TRACKING OF TARGETS USING LINEAR FREQUENCY MODULATION

B.Swarna Manasa[1], N.Meghana[2],SK.Raziyaa[3], P.Dayamani[4],MS. N. Roopavathi[5]

[1]*Department of ECE, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING FOR WOMEN, INDIA*
[2]*Department of ECE, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING FOR WOMEN, INDIA*
[3]*Department of ECE, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING FOR WOMEN, INDIA*
[4]*Department of ECE, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING FOR WOMEN, INDIA*
[5]*Department of ECE, GAYATRI VIDYA PARISHAD COLLEGE OF ENGINEERING FOR WOMEN, INDIA*

Abstract*—The main objective of this project is to design a radar system for tracking of targets using linear frequency modulation. Two important factors to be considered for radar waveform design are high range resolution and maximum range detection. In this we consider two cases, before that we have to know that the multiple missiles are fired together or one after another which is called as salvo; while firing takes place using that case then the fundamental issue in radar system is its capability to resolve two small targets that are located at long range with very small separation between them which are in same direction. The two missiles are appears like a single target, if the first missile gets destroyed then second missile get ready to attack. So, Pulse compression techniques are used in radar systems to avail the benefits of large range detection capability of long duration pulse and high range resolution capability of short duration pulse. In this technique a long duration pulse is in which frequency modulated using linear frequency modulation before transmission and the received signal is passed through a match filter to accumulate the energy into a short pulse. A matched filter is used for pulse compression to achieve high signal-to-noise ratio (SNR).

Range resolution is related to the pulse width of the waveform. The narrower the pulse width, the better is the range resolution. But, if the pulse width is decreased, the amount of energy in the pulse is decreased and hence maximum range detection gets reduced. To overcome this problem pulse compression techniques are used in the radar systems. The main application of pulse compression radars includes tracking of launch vehicles, missile guidance etc.

***Keywords*—— Salvo, Correlation, Chirp, LFM, Matched Filter, Pulse Compression, Radar, Range Resolution, Range Detection, Targets**

1. INTRODUCTION

The electronic system that uses electromagnetic waves to detect the presence of target objects is RADAR (Radio Detection and Ranging). RADAR works by transmitting short pulses of radio energy and receiving signals that are reflected by the target as echoes. It measures the range, direction, and velocity of the target. The received echoes provide information about the target, including range, angular position, velocity, and other characteristics. By comparing the received echo signal with the transmitted signal, the presence of the target can be detected, and further calculations can provide more information about the target. Air Traffic Control Systems commonly use RADAR. RADAR's chief attributes are its ability to detect a target at great distances and locate its position with high accuracy. The use of shorter pulse provides good range resolution to the Radar performance. But the usage of small short pulse requires more peak power and more energy to pack the pulse by increasing the peak power.

The complexity in designing the transmitter and receiver systems is increased by the higher peak power, since the entire components used in the system have to withstand the peak power. To overcome this issue, the short duration pulse is first converted into a longer duration pulse. Reduction of the peak power is achieved by increasing the length of the pulse, but the range resolution is reduced. To preserve the range resolution and modulation is to be used which results in an increase in the bandwidth of the transmitting pulse (long duration pulse). Pulse Compression Technique (PCT) is the term used for this method, which is widely used in Radar applications where high peak power is not required.

