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Matched Filtering Algorithm for Pulse Compression Radar

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Abstract: *Pulse Compression is one of the key steps in the signal processing of a radar system. Pulse compression technique is a method of achieving the benefits of short pulses while keeping the peak power within practical limits. This is a method of combining the high resolution capability of a short pulse with the high energy of a long pulse. This is achieved by modulating the transmitted pulse and then matching the received signal with the transmitted pulse. 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). In this paper we are discussing the application of pulse compression radar to track launch vehicles, the stationary target as well as moving vehicle so as to check whether it had followed the predetermined path or not. Here in this project, we propose to develop and simulate pulse compression and matched filter algorithm in MATLAB to study the LFM pulse compression technique with chirp diversity and the hardware implementation of the same in FPGA platform.*
LFM, Libero IdeV9.1, Matched Filter, Pulse Compression, Radar

I. Introduction

RADAR (Radio Detection And Ranging) is an electronic system that uses electromagnetic waves to detect the presence of objects. Radars can also be used to measure the range, direction and velocity of the target The echoes received are used to extract information about the target such as range, angular position, velocity and other characteristics. The reflected signal from the radar not only indicates the presence of a target, but also compares the received echo signal with the transmitted signal, so that various information can be extracted regarding the target. Nowadays, Radars are commonly used in Air Traffic Control System. It requires a good presence of target location and good target resolution. Good range resolution can be achieved with a shorter pulse. But on the other hand, shorter pulses require more peak power. The shorter the pulse gets, more energy is required to pack the pulse by increasing the peak power.

Introduction of high peak power makes the design of transmitters and receivers difficult since the components used in the entire system must be able to withstand the peak power. In order to overcome this problem, convert the short duration pulse into a longer pulse. Increasing the length of the pulse results in reduction in the peak power of it, but it reduces range resolution To preserve the range resolution, modulation is to be incorporated to increase the bandwidth of the long pulse (transmitting pulse). This used technique is called the Pulse Compression Technique (PCT) and is used widely in Radar applications where high peak power is undesirable.

Pulse-compression radar is the practical implementation of a matched-filter system. The reflected radar signal is corrupted by additive white Gaussian noise (AWGN) from the transmission channel. The probability of detection is related to signal-to-noise ratio (SNR) rather than exact shape of the signal received. Hence it need to maximize the SNR rather than preserving the shape of the signal. A matched filter is a linear filter whose impulse response is determined for a signal in such way that the output of the filter gives maximum SNR when the signal along with AWGN is passed through the filter. In the radar receiver, Pulse compression filter is used to increase the bandwidth of radar pulses and are compressed in the time domain, resulting in a range resolution which is finer than that associated with an uncoded pulse. There are several methods of pulse compression that have been used in the past. The most popular method is linear frequency modulation (LFM) which was invented by R.H. Dickie. Many methods exist to achieve this, including binary phase coding, polyphase coding, frequency modulation, and frequency stepping. Here by using the MATLAB tool we are designing to implement the matched filter algorithm for pulse compression radar which uses LFM. Matched filter has a better performance. In the de-chirpping processing we can track the path followed by the launch vehicle.

II. Literature Survey

Radar pulse compresssion 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, poly-phase codes and non-linear frequency modulation. Anuja D. Sarate. [1] discussed the merits and demerits of different Pulse Compression techniques called LFM, Biphase and Polyphase. Codes are known taking into consideration the important parameters like the mainlobe width, range resolution and PSL.

Kiran Patel, Usha Neelakantan , Shalini Gangele, J.G Vacchani, N.M. Desai implemented [2] 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. [3], 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 Side lobe ratio (PSL) and integrated side lobe 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.

Bruce Pollock, Nathan A. Goodman proposed [4]a new concept by evaluating the effects of random as well as structured hopping for a possible implementation of compressing sampling stretched processing. They explored the possibility of extending this concept to a multi-channel architecture, and shown that while independent kernels can be compensated in mainlobe, in the sidelobe distortion as a function of range will remain. We have shown that the process described in II-B is capable of increasing expected SNR based on prior information; however, the effects from switching at high rates have yet to be incorporated. It is expected that degradation in SNR should occur if de-chirps are formed that switch at every possible time interval.

Adnan Orduyılmaz, Gökhan Kara, Ali Cafer Gürbüz,Murat Efe in their work[5], different types of radar waveforms including phase coded, linear frequency (LFM) and non-linear frequency modulated (NLFM) signals are generated digitally in Xilinx Virtex-5 FPGA platform. Waveforms with different time bandwidth products are tested both in FPGA platform and computer. Digital matched filtering implementation procedure used in FPGA is presented and comparison of theoretical calculations and FPGA implementation results along with implementation resource utilization are presented. Results indicate that precise generation of real-time waveform matched filtering implementations deviate at most 1 dB on range sidelobe levels from theoretical results. Moreover adopted segmentation and parallel implementation of the received pulse both allows processing of divided pulses without SNR degradation and uses less FPGA resources in general compared to processing full PRI at once.

