

**SIDE LOBE REDUCTION ANALYSIS OF NLFM AND IMPROVED
NLFM PULSE COMPRESSION RADAR SIGNALS**

*A Project report submitted in partial fulfilment of the requirements for
the award of the degree of*

BACHELOR OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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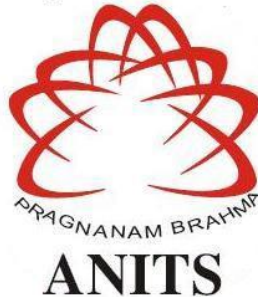
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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

**ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)**

*(Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC
with 'A' Grade)*

Sangivalasa, Bheemili mandal, Visakhapatnam dist.(A.P)

2018-2022

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CERTIFICATE

This is to certify that the project report entitled “**SIDE LOBE REDUCTION ANALYSIS OF NLFM AND IMPROVED NLFM PULSE COMPRESSION RADAR SIGNALS**” submitted by **S.RAKESH(318126512050), G.MANIKANTA(318126512018), K. PRAMOD (318126512024), K.TEJESWARARAO(318126512025)** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Engineering in Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.



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ABSTRACT

Signal design is an important component for good performance of radar systems. Here, the problem of determining a good radar signal with the objective of minimizing autocorrelation sidelobes is addressed. Linear Frequency Modulated signal (LFM) is frequently used pulse compression waveform. But using LFM makes it necessary to use weighting techniques in order to reduce the side lobes which considerably decrease the SNR. At the radar receiver, the LFM signal results in first side lobe of -13dB corresponding to the main lobe. This may reduce the resultant SNR usually by 1 or 2dB. In this paper, an attempt is done to design a radar signal to attain low autocorrelation Peak Side Lobe Ratio (PSLR) which exhibits high SNR and high range resolution. In order to maintain high SNR and to get suppressed side lobes of the signal, one can use Non-Linear Frequency Modulation (NLFM). A NLFM signal is designed for different time sweeps called as Improved NLFM. In Improved NLFM the total time sweep and bandwidth are divided into Two Stage and Tri-Stage sweeps NLFM. The quality of the overall best radar signal is assessed through the parameter PSLR for different values of BT. From this analysis, it is found that the tri stage NLFM gives the low PSLR up to -17.62dB. Simulation results shows the reduction in the sidelobe level from LFM to NLFM and in Improved two and Tri-Stage NLFM .

Index Terms— **LFM, NLFM, Peak side lobe level, Pulse width**

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CHAPTER-1
INTRODUCTION

CHAPTER-1

INTRODUCTION

In this chapter, a keen introduction regarding our project is given which justifies the solution to our problem posed, defines our project topic, and explains the aim, and scope of our work done. Thus, giving an entire overview of our project.

1.1 Aim and Scope

The matched filter and pulse compression concepts are the basic of radar processing algorithms. Since radar return is always susceptible to noise and interference from all kinds of objects illuminated by the antenna beam, the receiver must be optimized. The matched filter is a filter whose impulse response, or transfer function is determined by a certain signal, in a way that will result in the maximum attainable signal to noise ratio. Pulse compression involves using a matched filter to compress the energy in a signal into a relative narrow pulse. Pulse compression is a classical signal processing technique to increase the range resolution of transmitted pulse without having to increase the peak transmit power. Instead of a fixed frequency pulse, the transmitted pulse is modulated by a specific phase or frequency pattern during a wider pulse interval. The receiver uses a pulse-matched filter to pass reflected pulses that match the pattern of the outgoing pulse and at the same time, reject noise and other signals. The LFM, or chirp waveform, has superior performance in pulse compression radar since they can be easily generated and processed. Many diverse techniques and devices have been developed to provide the required pulse compression processing for these signals. However, the LFM has large sidelobes with respect to the main lobe. Reducing the sidelobes can be accomplished by linear filtering the output, i.e., applying window functions or data tapering. However, since the cumulative filtering is no longer precisely matched to the signal, it necessarily reduces output SNR as well, typically by 1–2 db. The non-linear frequency modulation (NLFM) signal is another continuous

phase modulation waveform applicable to pulse compression radar. It has been claimed to provide range sidelobe suppression since the modulation is designed to provide the desired amplitude spectrum with reduced sidelobes. The NLFM requires no time or frequency weighting for range sidelobe suppression.

Generally, radar has an issue of being sensitive to interference of noise from the surrounding objects. The concepts like matched filter and pulse-compression from the radar processing theory are used to optimize the strength of received signal by attaining maximum signal to noise ratio (SNR) and high range resolution.

Pulse compression aids to attain maximum range resolution and increasing SNR. In order to transmit a long pulse which has a bandwidth of short pulse, pulse compression is required. LFM signal has limitations when compressed the produced side lobe is of -13dB to the peak of main lobe. There will be a 25% of decrease in the transmitted power for a single dB of SNR lost. NLFM waveform is used to achieve high range resolution and high SNR as it is the drawback in LFM waveform. LFM waveforms have a disadvantage of using weighting functions which considerably decreases the SNR.

In pulse compression, a linear frequency modulation (LFM) is used. It is one of the types in different pulse compression techniques. LFM Pulse compression method is used in order to have the properties of both long pulse and short pulse which are high signal detection capability and range resolution respectively. LFM signal has limitations when compressed the produced side lobe is of -13dB to the peak of main lobe. There will be a 25% of decrease in the transmitted power for a single dB of SNR lost. NLFM waveform is used to achieve high range resolution and high SNR as it is the drawback in LFM waveform.

In this project, by using modified NLFM technique one can generate auto-correlated functions with peak side lobe levels (PSL) that can be modified by changing the BT values. Using PSL one can determine the interference of noise or the strength of signal received at the receiver when the peak side lobes are reduced then SNR increases and if the side lobe levels increase the SNR decreases. Increase in SNR means high signal strength. Similarly with a decreased SNR signal strength is low.

CHAPTRE-2

RADAR

CHAPTER-2

RADAR

2.1 Study about basic RADAR

In basic communications, there are two types of communications one is analog and the other is digital. But in advanced communication, we will discuss communication through radar, satellite, etc. Mostly they are developed for military purposes or security purposes.

RADAR Radio Detecting And Ranging

Radar is an electromagnetic system for the detection and location of reflecting objects such as aircraft, ships, vehicles, people and the natural environment. It can operate in darkness, haze, fog, rain, and snow. Its ability is to measure distance and position with high accuracy and in all weather, conditions is one of its most important attributes. The concepts from radar engineering can very well be used in satellites and microwave radio systems.

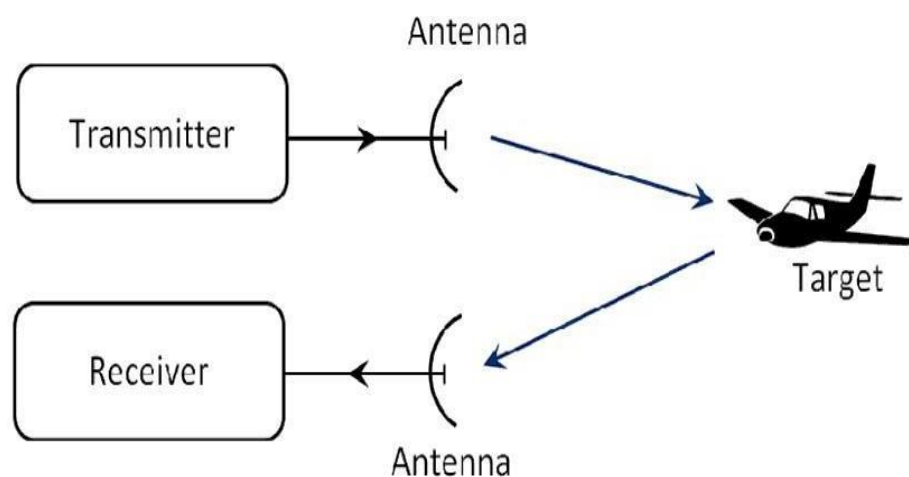


Figure 2.1: Elementary form of RADAR

A radar consists of a transmitter and receiver, each connected to a directional antenna. The transmitter radiates or transmits electromagnetic radiations generated by a magnetron oscillator. The receiver antenna collects the returned echo signal and delivers it to the receiver where it is processed to detect the presence of the target and to extract its relative velocity with respect to radar station if the target is moving.

Pulse Repetition Frequency (PRF) or Pulse Repetition rate (PRR) is the number of pulses per unit time. These pulses are transmitted by a highly directional parabolic antenna at the target, which can reflect (echo) some of the energy back to the same antenna. The reflected energy is received, and time measurements are made, to determine the distance of the target.

