 Kasami Sequence

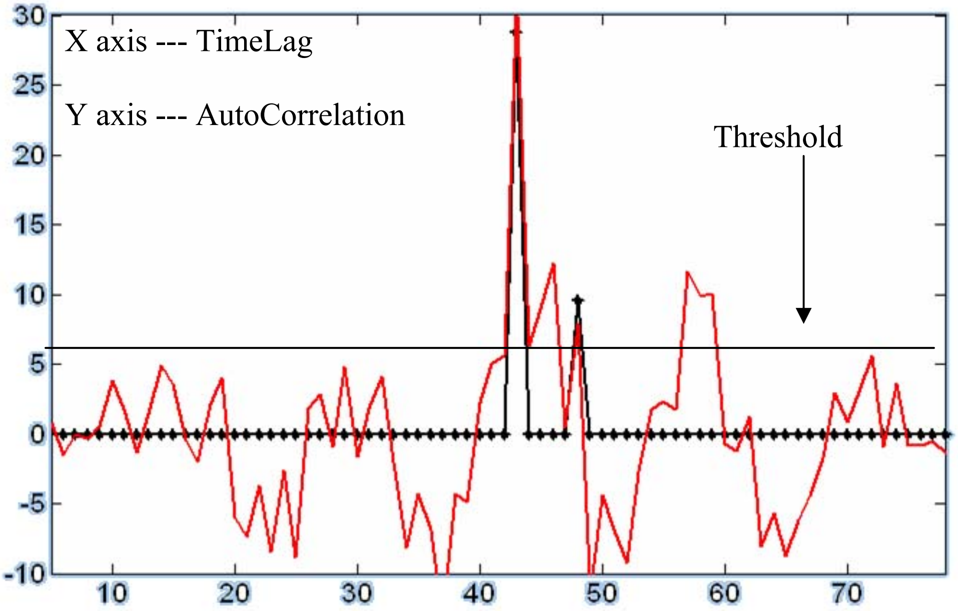

Figure 6.12 Gold Sequence

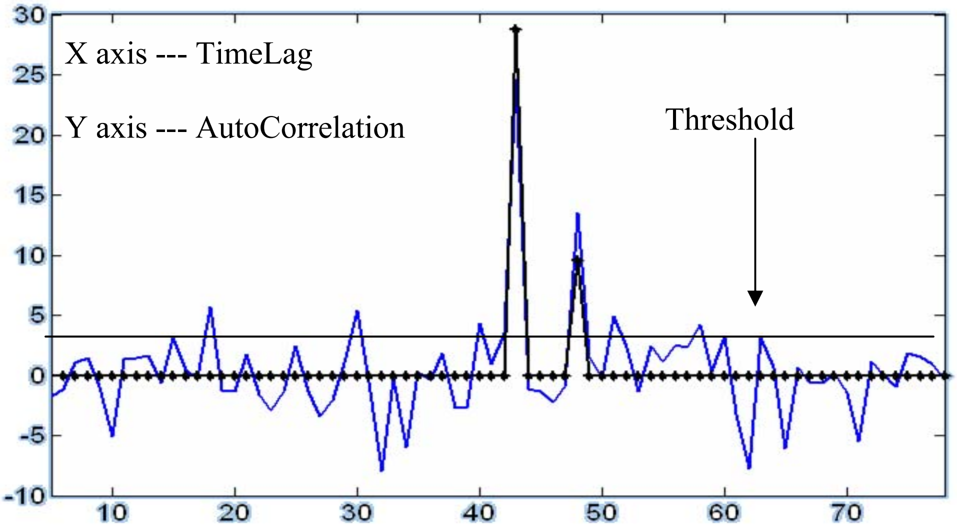

Figure 6.11 Golay Sequence

6.5 CONCLUSION

It can be concluded from the afore mentioned graphs that for the multi target detection golay codes are the best choice. As in the figure 6.9 where the coding sequence used is kasami sequence and weaker target is not at all detectable even the threshold is readjusted. It is not due to the noise but the negative side lobe of a weaker target which has pulled down the main lobe of the stronger target.In the figure 6.8, 6.9 and 6.10 there are significant numbers of false alarms .In the figure 6.10 though the weaker target is detectable at this threshold but if it were a bit delayed it was no more detectable. In the single target detection too golay codes have shown the best performance.