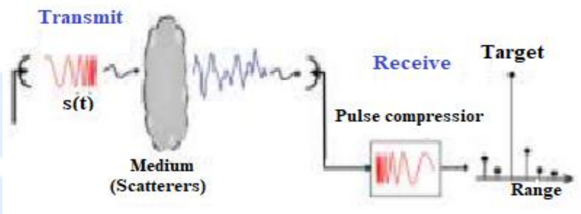


Fig 1:Pulse Compression

Matched filter performs correlation between the transmitted signal and received signal.The reflected signal from the radar gets corrupted by adding white Gaussian noise (AWGN) from the transmission channel. Maximizing the signal-to-noise ratio (SNR) is more important for detection probability than preserving the exact shape of the received signal. Therefore, the focus is on maximizing the SNR of the received signal. The matched filter, which is the optimal linear filter for maximizing the SNR in the presence of Additive White Gaussian Noise provides better performance. The Pulse compression filter is used in the Radar receiver to compress the signal in the time domain, resulting in finer range resolution as compared to uncoded pulses. Several pulse compression methods have been used in the past, including binary phase coding, polyphase coding, frequency modulation, and frequency stepping. The most well-known method was invented by R.H. Dickie and is termed as linear frequency modulation (LFM). In this implementation, the matched filter algorithm for pulse compression Radar using LFM is implemented using the MATLAB tool.In the de-chirping processing, after analyzing the graph obtained we can track the path followed by the missiles using linear frequency modulation.

2. PULSE COMPRESSION

One of the signal processing technique used to reduce the peak power of radar pulse and maintain range resolution is called Pulse Compression. The transmitter employs longer pulses, which are matched with filter output in the radar receiver to produce short pulse signals with improved SNR during pulse compression. This technique is widely used in radars to increase transmitted energy and range resolution, resulting in higher range detection. Pulse Compression techniques achieve the advantages of both larger range detection ability of long pulse and better range resolution ability of short pulse. Fig 2 shows two pulses with the same energy but different peak power and pulse width. Different modulation techniques can be used to modulate the pulse, such as linear frequency modulated signals or non-linear frequency modulated signals and discrete phase code modulation.

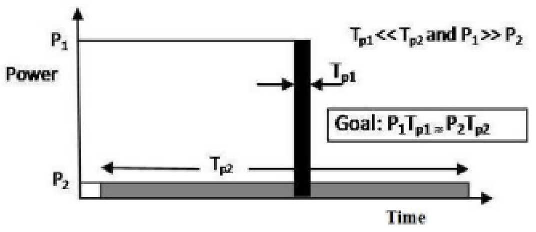


Fig 2:Transmitted signal and received signal

For range resolution, the bandwidth of the pulse is taken into account but not the duration of the pulse.

$$P = \frac{C\tau}{2} = \frac{C}{2B} \quad (1)$$

where ρ=range resolution; τ=duration of pulse; c=speed of light; B=signal bandwidth.

The Pulse Compression Ratio (PCR) is stated by

$$\text{PCR} = \frac{width\ of\ the\ pulse\ before\ compression}{width\ of\ the\ pulse\ ofter\ compression} \quad (2)$$

Fig 3 shows the Block Diagram of a Pulse Compression Radar system. In this technique, the modulation of a short pulse into a long duration pulse of low peak power occurs before transmission, either in frequency or phase. The use of a long duration pulse provides higher range resolution with limited peak power and concentrates the entire energy in the compressed pulse. The Trans-receiver (TR) is a switching unit that uses the same antenna for transmission and reception. The Pulse Compression filter performs the matching of the transmitted and received waveform spectra. In this filter, the correlation operation is performed on the received and transmitted signals. The matched filter extracts the portions of the received signal that are similar to the transmitted signal, while disregarding the remaining signal parts.

