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Implementation of Pulse Compression for Space Applications

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Abstract: Pulse Compression is one of the key steps in the signal processing of a Radar system. Radar system uses Pulse compression techniques to provide the benefits of larger range detection and high range resolution. This is gained by modulating the transmitted signal and after that matching the received echo with the transmitted signal. Matched filter is used as the pulse compression filter which provides high SNR at the output. Matched Filter is a time reversed and conjugated version of the received radar signal. There are several methods of pulse compression that have been used in the past, out of which most popular technique is Linear Frequency Modulation (LFM).

This paper deals with the design to develop and simulate pulse compression and matched filter algorithm in MATLAB to study the LFM pulse compression technique. Matched filter is used as the pulse compression filter which provides high SNR at the output. Matched Filter is mathematically equivalent to convolving the received signal with a conjugated time-reversed version of the reference signal. The main application of pulse compression Radars includes tracking of launch vehicles, unwanted particles in space, Missile guidance etc. Here, in this paper, we are discussing the pulse compression application in tracking the launch vehicle so as to check whether it had followed the predetermined path or not.

Keywords: Correlation, Chirp, LFM, Matched Filter, Pulse Compression, Radar

I. INTRODUCTION

RADAR (Radio Detection and Ranging) applies to an electronic system that uses electromagnetic waves to detect the presence of target objects. The basic working principle of Radar is the transmission of short bursts of radio energy and receives signals which are reflected by the target as echoes. The Radar is used to measure the range, direction, and velocity of the target. The received echoes are used to extract information about the target which includes- range, angular position, velocity and other characteristics. The echo signal from the radar indicates the presence of a target by comparing the received echo signal with the transmitted signal. By providing further calculations other information regarding the target can be obtained. In Air Traffic Control System, the application of Radar is commonly used. The chief attributes of Radar are the ability to detect a target at great distances and to locate its position with high accuracy. The use of shorter pulse provides good range resolution to the Radar performance. But on the other hand, the use of shorter pulses requires more peak power. The shorter the pulse gets, the more energy is essential to pack the pulse by increasing the peak power.

The introduction of high peak power increases design complexity of transmitters and receivers since the components used in the entire system have to withstand the peak power. In order to overcome this issue, the short duration pulse is first converted into a longer duration pulse. Increasing the length of the pulse results in a reduction of the peak power, at the same time it reduces range resolution. In order to preserve the range resolution, modulation is to be incorporated which results in an increase in bandwidth of the transmitting pulse (long duration pulse). This above-used method is termed as Pulse Compression Technique (PCT) where high peak power is not required and is widely used in Radar applications.

Pulse compression radar is the practical realization of a matched filter system. The reflected Radar signal gets corrupted by adding white Gaussian noise (AWGN) from the transmission channel. The detection probability is related to signal-to-noise ratio (SNR) rather than the exact shape of the received signal. Hence more importance is given to maximizing the SNR of the received signal than preserving the exact shape of it. The matched filter is the optimal linear filter for maximizing the signal-to-noise ratio (SNR) in the presence of Additive White Gaussian Noise. Matched filter provides better performance. In the Radar receiver, Pulse compression filter is used for compressing the signal in time domain, which results in finer range resolution as compared to uncoded pulses. Several methods of pulse compression have been used in the past out of which the most well-known method was invented by R.H. Dickie termed as linear frequency modulation (LFM). The other pulse compression methods are binary phase coding, polyphase coding, frequency modulation, frequencies stepping etc. Here, using the MATLAB tool, the matched filter algorithm for pulse compression Radar using LFM is implemented. In the de-chirping processing, after analyzing the graph obtained we can track the path followed by the launch vehicle.

II. LITERATURE SURVEY

Radar pulse compression is a topic of great interest over past few decades. A lot of research work has been carried out to achieve low side lobes and high range resolution in the radar pulse detection system. Several methods of pulse compression have been used in the past. The most common and popular among them is the Linear Frequency Modulation (LFM) which was invented by R.H Dickie in 1945. The other popular pulse compression techniques include Costas codes, Binary-phase codes, polyphase codes and non-linear frequency modulation.