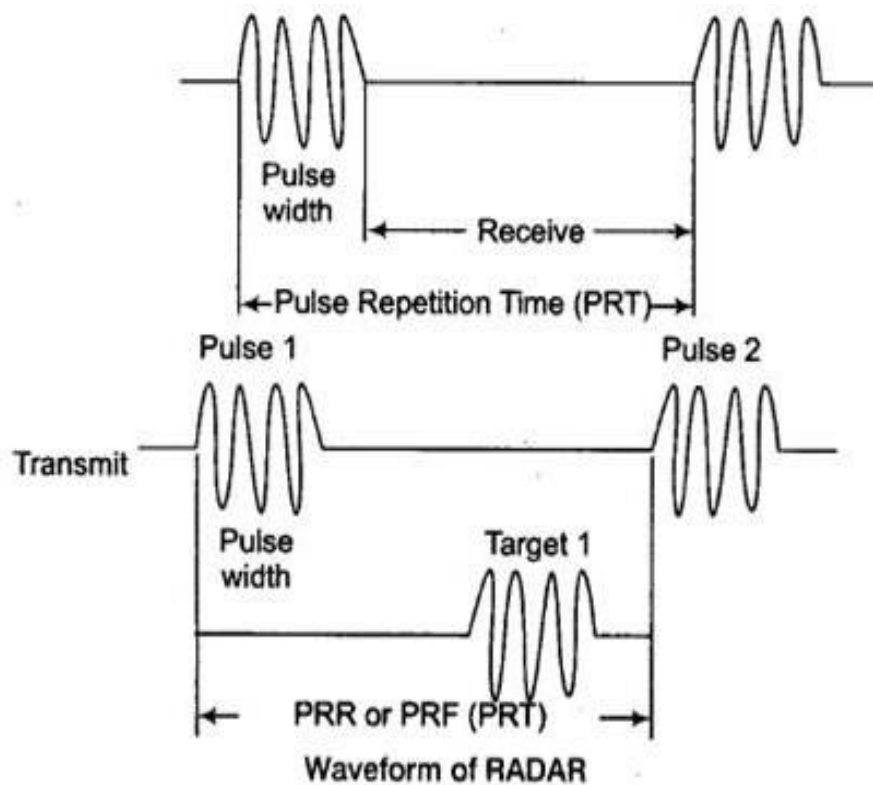


Figure 2.2: Waveforms of the RADAR

After the radar pulse has been transmitted, enough rest time must be allowed for the echo to return so as not to interfere with the next transmit pulse. Time difference between two successive pulses is called Pulse Repetition Time (PRT).

$$PRF = \frac{c}{2 * \text{Unambiguous Range}} = \frac{1}{PRT} \dots (1)$$

$$PRT = \frac{2 * \text{Unambiguous Range}}{c}$$

2.2 Principle of RADAR

- The radar signal, usually a repetitive train of short pulses, is generated by the transmitter and radiated into space by the antenna.
- The duplexer acting as a switch permits a single antenna to be time-shared for both transmission and reception.
- Reflecting objects (targets) intercept and reradiate a portion of the radar signal, a small amount of which is returned in the direction of the radar.
- The returned echo signal is collected by the radar antenna and amplified by the receiver. If the output of the radar receiver is sufficiently large, detection of a target is said to occur.
- The range to a target is determined by time T_R , it takes the radar signal to travel to the target and back i.e.,

$$R = \frac{cT_R}{2} \dots (2)$$

- Once a signal is radiated into space by a radar, enough time elapse to allow all echo signals to return to the radar before the next pulse is transmitted.

The maximum Unambiguous range is given by

$$R_{un} = \frac{cT_P}{2} = \frac{c}{2f_P}$$

Where,

T_P is pulse repetition period, f_P is pulse repetition frequency

2.3 Radar Range Equation

The radar range equation represents the physical dependence of the transmit power, which is the wave propagation up to the receiving of the echo signals. Radar range equation is useful to know the range of the target theoretically.

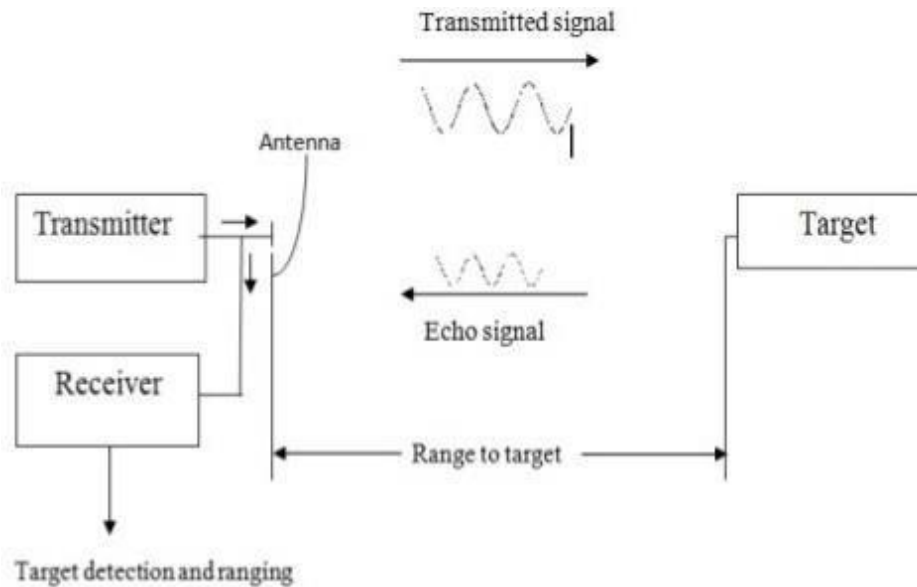


Figure 2.3: Radar range equation

We know that power density is nothing but the ratio of power and area. So, the power density, P_d at a distance, R from the Radar can be mathematically represented as

$$P_d = \frac{P_t}{4\pi R^2} \dots (3)$$

If the Gain of antenna of target is G , then power density is

$$P_d = \frac{P_t}{4\pi R^2} \cdot G \dots (4)$$

Radar cross-section (σ) is a measure of how detectable an object is by radar. An object reflects a limited amount of radar energy back to the source. The factors that influence this include such as target's material type, size and at its angle.

If target area is σ then the power at target is,

$$P_d = \frac{P_t}{4\pi R^2} \cdot \sigma \dots (5)$$

The power density of reflected signal is,

$$P_d = \left[\frac{P_t G \sigma}{4\pi R^2} \right] \frac{1}{4\pi R^2}$$

$$= \frac{P_t G \sigma}{[4\pi R^2]^2} \dots (6)$$

For a pulsed radar, the peak power transmitted is usually much higher than the average power transmitted. The ratio of the average power to the peak power equals the duty cycle, which is the product of the pulse duration and the PRF.

The power received in all directions is P_r , then effective area (A_e) of antenna is expressed as

$$P_r = \frac{P_t G \sigma}{[4\pi R^2]^2} \cdot A_e \dots (7)$$

For maximum range R_{max} , the received signal $P_r = S_{min}$ is represented as,

$$S_{min} = \frac{P_t G \sigma A_e}{[4\pi]^2 (R_{max})^4} \dots (8)$$

$$R_{max} = \left[\frac{P_t G \sigma A_e}{[4\pi]^2 S_{min}} \right]^{\frac{1}{4}} \dots (9)$$

Equation (9) represents the standard form of Radar range equation. By using the above equation, we can find the maximum range of the target.

For parabolic antenna,

$$G = \frac{4\pi A_e}{\lambda^2}$$

then,

$$R_{max} = \left[\frac{P_t \left(\frac{4\pi A_e}{\lambda^2} \right) \sigma A_e}{[4\pi]^2 \cdot S_{min}} \right]^{\frac{1}{4}}$$

$$R_{max} = \left[\frac{P_t (A_e)^2 \sigma}{4\pi \lambda^2 \cdot S_{min}} \right]^{\frac{1}{4}} \dots (10)$$

Factors effecting the Radar range:

$$R \propto [P_t]^{\frac{1}{4}} \propto \left[\frac{1}{S_{min}} \right]^{\frac{1}{4}} \propto \sqrt{A_e} \propto \sqrt{G}$$

2.4 Limitations and Applications

2.4.1 Limitations of Radar Systems

1. Radars cannot resolve in detail like the human eye, especially at short distance.
2. Radars do not recognize the colour of the target.
3. Radars cannot identify internal aspects of the target.

2.4.2 Applications of Radar Systems

1. Civilian applications
2. Military applications
3. Remote Sensing
4. Ground Traffic Control
5. Air Traffic Control

CHAPTER-3
MATCHED FILTER

CHAPTER-3

MATCHED FILTER

The **matched filter** is the optimal linear **filter** for maximizing the signal-to-noise ratio (SNR) in the presence of additive stochastic noise. **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.

Derivation of matched filter as highest SNR linear filter:

Let us consider a matched filter of impulse response $h(t)$. the filter input $x(t)$ consists of a pulse signal $g(t)$ corrupted by additive noise $w(t)$ of zero mean and power spectral density $\frac{N_0}{2}$. the resulting output $y(t)$ is composed of $g_0(t)$ and $n(t)$, the signal and noise components of the input $x(t)$, respectively.

$$x(t) = g(t) + w(t), \quad 0 \leq t \leq T \quad (\text{where } T \text{ is sampling time period})$$

$$y(t) = g_0(t) + n(t)$$

Signal to noise ratio is:

$$\text{SNR} = \frac{|g_0(T)|^2}{\sigma_n^2} = \frac{|g_0(T)|^2}{E[n^2(t)]}$$

Where $|g_0(T)|^2$ is the instantaneous power of filtered signal $g(t)$ at point $t=T$, and σ_n^2 is the variance of the white Gaussian zero mean filtered noise.

We sampled at $t=T$ because that gives you the max power of filtered signal.