III. Pulse Compression

Pulse Compression is one of the important signal processing technique which is used in radar systems 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. Fig 1 illustrates two pulses having same energy with different pulse width and peak power. Longer pulse is employed at transmitter side 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 detection ranges due to increasing the transmitted energy and realization of high range resolution. The advantages of larger range detection ability of long pulse and better range resolution ability of short pulse are achieved by Pulse Compression techniques areused in Radar systems. In pulse we can use different types of modulations, such as linear/ nonlinearfrequency modulation signals (chirp modulation) or discrete phase code modulation.

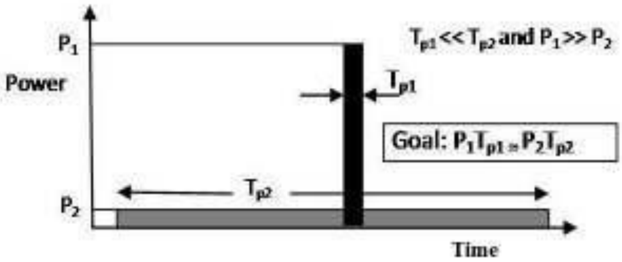

Fig 1: Transmitter and receiver ultimate signals

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

$$\rho = \tau c/2 = c/2B \qquad (1)$$

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

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

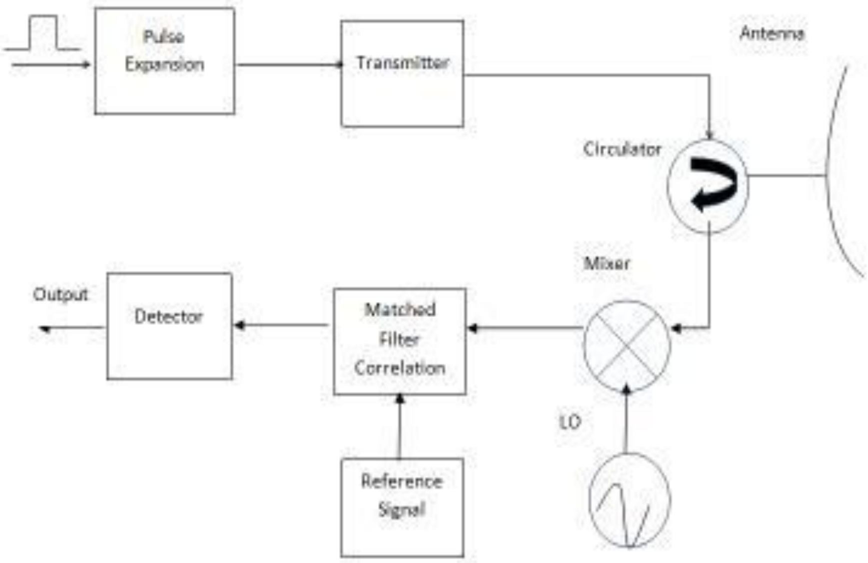

Fig 2: Block diagram of the system

The entire system block diagram is given above in Fig. 2. The pulse given at the input is undergone expansion by modulation to increase the range resolution and it is transmitted. The reflected signal from the radar not only indicates the presence of a target, but also compares the received echo signal with the transmitted signal, so that various informations can be extracted regarding the target.

IV. Algorithm

The algorithm for pulse compression in radar involves mainly two steps, first of all generation of Linear Frequency Modulation waveform followed by Matched Filtering. The flow chart which describes the whole work is shown below:

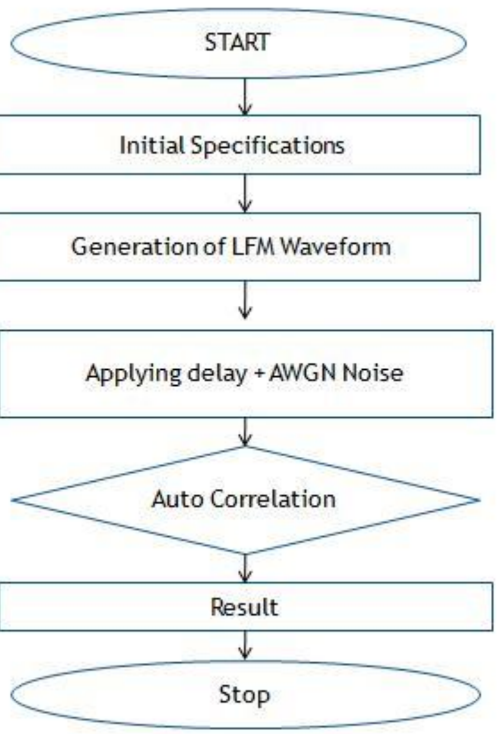

Fig 3. Flow chart of the work

For hardware implementation we use Libero IDE v9.1, it is designing software in FPGA environment, where we are using VHDL programming language.