Kiran Patel, Usha Neelakantan , Shalini Gangele, J.G Vacchani, N.M. Desai implemented [1] the Pulse compression using LFM technologies is a useful technique for SAR; it is an enabling technology to facilitate the use of the low power component in the transmitter. It also has the benefit of improving the dynamic range and range resolution of the radar. LFM generation using DDCS techniques has lower computational complexity compared to other techniques and better programmability, flexibility, and repeatability.

Vijay Ramya K., A. K. Sahoo., G. Panda. [2], had proposed a technique in which amplitude weighting is applied to a combination of the incoming signal and one bit shifted version of the incoming signal. Here matched filter is used as the cross correlation between the amplitude weighted signal and the combined signal. This technique produces better Peak Sidelobe ratio (PSL) and integrated sidelobe ratio (ISL) than all other conventional side lobe reduction techniques. The significant Main lobe splitting which is the main disadvantage in Woo filter is eliminated in this technique and implemented and incurs a minimal signal to noise ratio SNR loss.

Keeler and Hwang [3] presented one of the first holistic studies involving what was known about pulse compression for weather radar at the time. This was the first mention of the possibility of higher spatial and temporal resolution using phased array antennas for weather observations, and it helped define many of the parameters still used to analyze waveform performance. Also of concern to weather radar specifically was how tolerant pulse compression waveforms would be to Doppler shifts.

Bucci and Urkowitz [4] showed successful simulations indicating a lack of significant degradation using certain types of waveforms. A number of simulations using Barker codes were performed (Baden and Cohen 1990; Bucci et al. 1997; Mudukutore et al. 1998; Duh et al. 2004), showing limited usefulness for weather radar.

Griffiths and Vinagre [5] presented a study involving the use of a piecewise LFM, also known as nonlinear frequency modulation (NLFM), for use with satellite based weather radar systems. By introducing slightly different LFM rates at the edges of the waveform, and keeping LFM throughout the center of the waveform, lower sidelobes were made possible. To achieve the desired sidelobes of 262 dB, however, significant windowing was still used in conjunction with the NLFM technique.

III.PULSE COMPRESSION

Pulse Compression is one of the important signal processing technique which is used to reduce the peak power of radar pulse by the usage of long especially modulated pulses in order to sacrificing the range resolution associated with a shorter pulse. In the transmitter side longer pulse is employed and at radar receiver the matched filter output results in short pulse signals with improved SNR during pulse compression procedure. This pulse compression is widely used in the radars to get higher range detection due to increasing the transmitted energy and high range resolution. The advantages of larger range detection ability of long pulse as well as better range resolution ability of short pulse are achieved by Pulse Compression techniques. In pulse, we can modulate in different ways, such as linear frequency modulated signals or non-linear frequency modulated signals and discrete phase code modulation

The Block Diagram of Pulse Compression Radar system is shown in Fig 1. In Pulse Compression technique, a short pulse is converted to long duration pulse of low peak power, which is then modulated either in frequency or phase before transmission. The use of long duration pulse gives higher range resolution in limited peak power and in the received signal the whole energy will concentrate at the compressed pulse. For transmission and reception purpose the same antenna is used, Trans-receiver (TR) which is a switching unit.

Pulse Compression filter, which performs the matching when the transmitted and received spectrum of waveform matches. The correlation between the transmitted and the received pulses is carried out in this filter. The received pulses with similar characteristics to the transmitted pulses are spotted by the matched filter whereas other received signals are ignored.