Chapter 7

DOPPLER EFFECTS AND GOLAY CODES

7.1 INTRODUCTION

As discussed in chapter 3, since the complementary-coded pulse radar is to be onboard a moving vehicle and the pulses coded by complementary codes are to be transmitted using quadrature phase shift keying, the effects of Doppler phase shift on pulse compression and sidelobes cancellation have to be studied. Simulations were run by introducing phase shift of 0.5°, 1°, 5°, 10°, 15°, 20°, and 25°, respectively, in the IQ demodulation for the second pulse. It was expected that the main lobe peak would decrease and the sidelobes would appear when phase shift was included. The carrier frequency used in the simulations is 150MHz. With the help of these phase shifts the differential speed of the target is calculated.

$$\delta R = \frac{c\Delta\phi}{4\pi f_c} \qquad (7.1)$$

where $\delta R =$ differential speed

$\Delta\phi =$ Doppler phase shift in radians

$f_c =$ carrier frequency

$c =$ Electromagnetic velocity.

7.2 DOPPLER SHIFT AND NP CRITERION

The Neymen pearson criterion according to the doppler shift also changes.NP detector for the significance of the test 0.001 ,the power of the test has also changed for different Doppler shift.

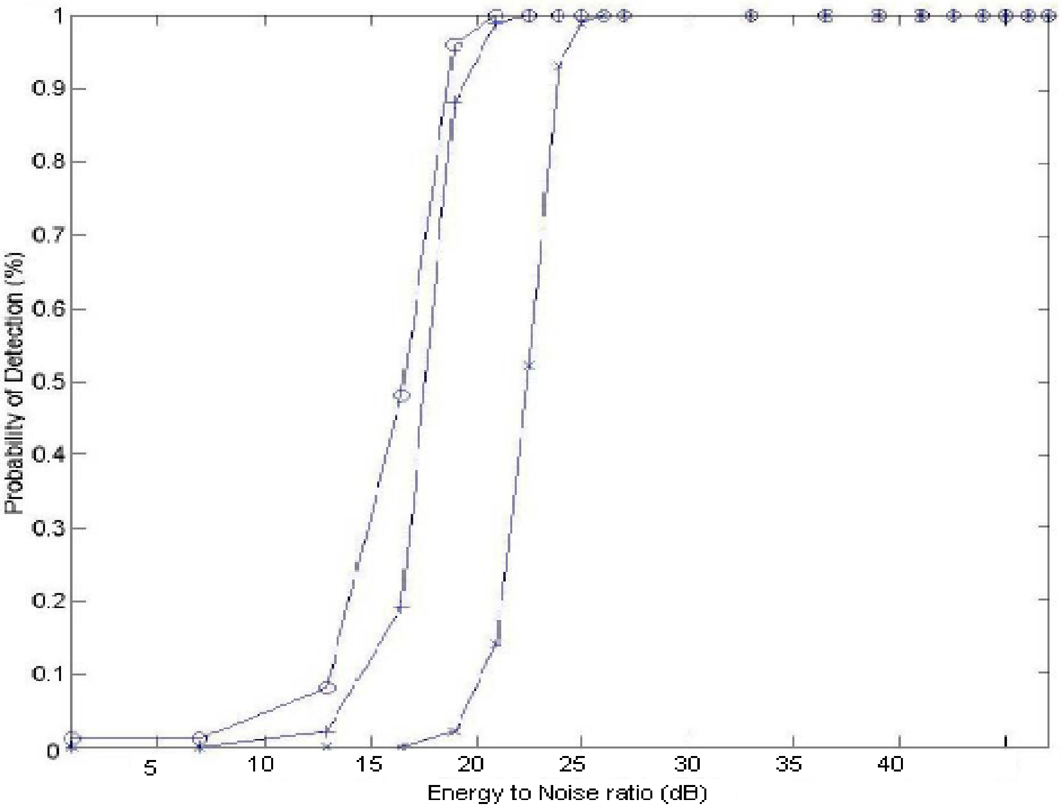

Figure 7.1

7.3 AMBIGUITY DIAGRAM

The ambiguity diagram is a waveform analysis tool. It is a three-dimensional plot that represents the matched filter output at different Doppler shift levels and range delays. Ambiguity diagram data points come from correlating the returning waveform with a filter set as the outgoing waveform.

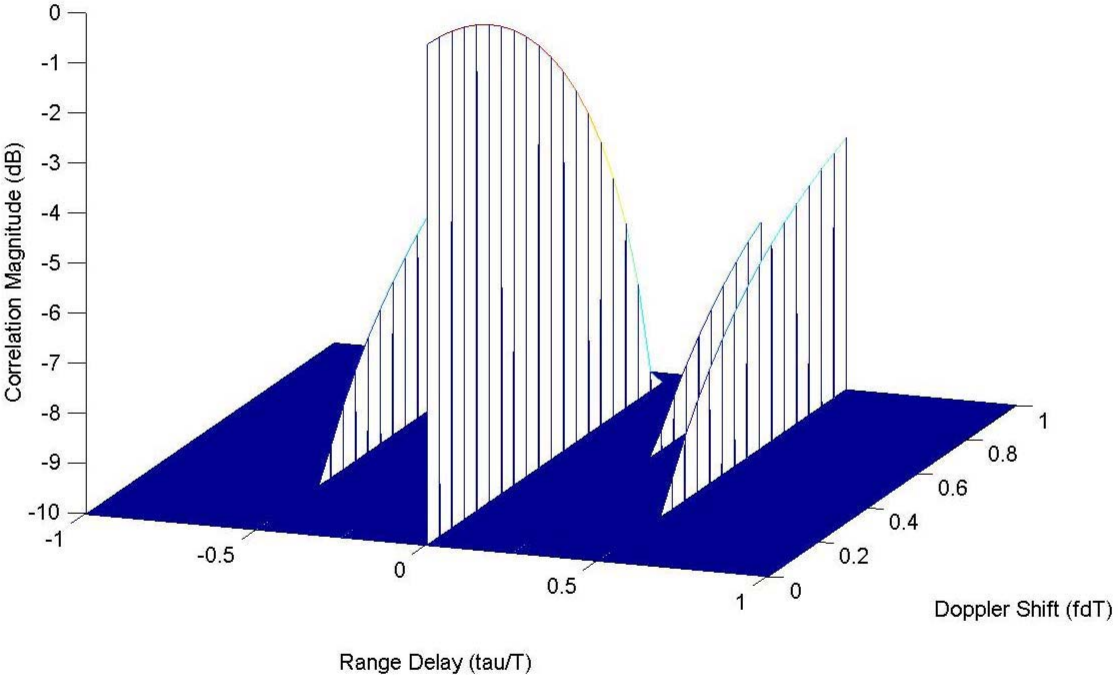

Figure 7.2

It can be analysed from the ambiguity diagram of the golay codes in the figure 7.2 that as the phase shift increases , sides lobes start to arrive and the main lobe begins to diminish.In the table 7.1 it can be seen that for increasing phase shift peak side lobe ratio also increases.

Table 7.1

Phase shift (degrees)	0.5	1	5	10	15	20	25
Maximum SL/ML ratio (dB)	-60.41	-54.38	-40.4	-34.4	-31.1	-28.7	-26.3

For different differential speeds which are calculated from the formula in equation 7.1 for the carrier frequency which is taken is 150 MHz, the maximum side lobe to main lobe ratio increases drastically and the prominent characteristic of golay codes i.e. the absence of the side lobes, is no more significant.