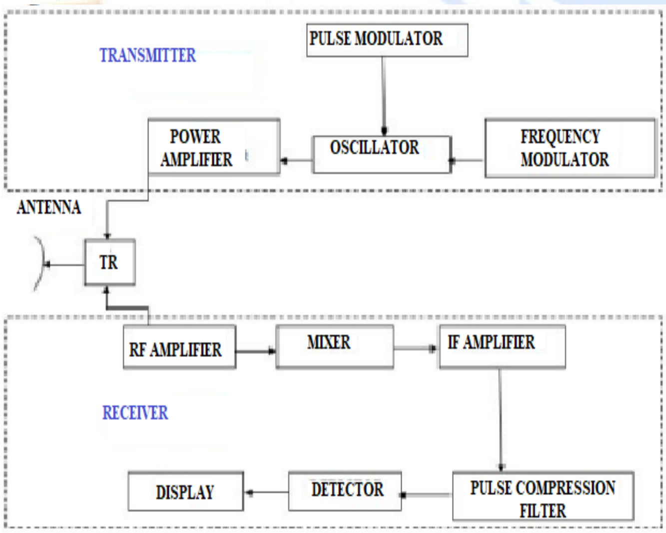


Fig 3: pulse compression radar

3.DESIGN

The algorithm for pulse compression in radar consists of two main steps. First, generate the Linear Frequency Modulation waveform by generating In-phase and quadrature phased base band signals and combining them based on the mathematical equation of chirp signal. Second, adopt the correlation method for the matched filtering process. Match the LFM signal with the delayed version of it to obtain the result. The flow chart(Fig.4) that describes the whole work is shown below.

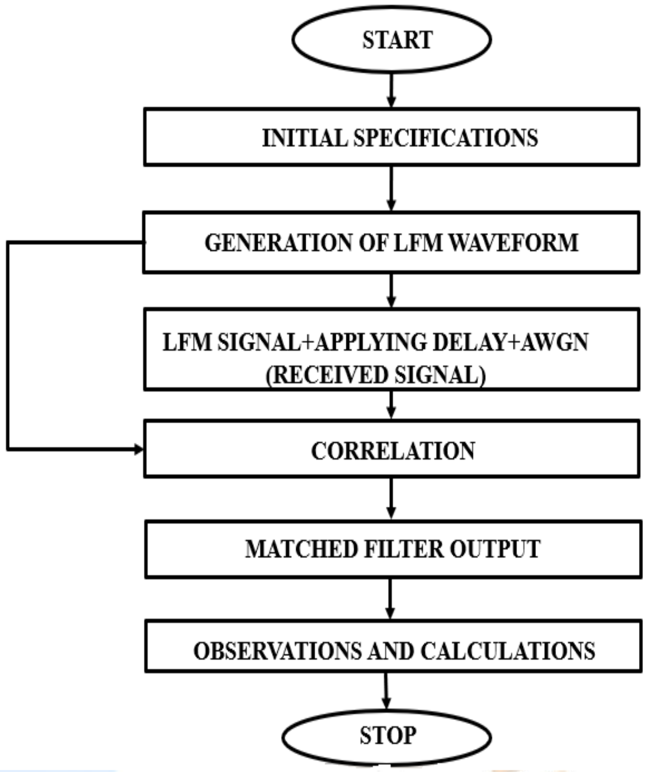


Fig 4: Flow chart of the system

The higher peak power increases the complexity in designing the transmitter and receiver systems since the entire components used in the system have to withstand the peak power. To overcome this issue, pulse expansion is used. The range detection and range resolution of the transmitted signal from the Radar are increased by undergoing expansion followed by modulation. The target presence is indicated by the reflected signal from the Radar and various information regarding the target can be extracted by comparing the received echo signal with the transmitted signal. The system's block diagram shown below.