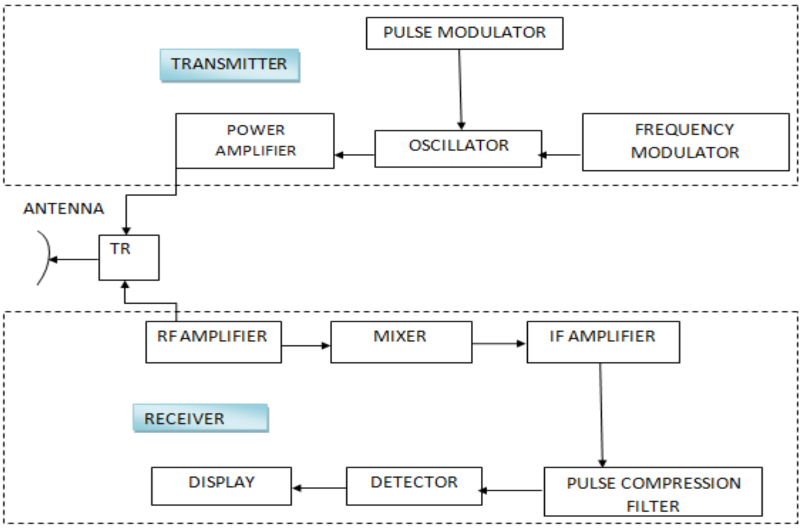

Fig.1.Block diagram of pulse compression radar

IV. METHODOLOGY

In principle, a radar system emits an electromagnetic (*EM*) wave into free space and "listens" for its echo. If an object is within the radar system's beam, a current is induced, generating an EM-field itself. From this EM-field, called scattering field, an EM-wave is reradiated in all directions. Fig 2 illustrates the basic principle of Radar. Fig.3 illustrates two pulses having same energy with different pulse width and peak power.

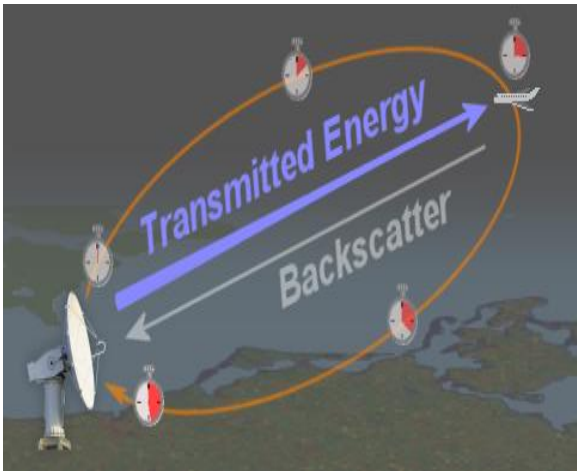

Fig.2. Basic Principles of the Radar

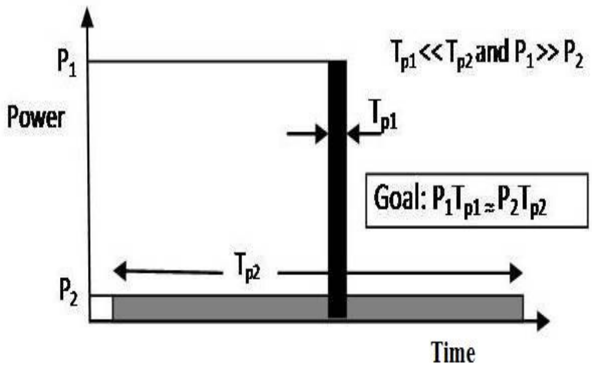

Fig 3: Transmitted signal and receiver signal

Fig.3 illustrates two pulses having same energy with different pulse width and peak power. For range resolution, the bandwidth of the pulse is taken into account but not the duration of the pulse.

$$\rho = \frac{c\tau}{2} = \frac{c}{2B} \tag{1}$$

Where ρ=range resolution; τ=duration of the pulse; c=speed of light; B=signal bandwidth.
The Pulse Compression Ratio (PCR) is defined as

$$PCR = \frac{\text{width of the pulse before compression}}{\text{width of the pulse after compression}} \tag{2}$$

III. DESIGN

The algorithm for pulse compression in Radar involves mainly two steps. First is the generation of Linear Frequency Modulation waveform followed by Matched Filtering. For the generation of LFM waveform firstly In-phase and quadrature phased baseband signals are generated. Then combining these two waveforms based on the mathematical equation of chirp signal yields the LFM signal. For matched filtering process correlation method is adopted here. In matched filtering, the LFM signal and the delayed version of it is matched to obtain the result. The flow chart (Fig.3) which describes the whole work is shown below:

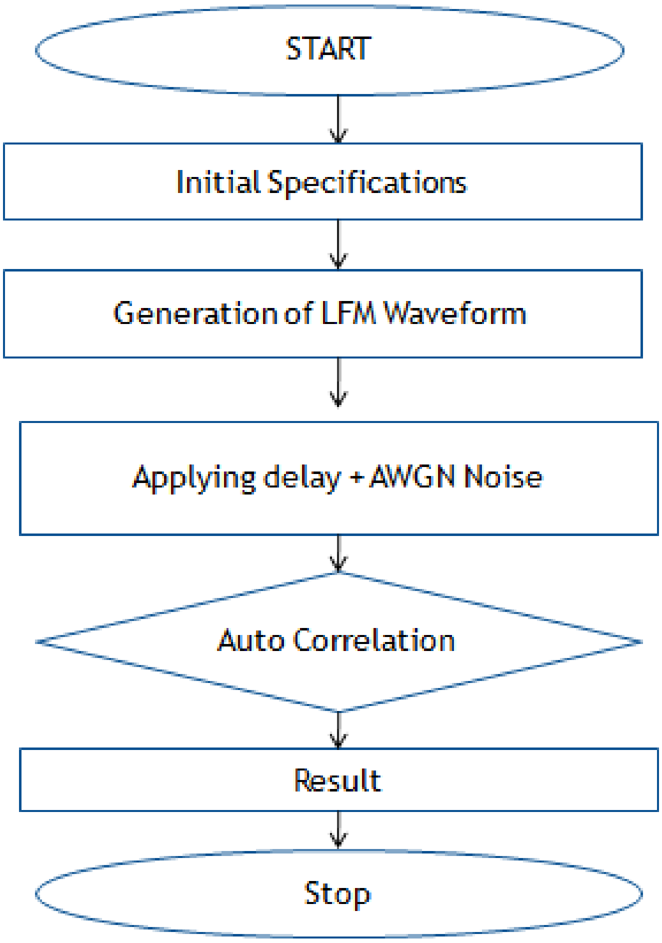

Fig 3: Flowchart of the system

V. SYSTEM DESIGN

The transmitted signal of the Radar undergoes expansion followed by modulation to increase the range detection and resolution. The reflected signal from the Radar not only indicates the target presence but also compares the received echo signal with the transmitted signal, so that various information can be extracted regarding the target. The block diagram of the system is shown below:

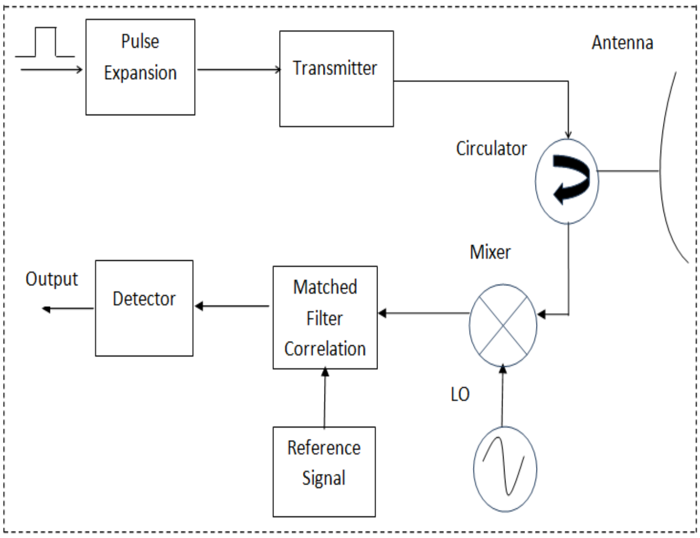

Fig 4: Block diagram of the system

5.1. Model of LFM Transmitted Signal

An LFM signal is a frequency modulated waveform in which carrier frequency varies linearly with time, over a specific period. This is one of the oldest and frequently used waveforms. LFM has application in CW and pulsed radars. Since an LFM waveform is a constant amplitude signal, it makes sure that the amplifier works efficiently. Also, this waveform spreads the energy widely in the frequency domain.

The mathematical expression of LFM signal is

$$s(t) = rect\left(\frac{t}{T}\right) e^{j2\pi\left(f_c t + K t^2\right)} \quad (3)$$

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

Here we are taking the pulse width as 60µs and bandwidth as 5MHz and the center frequency as 20 KHz.

5.2. Model of Matched Filter

A correlation operation at indicates the presence of a received echo at the radar receiver by compressing the received signal in time using its time correlation properties. Matched Filter performs the correlation operation. The correlation technique, which is one of the popular DSP methods, is used to implement a pulse matched filter. This can be achieved by multiplying the frequency responses in the frequency domain. The two-time domain correlated signals are to be transformed to the frequency domain by applying Fourier Transforms. The portion of the transformed signal with matching patterns will have identical frequency domain signatures. 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 target 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. Fig 5 illustrates the matched filtering core.