Examine $g_0(t)$:

Fourier transform of $g_0(t) = G_0(f)$

$$G_0(f) = G(f) H(f)$$

$$\text{So } g_0(t) = \int G(f) H(f) e^{j2\pi f t} df$$

Then $|g_0(t)|^2 = \left| \int G(f)H(f)e^{j2\pi ft} df \right|^2$

Examine σ_n^2 :

$\sigma_n^2 = E[n(t)^2] - E[n(t)]^2$ but this is zero mean so

$$\sigma_n^2 = E[n(t)^2]$$

$E[n(t)^2] = \text{var}[n(t)] = R_n(0)$ autocorrelation at $\tau = 0$

$$R_n(\tau) = \int S_n(f)e^{j2\pi f\tau} df$$

autocorrelation is inverse fourier transform of power spectral density

$$R_n(0) = \int S_n(f) \cdot 1 df$$

$$S_n(f) = \frac{N_0}{2} |H(f)|^2$$

$\sigma_n^2 = E[n(t)^2] = R_n(0) = \int \frac{N_0}{2} |H(f)|^2 df$ so

$$\text{SNR} = \frac{\left| \int G(f)H(f)e^{j2\pi ft} df \right|^2}{\int \frac{N_0}{2} |H(f)|^2 df}$$

To maximize, we use Schwartz inequality

$$\int |\phi_1(x)|^2 dx < \infty$$

$$\int |\phi_2(x)|^2 dx < \infty$$

$$\left| \int \phi_1(x)\phi_2(x) dx \right|^2 < \int |\phi_1(x)|^2 dx \int |\phi_2(x)|^2 dx$$

This equality holds if $\phi_1(x) = k \phi_2^*(x)$

We pick $\Phi_1(x) = H(f)$ and $\Phi_2(x) = G(f)e^{j2\pi fT}$ and want to make the numerator of SNR to be large as possible.

$$\int |H(f)G(f)e^{j2\pi ft} df|^2 \leq \int |H(f)|^2 df \int |G(f)e^{j2\pi fT}|^2 df$$

$$\frac{\int |H(f)G(f)e^{j2\pi ft} df|^2}{\frac{N_0}{2} \int |H(f)|^2 df} \leq \frac{\int |H(f)|^2 df \int |G(f)e^{j2\pi fT}|^2 df}{\frac{N_0}{2} \int |H(f)|^2 df}$$

$$\text{SNR} \leq \frac{\int |G(f)|^2 df}{\frac{N_0}{2}} = \frac{2 \int |G(f)|^2 df}{N_0} \text{ maximum SNR according to Schwarz inequality}$$

Assume $g(t)$ is real. this means $g^*(t) = g(t)$(1)

If $F.T\{g(t)\} = G(f)$ then $F.T\{g^*(t)\} = G^*(-f)$ [where F.T is Fourier transform] ...(2)

From (1) & (2) $G(f) = G^*(-f)$

$$G^*(f) = G(-f)$$

Find $h(t)$ [inverse Fourier transform of $H(f)$]:

$$h(t) = k \int G(-f) e^{-j2\pi fT} e^{j2\pi ft} df$$

$$= k \int G(-f) e^{-j2\pi f(T-t)} df$$

$$= k \int G^*(f) e^{j2\pi f(t-T)} df$$

$h(t) = k g(T-t)$ it is matched to the input signal.

Therefore, impulse response of matched filter is $h(t) = k g(t)$ is given the name matched filter since, the spectral width of the filter needs to be matched with the spectral width of the input signal being given otherwise, in case of the spectral width of input less than the spectral width of the system then we will get more noise in the other case if the spectral width of input more than the spectral width of the system then we there is a loss of information.

CHAPTER-4
Pulse Compression Technique

CHAPTER-4

PULSE COMPRESSION TECHNIQUE

4.1 What Is Pulse Compression?

Pulse compression is a signal processing technique commonly used by radar, sonar and echography to increase the range resolution as well as the signal to noise ratio. This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse. Pulse compression involves the transmission of a long-coded pulse and the processing of the received echo to obtain a relatively narrow pulse. The increased detection capability of a long-pulse radar system is achieved while retaining the range resolution capability of a narrow-pulse system. Several advantages are obtained. Transmission of long pulses permits a more efficient use of the average power capability of the radar. Generation of high peak power signals is avoided. The average power of the radar may be increased without increasing the PRF and, hence, decreasing the radar's unambiguous range. An increased system resolving capability in doppler is also obtained as a result of the use of the long pulse. In addition, the radar is less vulnerable to interfering signals that differ from the coded transmitted signal. A long pulse may be generated from an arrow pulse. A narrow pulse contains many frequency components with a precise phase relationship between them. If the relative phases are changed by a phase-distorting filter, the frequency components combine to produce a stretched, or expanded, pulse. This expanded pulse is the pulse that is 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. The pulse compression ratio is the ratio of the width of the expanded pulse to that of the compressed pulse. The pulse compression ratio is also equal to the time bandwidth product of the transmitted signal. Although combination of active and passive techniques may be used in same radar system, most systems employ same type for generation and processing; e.g., a passive system uses both passive generation and passive processing.

4.1.1 Factors affecting Pulse Compression System

The choice of a pulse compression system is dependent upon the type of waveform selected and the method of generation and processing. The primary factors influencing the selection of a particular waveform are usually the radar requirements of range coverage, doppler coverage, range and doppler sidelobe levels, waveform flexibility, interference rejection, and signal-to-noise ratio (SNR). The methods of implementation are divided into two general classes, active and passive, depending upon whether active or passive techniques are used for generation and processing. Active generation involves generating the waveform by phase or frequency modulation of a carrier without the occurrence of an actual time expansion. An example is digital phase control of a carrier. Passive generation involves exciting a device or network with a short pulse to produce a time-expanded coded waveform. An example is an expansion network composed of a surface-acoustic wave (SAW) delay structure. Active processing involves mixing delayed replicas of transmitted signal with received signal and is a correlation-processing approach. Passive processing involves use of compression network that is the conjugate of the expansion network and is a matched-filtering approach. Although combination of active and passive techniques may be used in same radar system, most systems employ same type for generation and processing; e.g., a passive system uses both passive generation and passive processing. The performance of common types of pulse compression systems is summarized. The systems are compared on the assumption that information is extracted by processing a single waveform as opposed to multiple-pulse processing. The symbols B and T are used to denote, respectively, the bandwidth and the time duration of the transmitted waveform. Passive processing involves use of compression network that is the conjugate of the expansion network and is a matched-filtering approach. Ripple loss refers to the SNR loss incurred in active systems because of the fluctuation or ripple in the SNR that occurs as a target moves from range cell to range cell. Clutter rejection performance of a single waveform is evaluated based on doppler response rather than range resolution; pulse compression provides a means for realizing increased range resolution and, hence, greater clutter rejection. In applications where

an insufficient doppler frequency shift occurs, range resolution is the chief means for seeing a target in clutter.

4.1.2 Pulse Compression Devices

Major advances are continually being made in the devices used in pulse compression radars. Significant advances are evident in the digital and SAW techniques. (a) Symmetrical (b) Non-Symmetrical Time. These two techniques allow the implementation of more exotic signal waveforms such as nonlinear FM. The digital approach has blossomed because of the many fold increase in the computational speed and also because of the size reduction and the speed increase of the memory units. SAW technology has expanded because of the invention of the inter digital transducer,³ which provides efficient transformation of an electrical signal into acoustic energy and vice versa. In spite of these advanced technologies, the most commonly used pulse compression waveforms are still the linear-FM and the phase-coded signals. Improved techniques have enhanced the processing of these "old standby" waveforms.

| | Linear FM | | Non-Linear FM | | Phase coded | |
|----------------|--|-------------------------------|--|-------------------------------|--|-------------------------------|
| | Active | Passive | Active | Passive | Active | Passive |
| Range coverage | Limited Range coverage per active correlation processor. | Provides Full range coverage. | Limited Range coverage per active correlation processor. | Provides Full range coverage. | Limited Range coverage per active correlation processor. | Provides Full range coverage. |

| | | |
|------------------|--|---|
| Doppler coverage | Covers any doppler up to B/10, but range error is introduced. SNR and time-sidelobe performance poor for larger doppler | Multiple doppler channels required, spaced by (1/T) Hz. |
|------------------|--|---|

| | | | | | |
|------------------------|--|--|--|---|--|
| Range sidelobe level | Requires weighting to reduce the range sidelobes below (sinx)/x falloff. | Good range sidelobes possible with no weightlifting. Sidelobes determined by waveform design. | Good range sidelobes $N^{-\frac{1}{2}}$ for an N element code. | | |
| Waveform flexibility | BW and pulse width can be varied | Limited to one BW and pulse width per compression network. | BW and pulse width can be varied | Limited to one BW and pulse width per compression network | Bandwidth, pulse width, and code can be varied |
| Interference Rejection | Poor clutter rejection | Fair clutter rejection | Fair clutter rejection | Fair clutter rejection | |

| | | | | | | |
|-----|---|---------------------------|-------------------------------------|-------------|-------------------------------------|-------------|
| SNR | Reduced by weight-lifting and by ripple loss versus range | Reduced by weight-lifting | Reduced by ripple loss versus range | No SNR loss | Reduced by ripple loss versus range | No SNR loss |
|-----|---|---------------------------|-------------------------------------|-------------|-------------------------------------|-------------|

Table 5.1 Summary of performance of various pulse compression implementation

4.2 Why Pulse Compression?

Pulse compression allows a radar to utilize a long pulse to achieve a large, radiated energy, but with the range resolution of a short pulse of wide bandwidth. It achieves this by modulating the long pulse of width T to obtain bandwidth $B \gg 1/T$. The received signal is passed through a matched filter to produce a compressed pulse of width $1/B$. The pulse compression ratio, which is the duration of the long pulse divided by the duration of the short (compressed) pulse, is equal to BT . Frequency and phase modulations have both been used for pulse compression. Amplitude modulation could also be employed, in principle, but it is seldom found in practical pulse compression systems. 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 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 needs 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.