4.1. Model of LFM Transmitted Signal

An LFM signal (Fig 4.) is a frequency modulated waveform in which carrier frequency varies linearly with time, over a specific period.

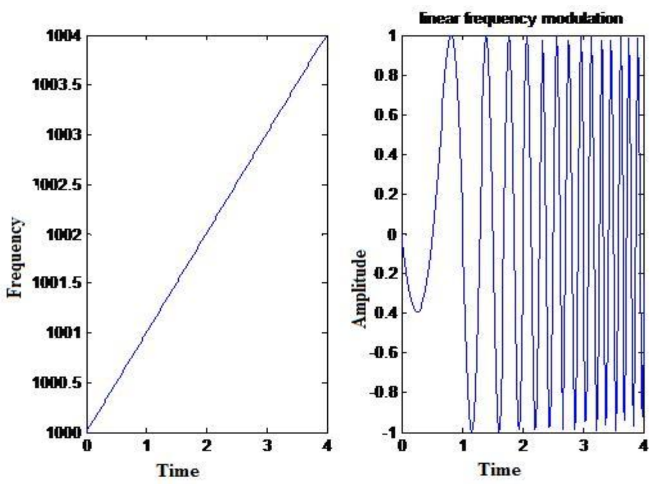

Fig 4: LFM Signal

This is one of the oldest and frequently used waveforms. It finds application in CW and pulsed radars. Since 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

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

Where T=pulse width; fc=center frequency; K= rate of frequency change. Here we taking the pulse width as 60µs and bandwidth as 5MHz and the center frequency as 20KHz.

4.2. Model of Matched Filter

Matched filtering is a process for detecting a known piece of signal that is corrupted by noise. 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. Correlation of signals in time domain, the well-known DSP technique has been a popular method to implement a pulsed matched filter in DSP. This can be achieved by performing multiplying their frequency responses in frequency domain. The two time domain correlated signals are to be transformed to 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 signals to frequency domain signals and the inverse FFT (IFFT) performs the reverse conversion, these two algorithms are key blocks in the pulse compression system. The Fig.5 shows block diagram of matched filtering core.

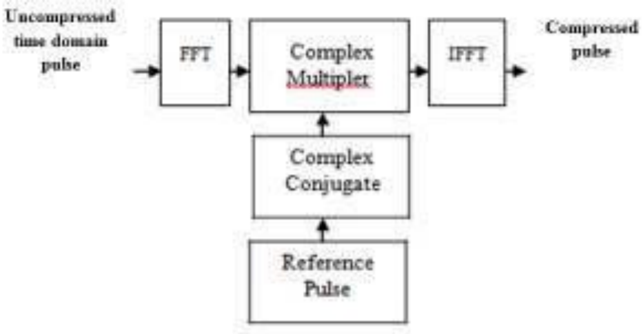

Fig 5: Matched Filtering Core

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

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

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 frequency domain which is describe by:

$$y(t) = IF\ F\ T[X(w)H(w)] \quad (5)$$

Here, X[w] and H[w] are the fast fourier transform coefficients (FFT) of the x[n] and h[n] respectively and IFFT stands for Inverse Fast Fourier Transform.

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 frequency domain.

V. Simulation Results

The experimental results are the given below in graphical model. Here in the graph the pulse compression filter is used for the compression of pulse. Pulse-compression radar is the practical implementation of a matched-filter system.