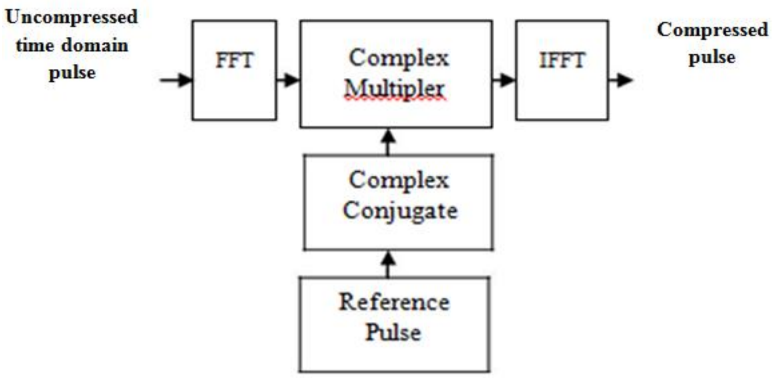

Fig 5: Matched Filtering Core

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

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

Here x[t] is the received signal, h[t] reference signal where h[t] =x [-t] for the filter to be matched to the transmitted pulse.

Matched filtering can also be accomplished in the frequency domain which is described by:

$$y(t) = IFFT[X(w)H(w)] \qquad (5)$$

Here, X[w] and H[w] are the fast fourier transform coefficients (FFT) of the x[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 x(t) and its time-reversed complex conjugate can represent the matched filter in the frequency domain.

VI. SIMULATION RESULTS

The experimental results are the given below in graphical model. Pulse compression radar is the practical implementation of a matched filter system. Here in the paper, the pulse compression filter is used for the compression of the pulse. The table 1 below shows the specifications used for simulation.

Table 1: Specifications of simulation

Parameters	
Pulse width, T	60µs
Band width, BW	5MHz
Center Frequency, fc	20KHz
Sampling Frequency, f	10MHz

In the receiver section, the path followed is traced by analyzing the result gained from the graphical model. The strength of the Signal decreases as the range increases. The amplitude decrease corresponds to that. Fig 6.represents the transmitted LFM signal and Fig 7 corresponding to the output of matched filter for stationary target and Fig 8 represents to that of moving the target.

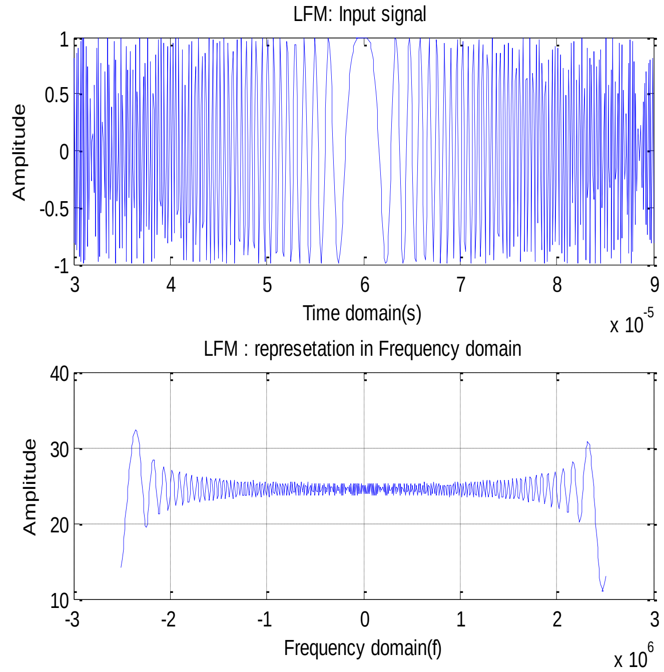

Fig 6: (a) LFM signal transmitted
(b) The frequency response of the transmitted LFM signal.