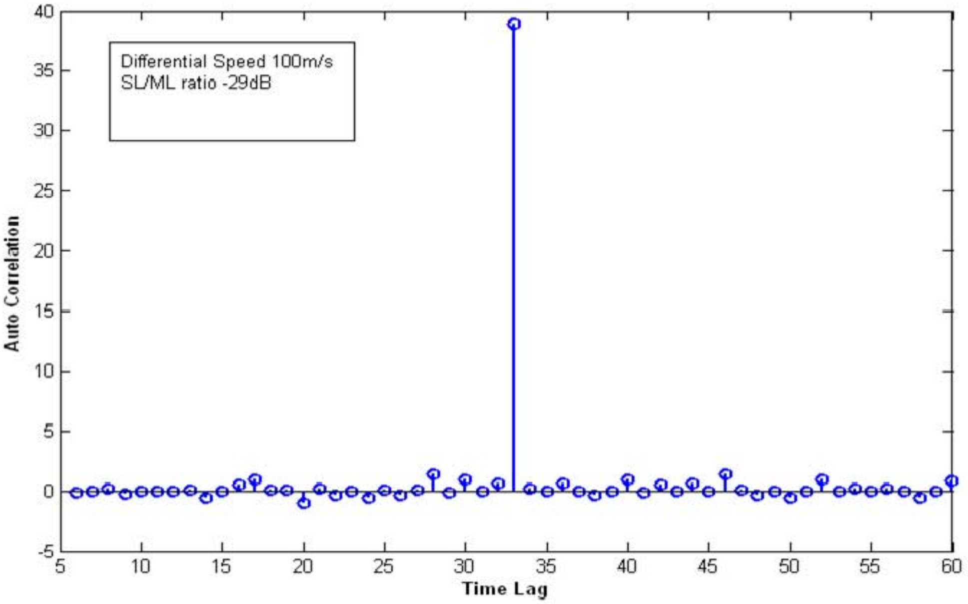

Figure 7.2

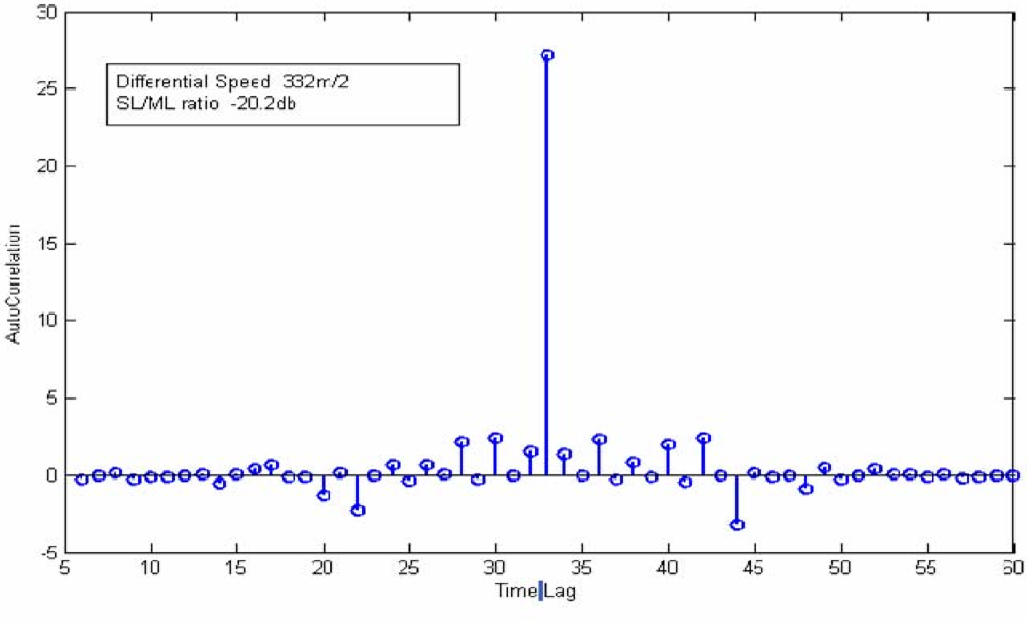

Figure 7.3

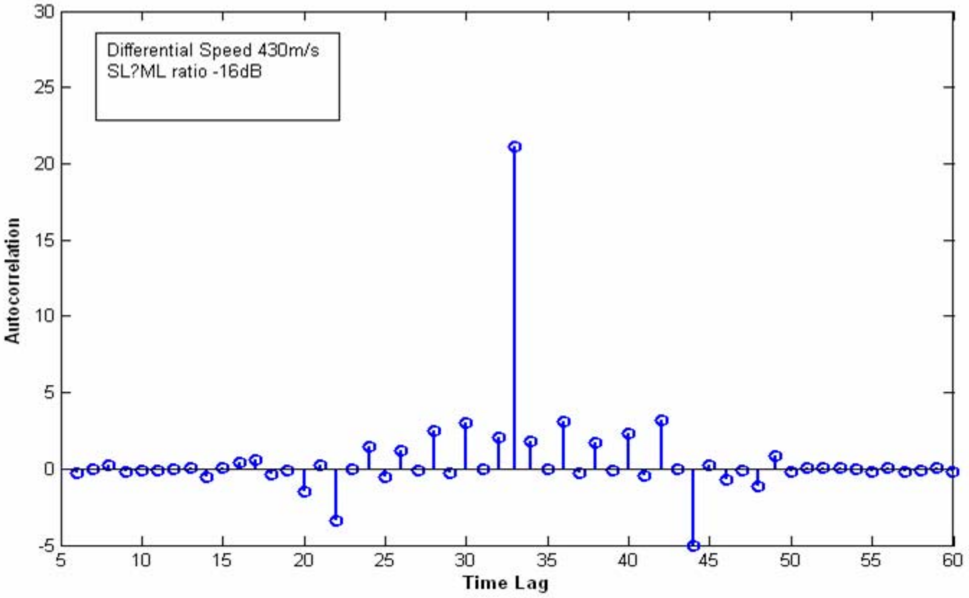

Figure 7.4

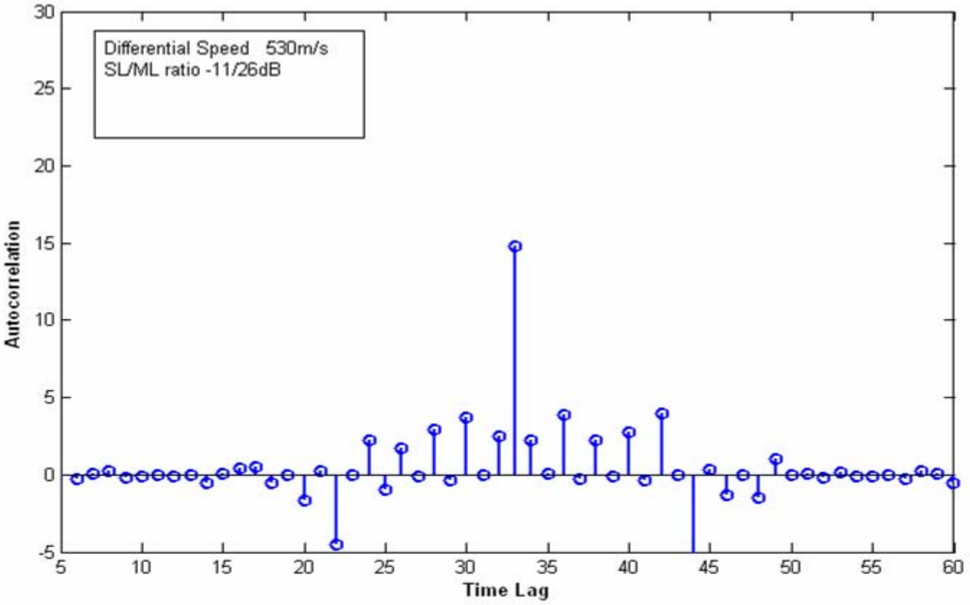

Figure 7.5

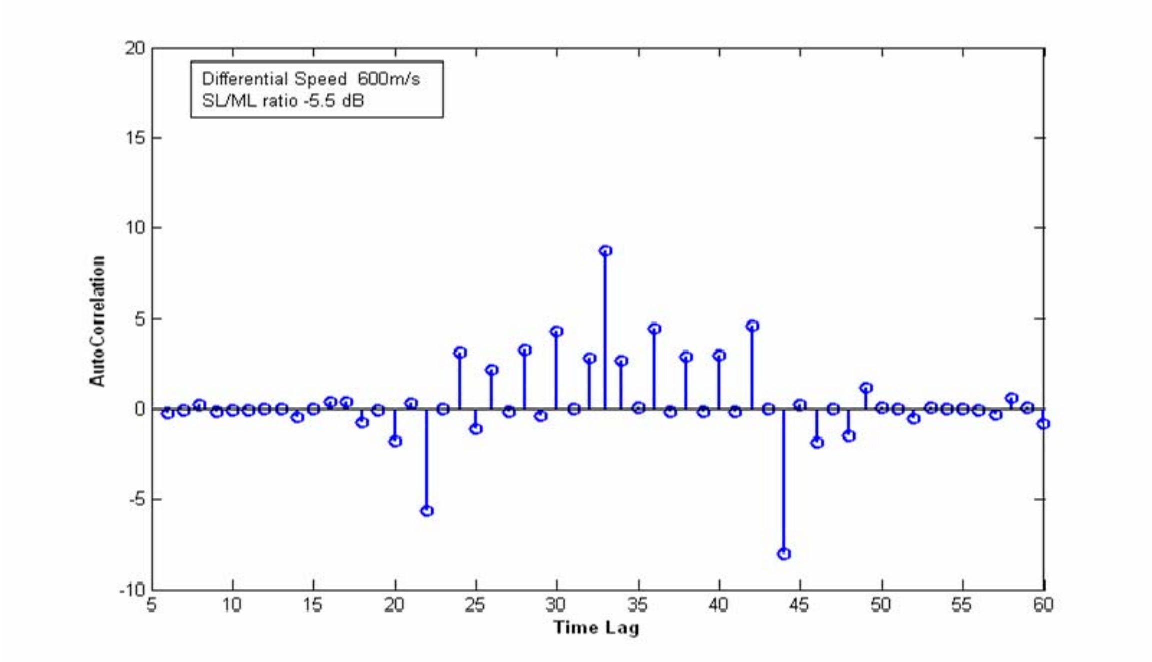

Figure 7.6

7.4 Conclusion on Doppler Shift

From figure 7.2 to 7.6 it can be concluded that golay codes lose their efficiency as the differential speed goes high. Acceptable performance of golay codes is upto the sonic speed. Hence it can be said that for terrain follower environment golay codes performance is metter than any other known compression technique. But for air to air surveillance golay codes are not a decent choice.

CHAPTER 8

CONCLUSION & FUTURE RECOMMENDATIONS

8.1 Conclusion

For the detection of multiple targets through a single sensor in non adaptive environment, these points can be concluded.

- For detection of targets in low ENR golay code exhibit best performance.
- In multi target scenario,with the help of Golay codes Neymen Pearson criterion can be achieved for static environment ,which can not be achieved by any other code.
- Higher order Statistics satisfactorally suppress the noise only chunks of received data.So threshold can be set at much higher value without the consideration of false alarms.
- At supersonic differential speeds performance of golay codes are not satisfactory.

8.2 Recommendations:

In the thesis additive white Gaussian noise was added with the golay coded sequence. For the future work following aspects are recommended

- Implementation of the system using multiplicative channel noise.
- Effects of non Gaussian and colored Gaussian noise in higher order statistic implementation.
- For Higher differential speeds employment of Frank Codes.

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