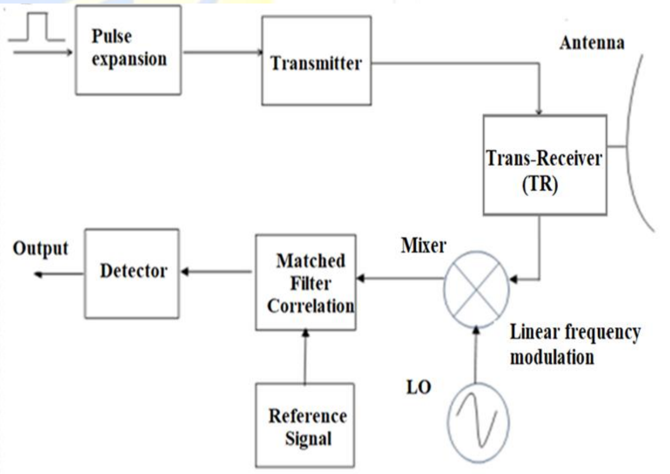


Fig 5: Block diagram of the system

3.1 LFM Transmitted Signal:

An Linear frequency modulated (LFM) signals are used in most of the radar systems to achieve wide operating bandwidth. The (Fig 6a) is a linear frequency modulated waveform in which carrier frequency varies linearly with time(Fig 6b) over a specific period.

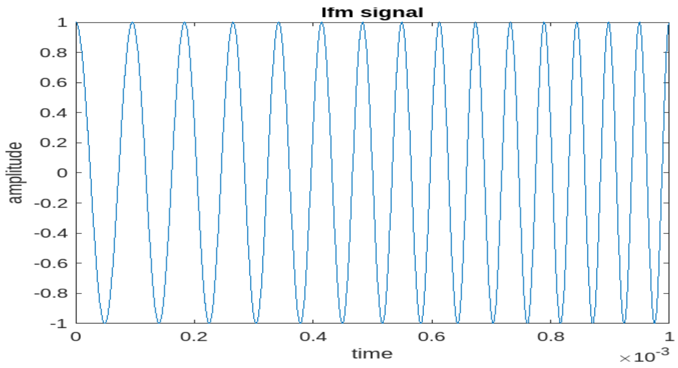


Fig 6a: Linear frequency modulation signal

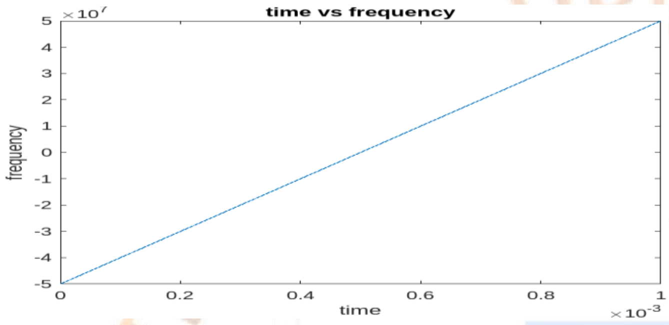


Fig 6b: Time versus Frequency

An LFM waveform is constant amplitude signal, it makes sure that the amplifier works efficiently. Also, this waveform spreads the energy widely in frequency domain.

The mathematical expression of LFM signal is:

$$S(t) = Re\,c\,t\left(\frac{t}{T}\right)e^{j2\Pi(f_c t+kt^2)} \quad (3)$$

Where T=pulse width; fc=centre frequency; K= rate of frequency change.

3.2 Matched filter:

Matched Filter performs the correlation operation. The correlation technique, which is one of the popular DSP methods, is used to implement a pulsed matched filter. Matched filters are commonly used in radar, in which a known signal is sent out, and the reflected signal is examined for common elements of the out-going signal. Pulse compression is an example of matched filtering.

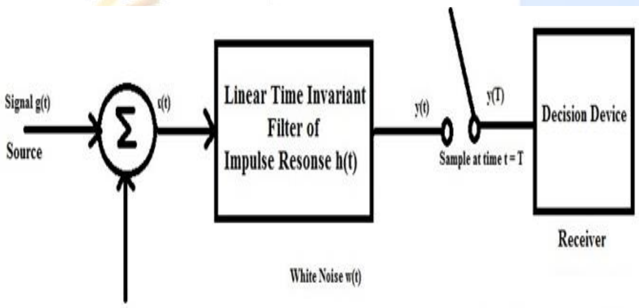


Fig 7: Matched filter Diagram

The block diagram of the matched filter is shown below. Consider the following diagram where g(t) is the input signal & w(t) is the white noise. These two signals are fed to the h(t) filter, which maximizes the signal-to-noise ratio (SNR) of the y(t) output.When two frequency domain vectors are multiplied, the product obtained will be a match which is independent of time alignment between the two signals. The matched filter always responds for each targets reflected energy irrespective of the received radar signals. When converting back the product vector to the time domain, each target will produce a narrow pulse whose delay and amplitude correspond to target distance and size respectively. The FFT converts time domain to frequency domain of signals and the inverse FFT (IFFT) performs the reverse conversion, these two algorithms are key blocks in the pulse compression system.