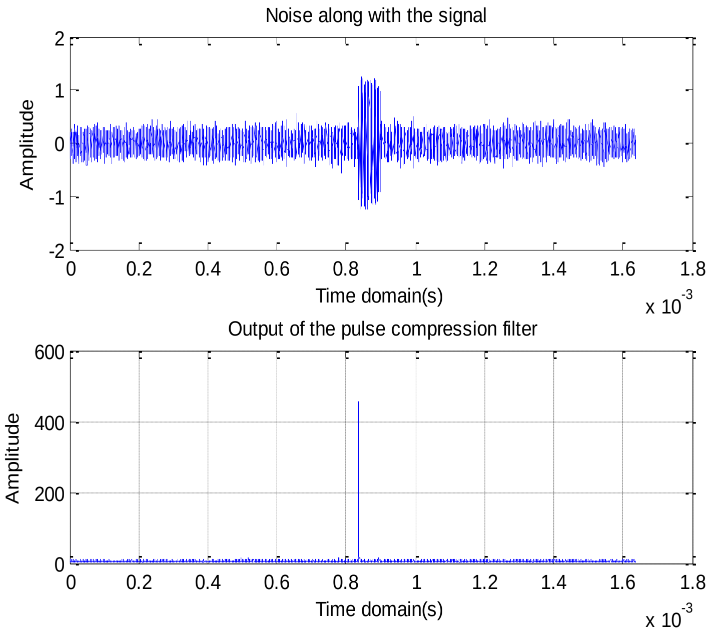

Fig 7: (a) The received stationary target echo signal
(b) Output of matched filter

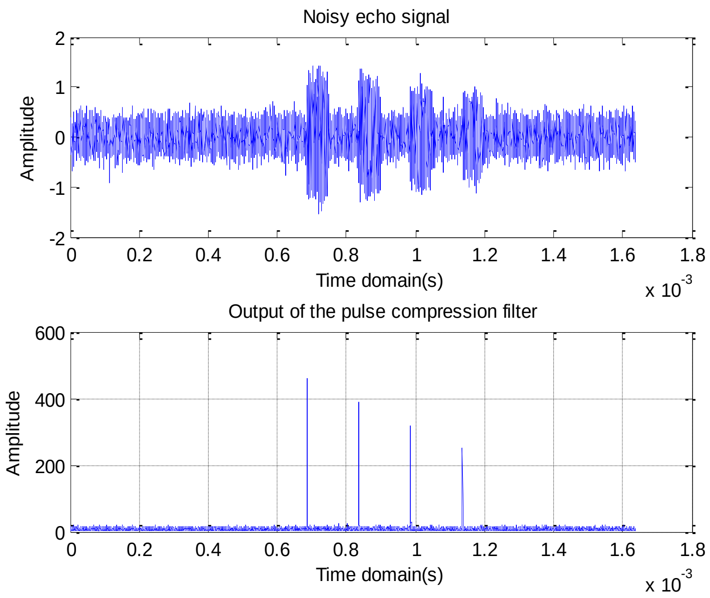

Fig 8: (a) The received echo signal
(b) Output of matched filter

VII. RESULT ANALYSIS

In this work, firstly a pulse compression radar waveform generation tool is developed to evaluate the performance of the generated waveforms. From the output graph obtained from pulse compression filter (matched filter) undergoes suitable calculations and compares it with the predetermined values which are stored. The following table 2 shows the calculated distance of the launch vehicle at different times to track the path followed.

Table 2: Calculated distance Vs Stored distance corresponding to time

Time	Calculated Values	Stored Values
0.68ms	102km	102km
0.84ms	126km	125.58km
0.98ms	147km	147km
1.14ms	171km	171km
1.32ms	198km	198km

CONCLUSION AND FUTURE WORK

In this paper, the concept of pulse compression was presented using the linear FM (or chirp) pulse modulation. In this method, the received echo signal is compared to matched filter impulse by correlation. The compressed pulse width of the received pulse provides advantages in range as well as resolution. The selection of signal processing techniques according to the radar performance requirements is one of the most important steps in military radar design. Nowadays, digital processing provides fast and efficient computation. The basic example is the use of FFT and IFFT to perform time-convolution (filtering).Here by using the MATLAB tool, we are designed to implement the matched filter algorithm for pulse compression radar which uses LFM. In this paper, the moving target path is identified to check whether it is following the predetermined path or not. As an extension of this, we can implement it in hardware under FPGA Platform using the programming language VHDL in the designing software Libero IDE v9.1.

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