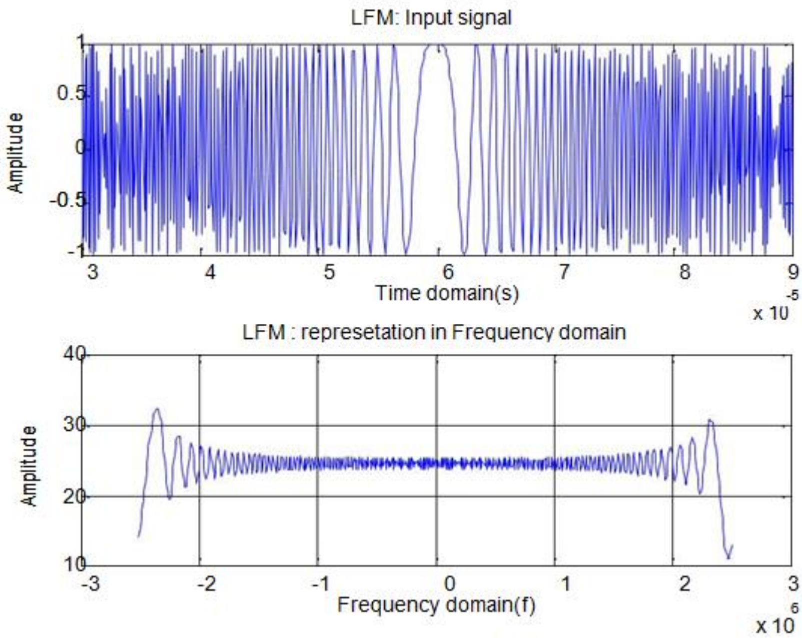

Fig 6: (a) LFM signal transmitted
(b) Frequency response of the transmitted LFM signal.

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. So the amplitude decrease corresponds to that.

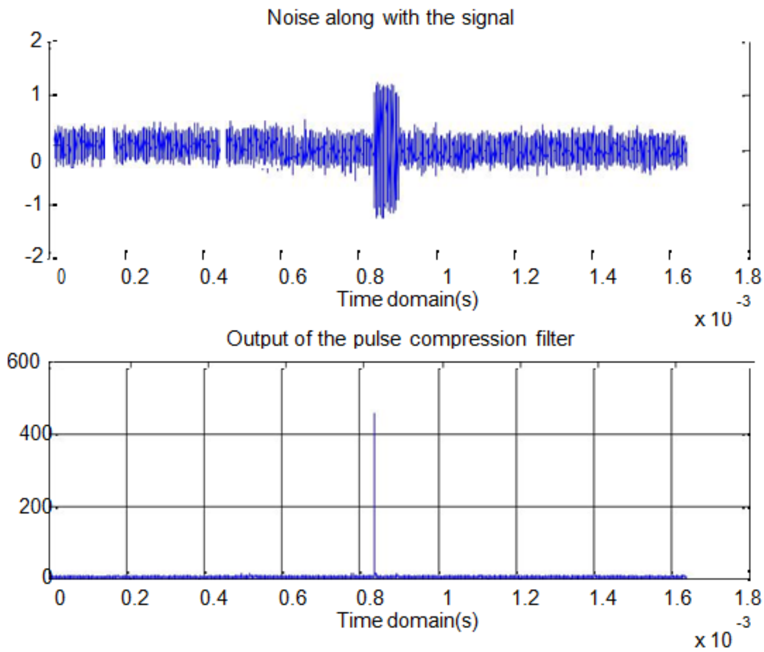

Fig 7: (a) The received stationary target echo signal
(b) Output of pulse compression filter

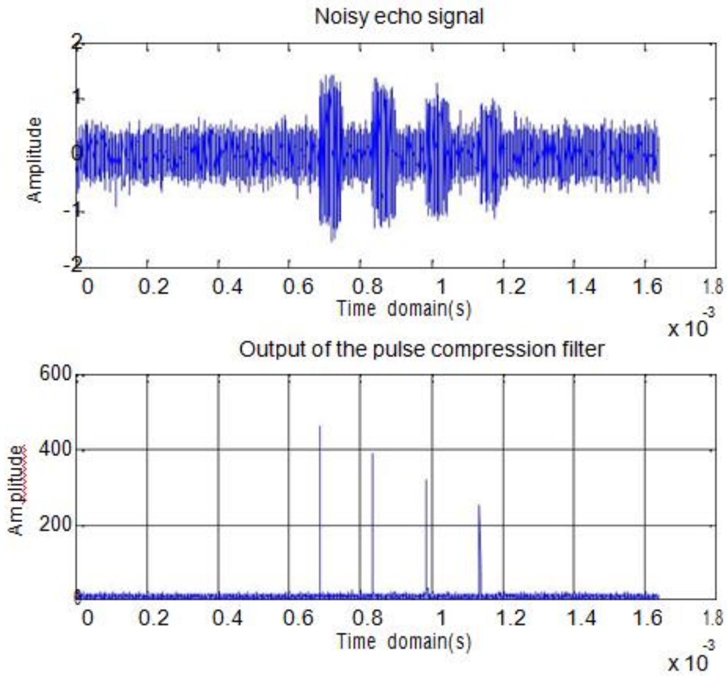

Fig 8: (a) The received echo signal
(b) Output of pulse compression filter

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

Table 1: Specifications of simulation

VI. Conclusion

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 step in military radar design. Signal processing, as we have seen throughout this paper, provides figures that tactical leaders take into account when looking for performances and capabilities. Nowadays, digital processing allows 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 designing 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.

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