Pulse Compression is one of the important signal processing techniques 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 are used in Radar systems. In pulse we can use different types of modulations, such as linear/ non-linear frequency modulation signals (chirp modulation) or discrete phase code modulation.

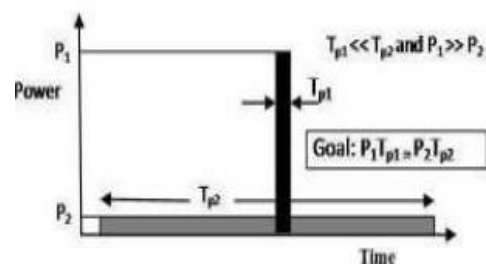


Figure 5.1 Transmitter and Receiver ultimate signal

For range resolution, the bandwidth of the pulse is taken into account but not necessarily the duration of the pulse. $\rho = \tau c/2 = c/2B$ (1) where ρ =range resolution; τ =pulse duration; c =speed of light; B =signal bandwidth.

Advantage of Pulse Compression

Pulse compression allows us to use a reduced transmitter power and still achieve the desired range resolution. The costs of applying pulse compression include: – added transmitter and receiver complexity – must contend with time sidelobes. The advantages generally outweigh the disadvantages so pulse compression is used widely.

CHAPTER-5
LINEAR FREQUENCY MODULATION

CHAPTER-5

LINEAR FREQUENCY MODULATION

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 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

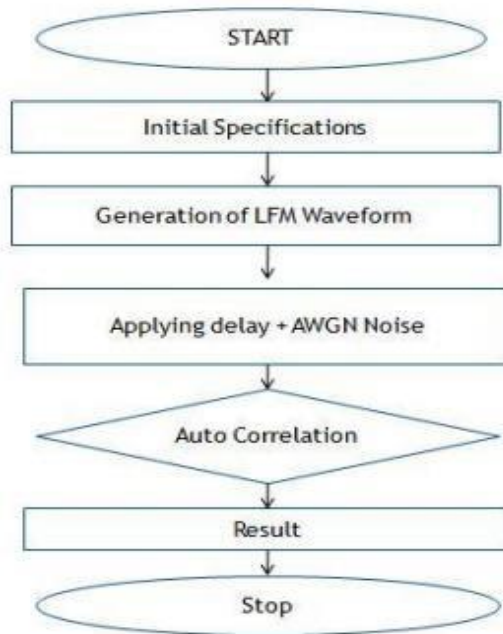


Figure 5.2 Flowchart of the work

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

$$s(t) = \exp \left\{ j2\pi \left(f_c t - \frac{kt^2}{2} \right) \right\} \quad , -\frac{\tau}{2} \leq t \leq \tau$$
$$= 0 \quad , \text{elsewhere}$$

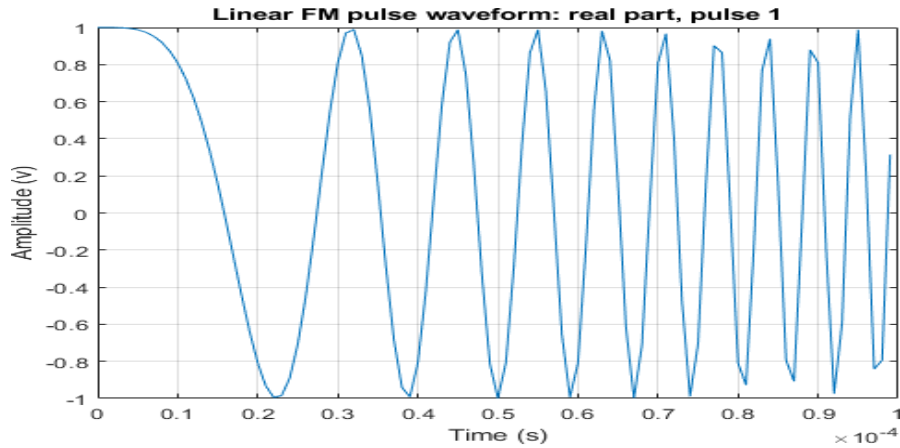


Figure 5.3 LFM signal

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.

What Is an LFM Signal?

The process of compressing a wide pulse into a narrow pulse is known as pulse compression. It requires that the signal has characteristic of large time width and band width product, and LFM signal, which is obtained by nonlinear phase modulation, is a typical signal with large time width and band width product. An LFM pulse is one in which the "instantaneous frequency" changes linearly over the duration of the pulse. By "instantaneous frequency" I mean the rate of change of phase. Over its $\tau=500\mu\text{s}$ duration, a pulse with "bandwidth" $B=50\text{kHz}$ and center frequency $f_c=150\text{kHz}$ would be defined by

$$f(t) = A \cos(\theta(t)) = A \cos(2\pi(f_c - B/2)t + \pi(B/\tau)t^2 + \theta_0)$$

Taking the derivative of phase with respect to time, we have

$$\partial\theta(t)/\partial t = 2\pi(f_c - B/2) + 2\pi(B/\tau)t$$

We can see that this sweeps from $2\pi(fc-B/2)$ to $2\pi(fc+B/2)$ over the duration of the pulse. An LFM pulse provides better range resolution than an unmodulated pulse of the same duration.

How to Create Linear FM Pulse Waveforms

To create a linear FM pulse waveform, use phased LFM waveform. You can customize certain characteristics of the waveform, including:

- Sample rate
- Duration of a single pulse
- Pulse repetition frequency
- Sweep bandwidth
- Sweep direction (up or down), corresponding to increasing and decreasing instantaneous frequency
- Envelope, which describes the amplitude modulation of the pulse waveform. The envelope can be rectangular or Gaussian.
- The Gaussian envelope is

$$a(t)=e^{-t^2/\tau^2} \quad t \geq 0$$

Number of samples or pulses in each vector that represents the waveform

Linear frequency modulated waveform:

LFM waveform commonly known as linear chirps are the most commonly used waveform in radar systems as it can be easily generated, have good range resolution and more doppler tolerant than NLFM. A linear FM chirp has a linear time frequency description as its frequency varies linearly over the pulse duration of the signal. In case of LFM frequency increases (up chirp) or decreases (down chirp) linearly with time. Following figure shows the time frequency characteristics of the signal. Fig 1 depicts the frequency versus time characteristics of a linear FM chirp.

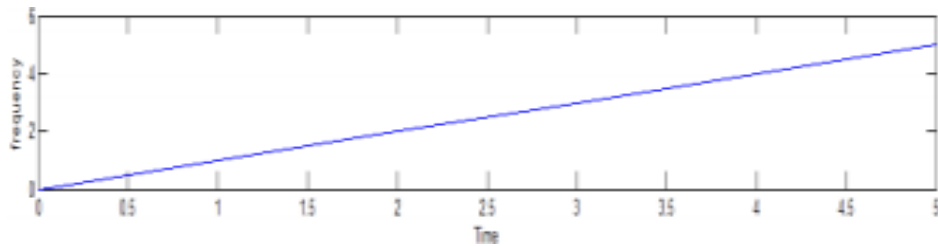


Figure 5.4 Time versus Frequency plot of linear chirp

Non-Linear frequency modulation (NLFM) waveform:

NLFM is considered to be capable of achieving fine resolution, good SNR, low cost and high-quality interference mitigation [3]. NLFM is having superior detection rate characteristics and is more precise in range determination than LFM [3]. In case of NLFM, it is observed that the time frequency characteristic is nonlinear in nature.

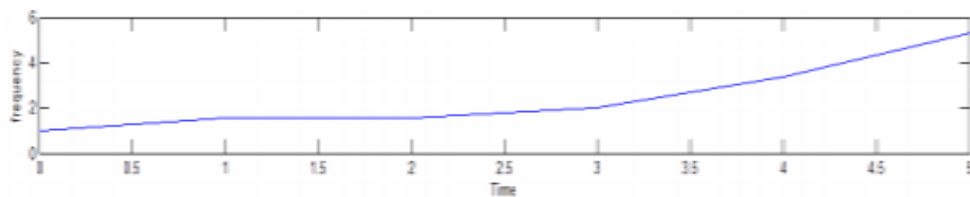


Figure 5.5 Time versus Frequency plot of Non-linear chirp

Advantages of LFM Pulse Compression

LFM is easy to implement in hardware - even more so if you can use stretch (de-chirp) processing. It has been the most popular type of pulse compression. Good range resolution which is a function of band width. Autocorrelation (matched filter output) has good side-lobe levels. The LFM spectrum is "nice" given its sharp band edges. This make it more robust to signal processing chains with lots of filtering. LFM is Doppler tolerant.