Let the matched filter operation between the received signal g(t) and impulse response h(t):

$$y(\tau) = g(t) * h(t) = \int_{-\infty}^{\infty} g(t)h(\tau - t)dt \quad (4)$$

Here, g[t] is the received signal, h[t] reference signal where h[t] =g[-t] for the filter to be matched to the transmitted pulse. Matched filtering can also be accomplished in frequency domain which is described by:

$$y(t) = IFFT[G(\omega)H(\omega)] \quad (5)$$

Here, G[w] and H[w] are the fast Fourier transform coefficients (FFT) of the g[n] and h[n] respectively and IFFT represents for Inverse Fast Fourier Transform.

Matched filtering is a process in which detecting a known piece of signal that is corrupted by noise. The filter will maximize the signal to noise ratio (SNR) of the detected signal with respect to the noise. The auto-correlation operation is mathematically equivalent to matched filter with a time-reversed complex conjugate of the signal. The product of the Fourier transforms of the signal g(t) and its time-reversed complex-conjugate can represent the matched filter in frequency domain.

The design mainly results in tracking of targets measuring the graph obtained by the followed steps. The main purpose of this design is for salvo firing missiles. The steps in computations are:

Step 1. Generation of Linear frequency modulated signal for transmission

(a) In-phase waveform generation.

(b) Quadrature phase waveform generation.

(c) Combining these two signals to generate linear frequency modulated signal

Step 2. Creating the received two echo signals By providing sufficient delay and adding AWGN noise (channel disturbances)

Step 3. Implementation of matched filtering algorithm

(a) Taking the Fourier transform of the received echo signals. (b) Taking the complex conjugate of the transmitted signal (reference signal).

(c) Taking the Fourier transform of the above complex conjugated signal.

(d) Multiplication of the two FFT signals

(e) Taking the IFFT of the above

Step 4. Calculate the range corresponding to the matched result from the graph.

Step5. Tabulate the result so as to find the range and range resolution according to the cases.

4. SIMULATION RESULTS

The experimental results are the given below in graphical model. Pulse compression radar is the practical implementation of a matched filter system.