Disadvantages of LFM Pulse Compression

LFM exhibits range-doppler coupling. A doppler shift will shift the peak of the matched filter output to a different delay (range). Jamming signals can be produced by relatively easy by so called "sweepers".

CHAPTER-6
NON-LINEAR FREQUENCY MODULATION

CHAPTER-6

NON-LINEAR FREQUENCY MODULATION

Using LFM there is a disadvantage of loss of signal due to weighting techniques used. To overcome that we can go for Non-Linear Frequency modulation. To get suppressed side lobes of the signal, we can use Non-Linear Frequency modulation. A NLFM signal is designed for different time sweeps called as Improved NLFM. They are stated below. The NLFM waveform can be used to achieve high range resolution, strong SNR and low interference of noise. NLFM has better range detection characteristics than Linear Frequency Modulated wave. The NLFM signal is represented by

$$SI(t) = \exp[j\phi(t)]$$

Here $\phi(t)$ is frequency modulation function and we can obtain $f(t)$ with Differential phase modulation. NLFM waveform does not require any weighting technique in order to suppress the side lobes.

6.1 Two stage NLFM

A simple two stage NLFM signal has been investigated. This NLFM modulation function has two LFM stages. It can be divided into two parts which has two distinct LFM sweep rate. The frequency of each part is linearly swept through the given time frame. The instantaneous frequency of this NLFM can be written as,

$$f(t) = \begin{cases} \frac{B_1}{T_1} t & , 0 \leq t \leq T_1 \\ B_1 + \frac{B_2}{T_2} t & , T_1 \leq t \leq T_2 \end{cases}$$

Thus, the phase of this two stages NLFM signal can be derived by integrating above equation

$$\phi(t) = \int f(t) dt = \begin{cases} \frac{B_1}{T_1} \times \frac{t^2}{2}, & 0 \leq t \leq T_1 \\ B_1 \times t + \frac{B_2}{T_2} \times \frac{t^2}{2}, & T_1 \leq t \leq T_2 \end{cases}$$

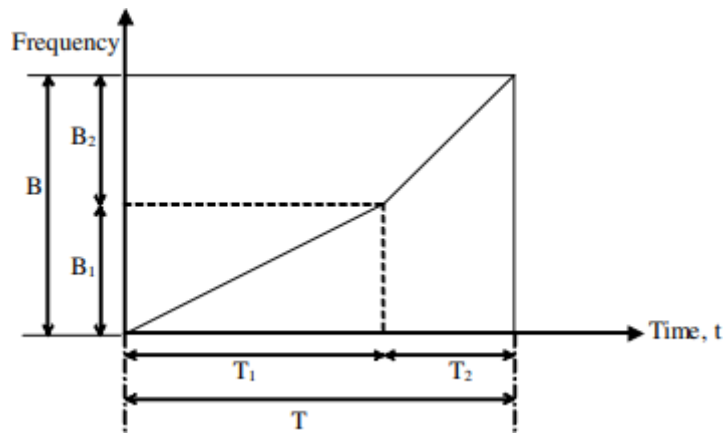


Fig 6.1 Modulation signal for simple two stages NLFM waveform.

Let us see different configurations for two-stage NLFM waveform response.

| Configuration | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------------|--------|--------|-------|-------|-------|-------|
| Sidelobe Level (dB) | -16.15 | -14.88 | -16.8 | -17.7 | -15.4 | -15.4 |

Table 6.1 Highest sidelobe level for two-stages LFM signal.

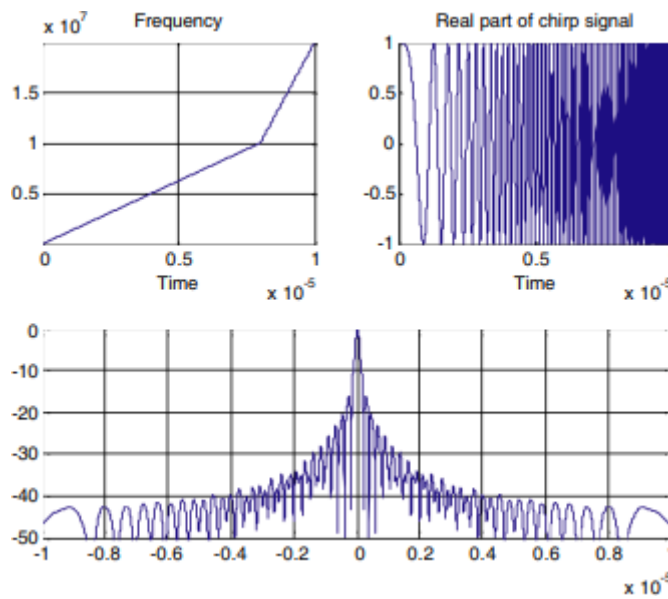


Fig 6.2 Two stages NLFM waveform response for configuration 1.

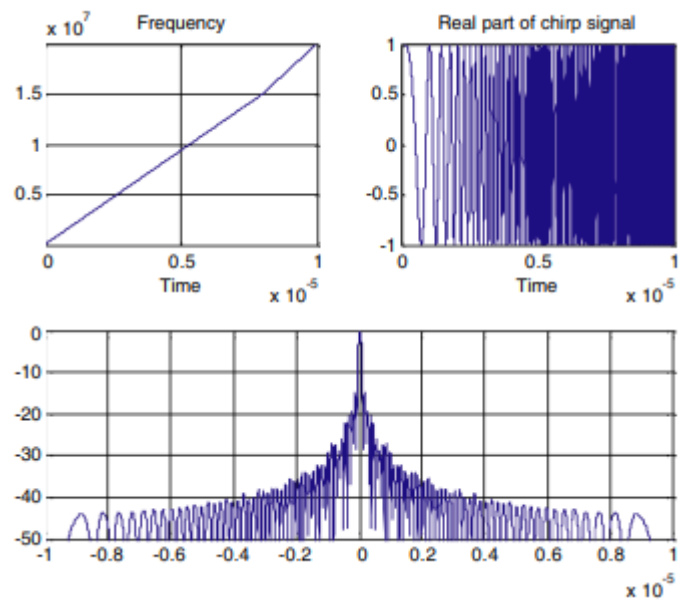


Fig 6.3 Two stages NLFM Waveform response for configuration 2.

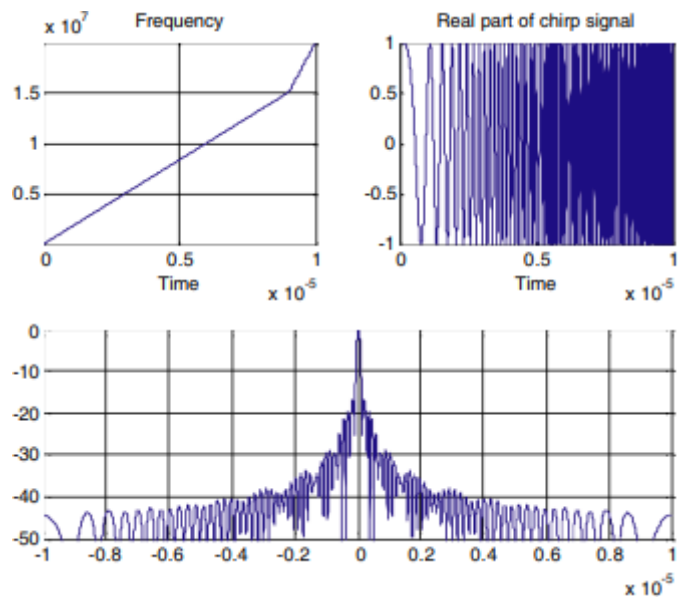


Fig 6.4 Two stages NLFM waveform response for configuration 3.

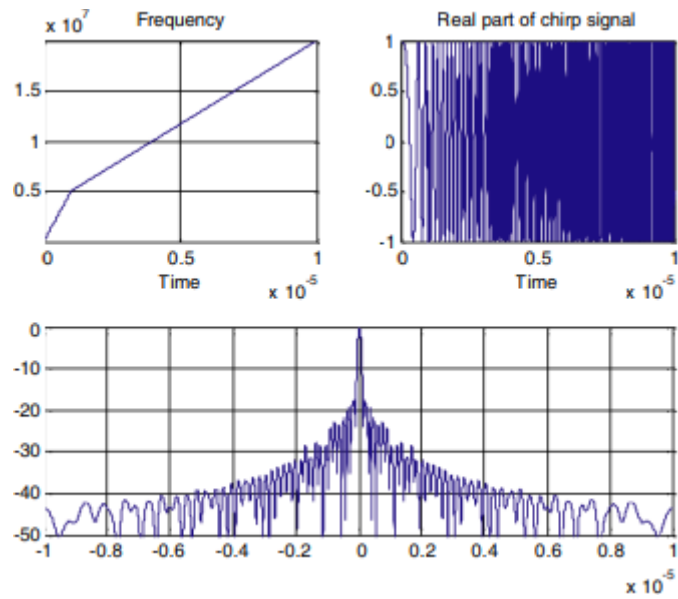


Fig 6.5 Two stages NLFM waveform response for configuration 4.

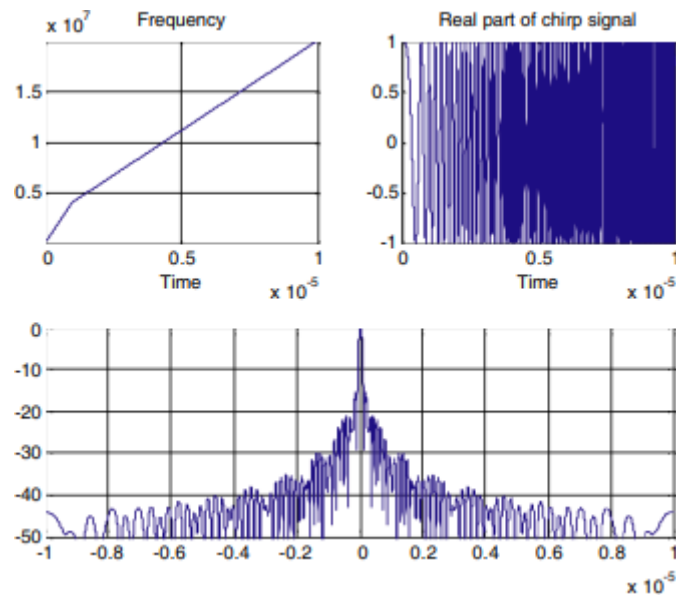


Fig 6.6 Two stages NLFM waveform response for configuration 5.

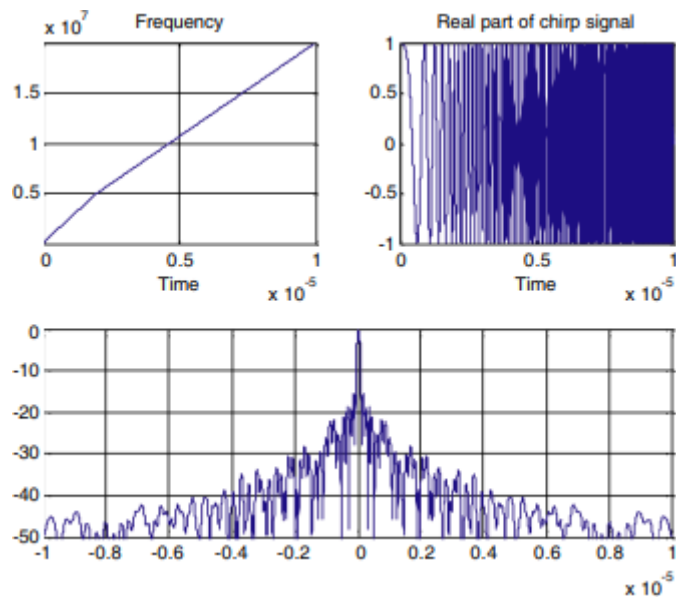


Fig 6.7 Two stages NLFM waveform response for configuration 6

6.2 Tri stage NLFM

Beside the possible configurations shown in Two stage NLFM, another possible FM modulation i.e., Tri-stages NLFM modulation signal can be applied in order to suppress the sidelobe level. Its general waveform is shown in Figure 7.1, which can be subdivided into three stages. Each of the segments is linearly sweep with a particular chirp rate. It composes of two LFM segments that increase the modulation rate at the leading and trailing edges of the waveform. Using LFM there is a disadvantage of loss of signal due to the weighting techniques used. To overcome that we can go for Non-Linear Frequency modulation . To get suppressed side lobes of the signal, we can use Non-Linear Frequency Modulation (NLFM). A NLFM signal is designed for different time sweeps called as Improved NLFM. In Improved NLFM the total time sweep and bandwidth are divided into Two Stage and Tri-Stage sweeps NLFM. Below are the few types of NLFM with different sweep rates. The instantaneous frequency of this NLFM can be written as,

$$f(t) = \begin{cases} \frac{B_1}{T_1}, & 0 \leq t \leq T_1 \\ B_1 + \frac{B_2}{T_2}t, & T_1 \leq t \leq T_2 \\ B_1 + B_2 + \frac{B_3}{T_3}t, & T_2 \leq t \leq T_3 \end{cases}$$

The Tri-stage NLFM waveform is used to suppress the side lobes. It has three stages as shown in Fig 7.1 . All the three stages are linearly swept with different chirp rate. Of the three stages, two LFM stages have increased modulation rate at leading and trailing edges.

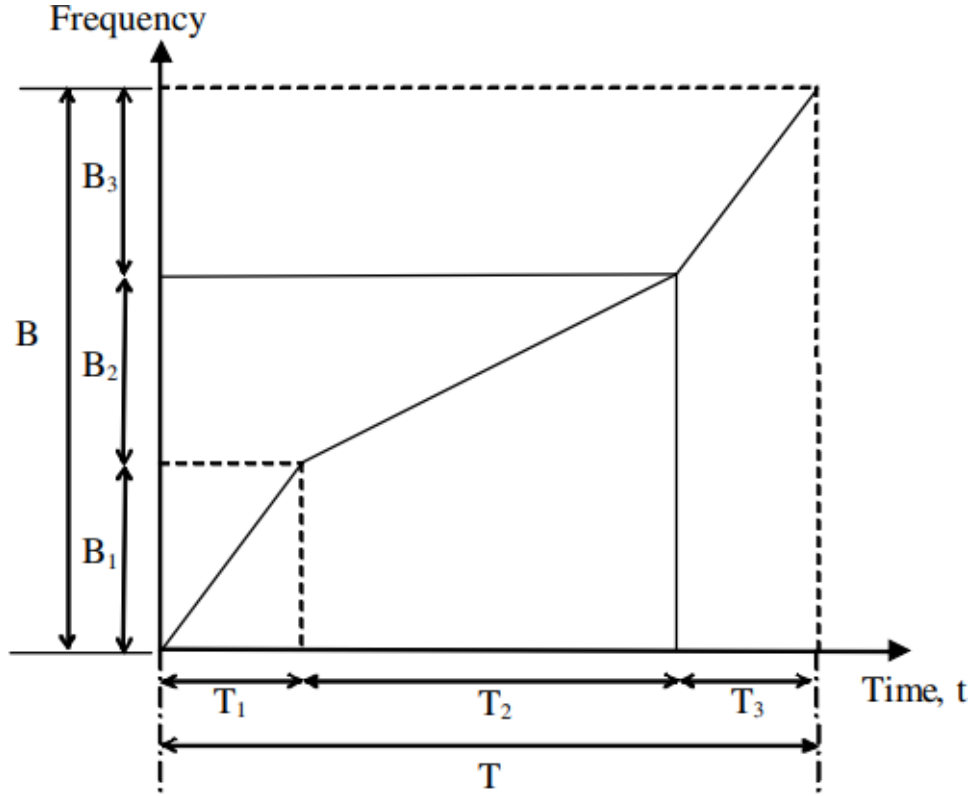


Fig 7.1 Modulation signal for Tri-stages NLFM waveform.

Thus, the phase of this two stages NLFM signal can be derived by integrating above equation

$$\phi(t) = \int f(t)dt = \begin{cases} \frac{B_1}{T_1} \times \frac{t^2}{2}, & 0 \leq t \leq T_1 \\ B_1 \times t + \frac{B_2}{T_2} \times \frac{t^2}{2}, & T_1 \leq t \leq T_2 \\ B_1 \times t + B_2 \times t + \frac{B_3}{T_3} \times \frac{t^2}{2}, & T_2 \leq t \leq T_3 \end{cases}$$

Simulations have been done with various configurations. It can be shown that the tri-stage NLFM waveform is able to produce lower sidelobe as compared to conventional LFM signal. Some of the simulation results are shown in Figures 18–23. It can be observed that some of the configurations are able to suppress the sidelobe for better

radar target detection. Table 3 listed the highest sidelobe level of autocorrelation function for some potentially tri-stage NLFM function.

| Configuration | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------------|--------|--------|--------|-------|--------|--------|
| Sidelobe Level (dB) | -14.26 | -17.37 | -17.35 | -19.2 | -18.45 | -17.13 |

Table 7.1 Highest sidelobe level for Tri-stages LFM signal.