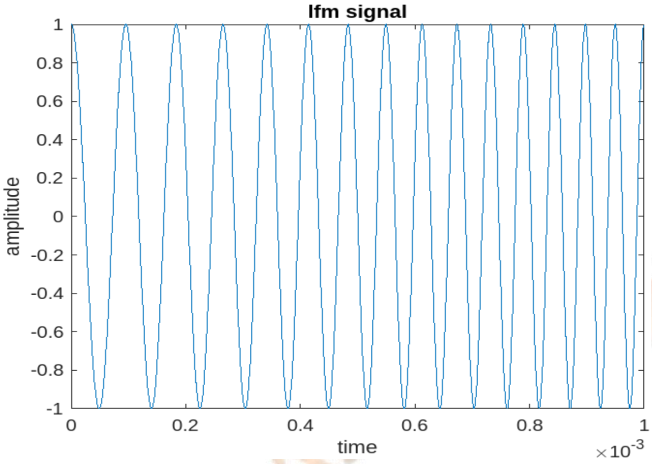


Fig 8(a) Transmitted LFM signal

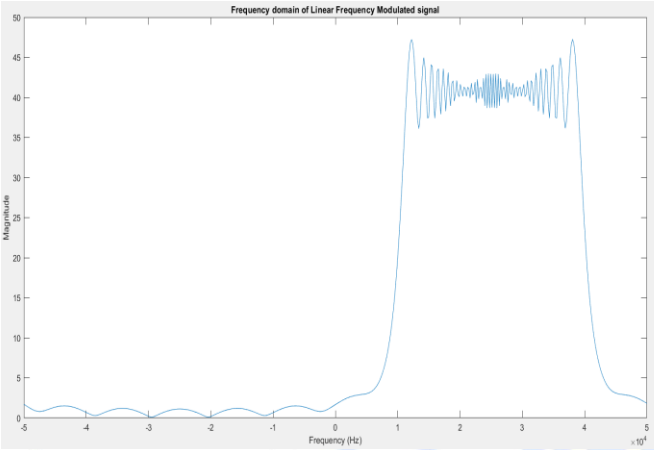
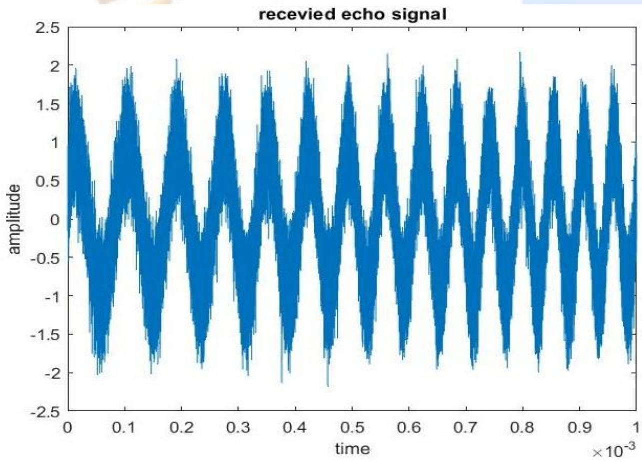


Fig 8(b) Frequency response of the transmitted LFM signal

In the receiver section missiles are traced by analysing the result gained from the graphical model. The strength of the Signal decreases as the range increases. In the below Fig 9a shows that single missile received echo signal and Fig 9b shows that single missile detected at the matched filter output.



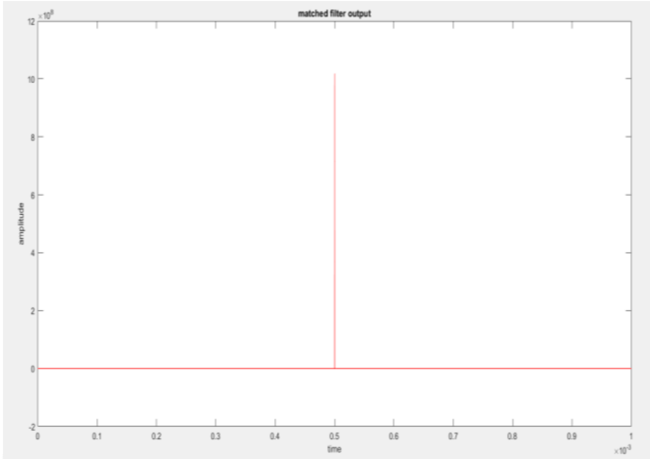
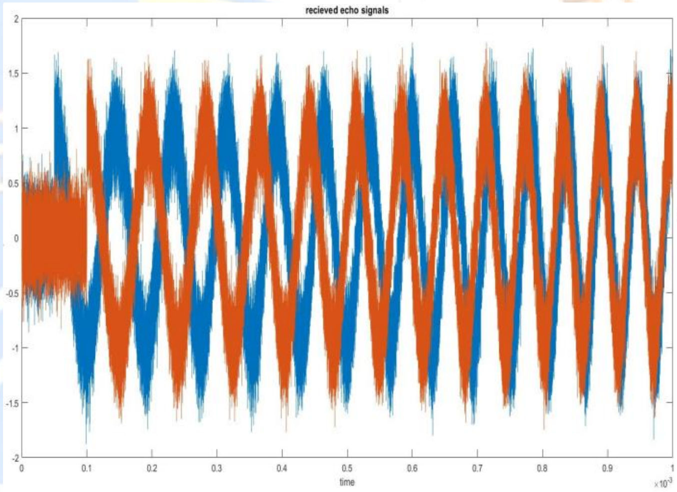


Fig 9(a) Received echo signal for single target

(b) Matched filter output

In the second case considering that two missiles are fired by salvo firing. So that we use linear frequency modulation technique to get maximum range detection and high range resolution. The below Fig 10(a) shows that two missiles received echo signals and Fig 10(b) shows that two missiles are detected at the matched filter output. Table 1 below shows the Specifications for single target detection as Case 1 and Table 2 below shows the Specifications for two target detection as Case 2.



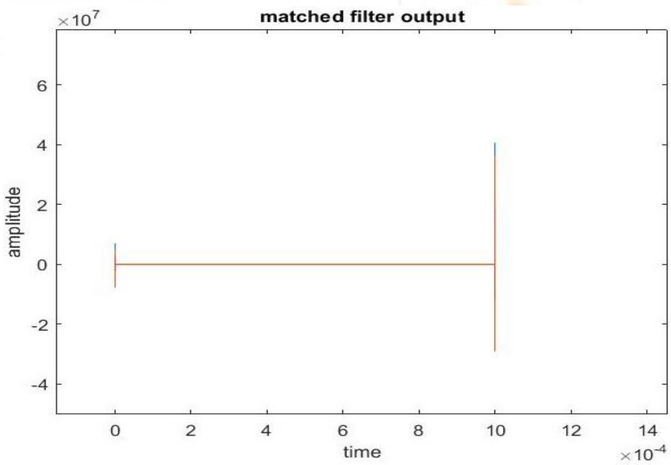


Fig 10(a): Received noise echo signals for two targets

(b): Matched filter output

Table 1: Specifications for single target detection (Case 1):

S.NO	Parameters	Values
1.	Pulse width	1ms
2.	SNR	10dB
3.	Carrier Frequency	10KHZ-20KHZ
4.	Sampling Frequency	100MHZ
5.	Delay time	10µs

Table 2: Specifications for two targets detection (Case 2):

S.NO	Parameters	Values
1.	Pulse width	1ms
2.	SNR	10dB
3.	Carrier Frequency	10KHZ-20KHZ
4.	Sampling Frequency	100MHZ
5.	Delay time of first missile	50µs
6.	Delay time of second missile	100µs

5. RESULT ANALYSIS:

In this work, primarily generated Linear frequency modulated waveform by combining the inphase and quadrature phase waveforms. By applying matched filter algorithm in the two case i.e., first case is single target detection for maximum range and second case is two targets detection which are in salvo firing for maximum range detection and high range resolution.

Table 3: Result for single target detection (case 1):

S.NO	Parameters	Values
1.	Range	1492507500 meters
2.	PCR (Pulse compression ratio)	2

Table 4: Result for two targets detection (case 2):

S.NO	Parameters	Values
1.	Missile1 Range	1108950000 meters
2.	Missile2 Range	7454550000 meters
3.	Range resolution	150000 meters

6. CONCLUSION:

we describe the design of a radar system for tracking of targets using linear frequency modulation. In this we consider two cases, first one is for detection of a single target to get maximum range detection. second case is for tracking of two missiles using linear frequency modulation to get longer range detection and higher range resolution.so that in the second case two missiles are fired simultaneously then it appears like a single target, if the first missile gets destroyed then second missile get ready to attack. So we conclude that Pulse compression techniques are used in radar systems to avail the benefits of large range detection capability of long duration pulse and high range resolution capability of short duration pulse.

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