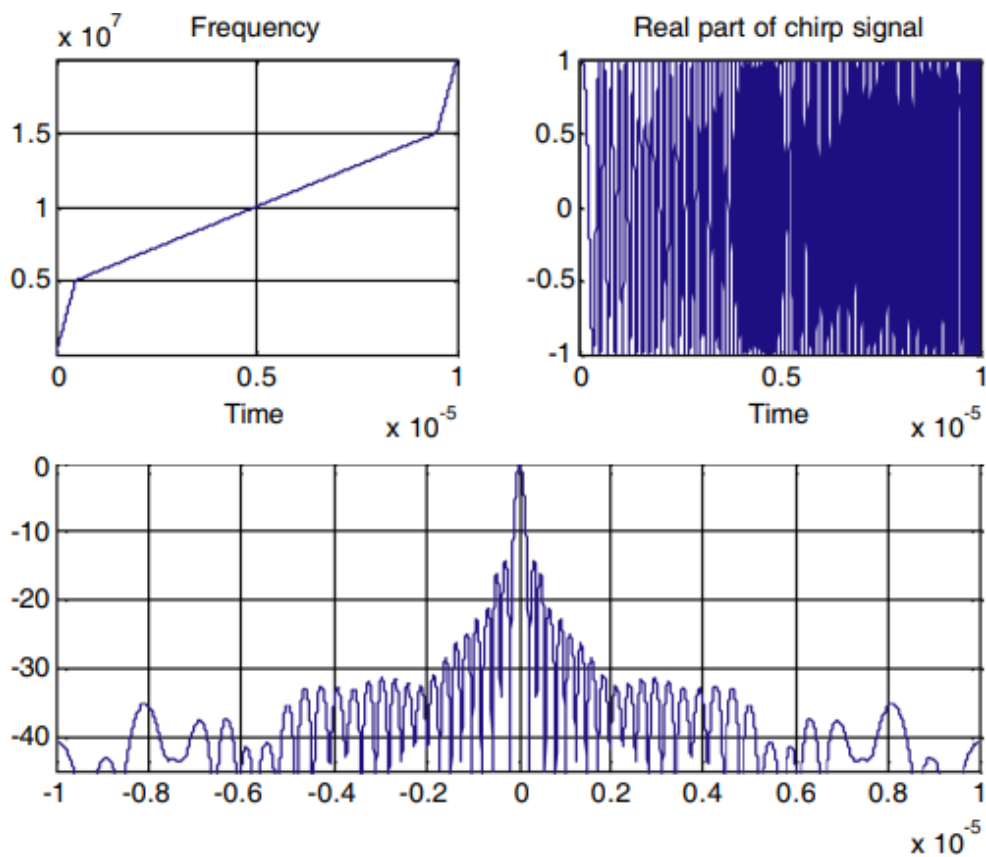


Fig 7.2 Tri-stages NLFM waveform response for configuration 1.

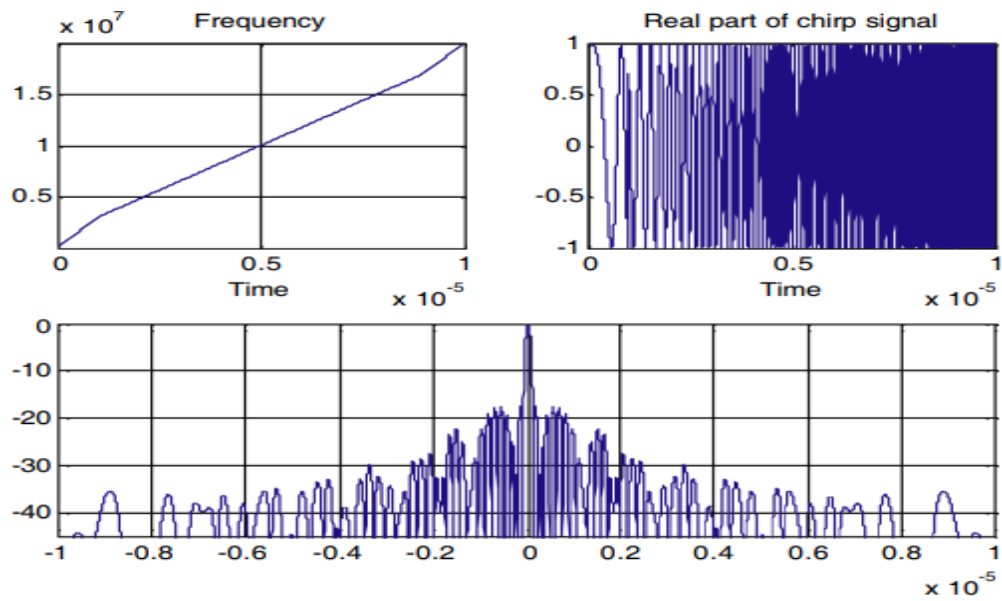


Fig 7.3 Tri-stages NLFM waveform response for configuration 2.

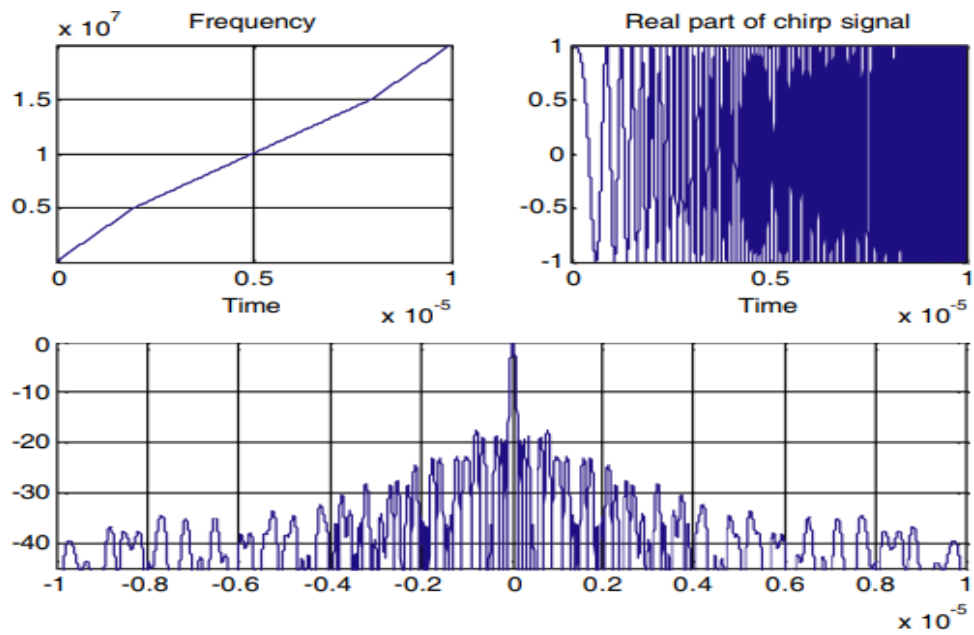


Fig 7.4 Tri-stages NLFM waveform response for configuration 3

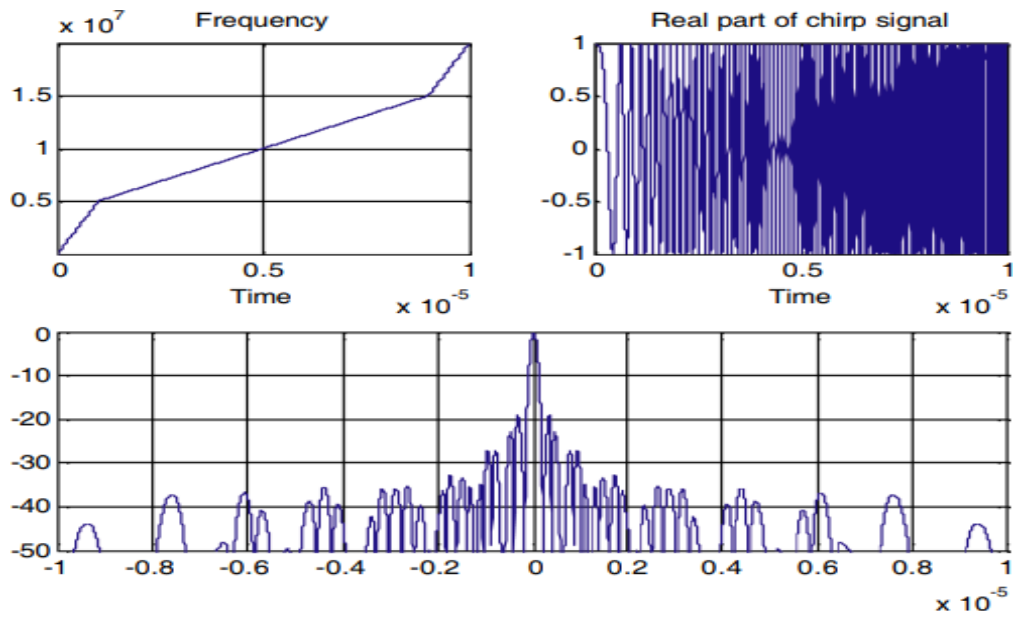


Fig 7.5 Tri-stages NLFM waveform response for configuration 4

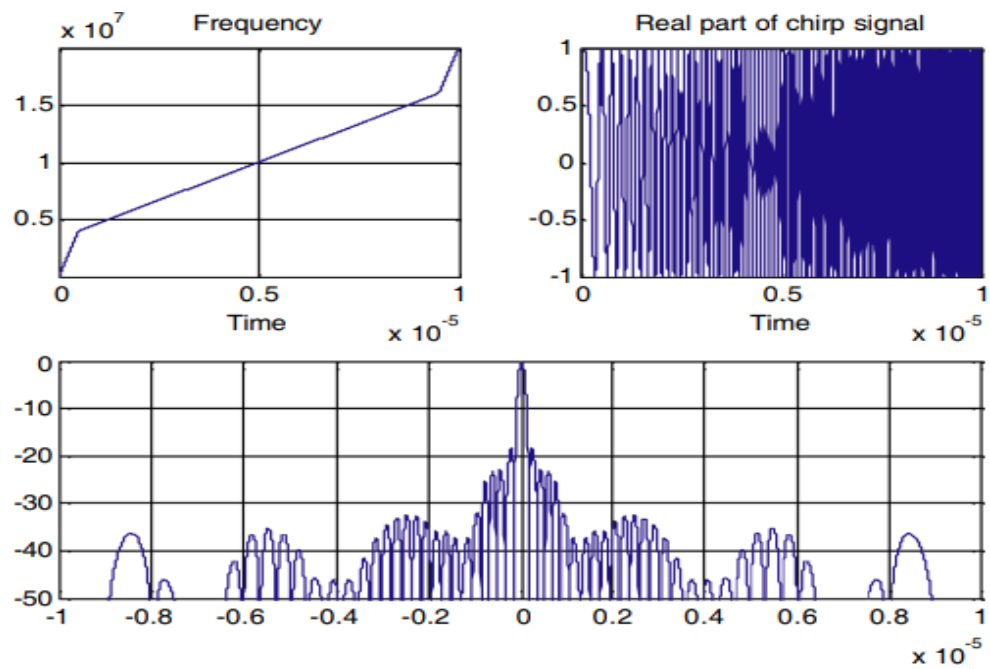


Fig 7.6 Tri-stages NLFM waveform response for configuration 5

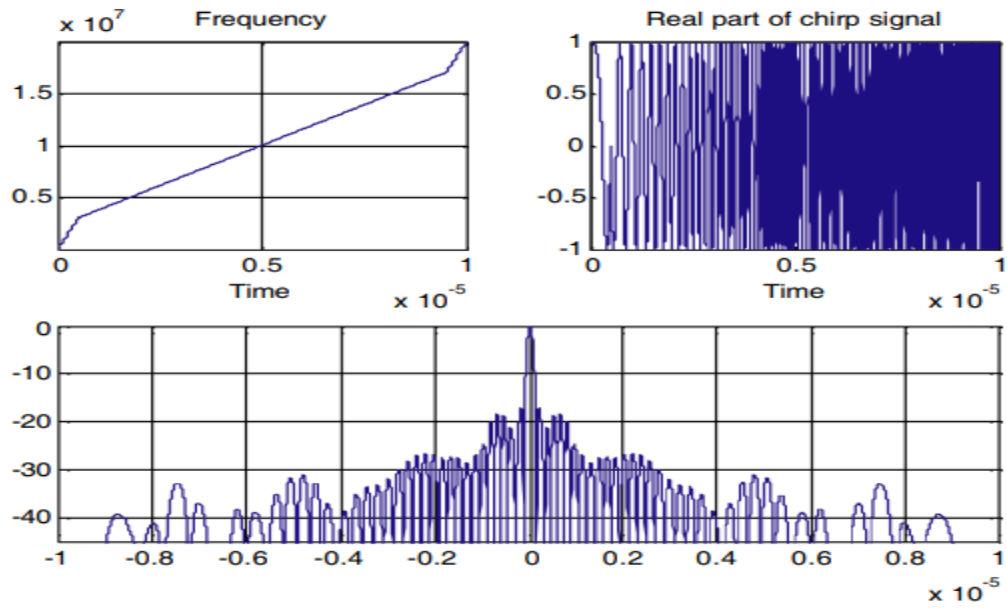


Fig 7.7 Tri-stages NLFM waveform response for configuration 6

CHAPTER-7

Software Implementation

CHAPTER 7

Software Implementation

MATLAB is widely used in all areas of applied mathematics, in education and research at universities, and in the industry. MATLAB stands for Matrix Laboratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra, but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and can produce nice pictures in both 2D and 3D. It is also a programming language and is one of the easiest programming languages for writing mathematical programs. MATLAB also has some toolboxes useful for signal processing, image processing, optimization, etc.

7.1 Introduction

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. MATLAB stands for matrix laboratory and was written originally to provide easy access to matrix software developed by LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is therefore built on a foundation of sophisticated matrix software in which the basic element is an array that does not require pre dimensioning which to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of time.

MATLAB features a family of applications specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow learning and applying specialized technology. These are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available to include signal processing, control system, neural networks, fuzzy logic, wavelets, simulation, and many others.

Typical uses of MATLAB include Math and computation, Algorithm development, Data acquisition, Modelling, simulation, prototyping, Data analysis, exploration, visualization, Scientific and engineering graphics, Application development, including graphical user interface building.

7.2 Basic Building Blocks of MATLAB

The basic building block of MATLAB is MATRIX. The fundamental data type is the array. Vectors, scalars, real matrices, and complex matrix are handled as a specific class of this basic data type. The built-in functions are optimized for vector operations. No dimension statements are required for vectors or arrays.

7.2.1 MATLAB Window

The MATLAB works based on five windows: Command window, Workspace window, Current directory window, Command history window, Editor Window, Graphics window, and Online-help window.

7.2.1.1 Command Window

The command window is where the user types MATLAB commands and expressions at the prompt (`>>`) and where the output of those commands is displayed. It is opened when the application program is launched. All commands including user-written programs are typed in this window at MATLAB prompt for execution.

7.2.1.2 Work Space Window

MATLAB defines the workspace as the set of variables that the user created in a work session. The workspace browser shows these variables and some information about them. Double-clicking on a variable in the workspace browser launches the Array Editor, which can be used to obtain information.

7.2.1.3 Current Directory Window

The current Directory tab shows the contents of the current directory, whose path is shown in the current directory window. For example, in the windows operating system, the path might be as follows: `C:\MATLAB Work`, indicating that directory "work" is a subdirectory of the main directory "MATLAB";

which is installed in drive C. Clicking on the arrow in the current directory window shows a list of recently used paths. MATLAB uses a search path to find M-files and other MATLAB related files. Any file nun in MATLAB must reside in the current directory or in a directory that is on the search path. The workspace browser shows these variables and some information about them. Double-clicking on a variable in the workspace browser launches the ArrayEditor, which can be used to obtain information.

7.2.1.4 Command History Window

History Window contains a record of the commands a user has entered in the command window, including both current and previous MATLAB sessions. Previously entered MATLAB commands can be selected and re-executed from the command history window by right-clicking on a command or sequence commands. This is useful to select various options in addition to executing the commands and is a useful feature when experimenting with various commands in a work session.

7.2.1.5 Editor Window

The MATLAB editor is both a text editor specialized for creating M-files and a graphical MATLAB debugger. The editor can appear in a window by itself, or it can be a sub-window in the desktop. In this window, one can write, edit, create and save programs in files called M-files.

MATLAB editor window has numerous pull-down menus for tasks such as saving, viewing, and debugging files. Because it performs some simple checks and also uses color to differentiate between various elements of code, this text editor is recommended as the tool of choice for writing and editing M-functions.

7.3 MATLAB Files

MATLAB has three types of files for storing information. They are M-files and MAT-files.

7.3.1 M-Files

These are standard ASCII text files with 'm' extension to the file name and creating own matrices using M-files, which are text files containing MATLAB code. MATLAB editor or another text editor is used to create a file containing the same statements which are typed at the MATLAB command line and save the file under a name that ends in .m. There are two types of M-files:

1. Script Files

It is an M-file with a set of MATLAB commands in it and is executed by typing the name of the file on the command line. These files work on global variables currently present in that environment.

2. Function Files

A function file is also an M-file except that the variables in a function file are all local. This type of file begins with a function definition line.

7.3.2 MAT-Files

These are binary data files with .mat extension to the file that is created by MATLAB when the data is saved. The data are written in a special format that only MATLAB can read. These are located in MATLAB with the 'load' command.

7.4 Some Basic Commands:

Pwd : Print working directory

Demo : Demonstrates what is possible in MATLAB

Who : Lists all of the variables in your MATLAB workspace?

Whose : List the variables and describes their matrix size

Clear : Erases variables and functions from memory

clear x : Erases the matrix 'x' from your workspace

`close` : By itself, closes the current figure window

`figure` : Creates an empty figure window

`xlabel(' ')` : Allows you to label x-axis

`ylabel(' ')` : Allows you to label y-axis

`title(' ')` : Allows you to give title for plot

A semicolon “;” at the end of a MATLAB statement suppresses printing of results.

Use **Up arrow** and **Down arrow** to edit previous commands you entered in Command Window.

Insert “%” before the statement that you want to use it as comment; the statement will appear in green color.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time.

The name MATLAB stands for Matrix laboratory, MATLAB features a family of applications solutions called toolboxes. Toolboxes are comprehensive collections of MATLAB(M-files) that extend the MATLAB environment to solve particular classes of problem. It is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB's support for object-oriented programming includes classes, inheritance, virtual dispatch, packages, pass-by value semantics, and pass-by reference semantics. A wrappers function it created allowing MATLAB data types to be passed and returned.

7.5 The MATLAB language

Versions such as R2009, R2010, R2012, R2013, R2015 R2017 are available in both ‘a’ and ‘b’ versions. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming

features. It allows both “programming in the small” to rapidly create quick and dirty throw-away programs, and “programming in the large” to create complete large and complex application programs.

7.6 MATLAB program control

MATLAB is also a programming language. Like other computer programming languages, MATLAB has some decision-making structures include for loops, while loops, and if-else-end constructions. Control flow structures are often used in script M-files and function M-files.

By creating a file with the extension .m, we can easily write and run programs. We do not need to compile the program since MATLAB is an interpretative (not compiled) language. MATLAB has thousands of functions, and you can add your own using M-files. MATLAB provides several tools that can be used to control the flow of a program.

7.7 Types of Functions

MATLAB offers several different types of functions to use in your programming.

7.7.1 Anonymous Functions

An anonymous function is a simple form of the MATLAB function that is defined within a single MATLAB statement. It consists of a single MATLAB expression and any number of input and output arguments. You can define an anonymous function right at the MATLAB command line, or within a function or script. This gives you a quick means of creating simple functions without having to create a file for them each time.

7.7.2 Primary and Sub functions

Any function that is not anonymous must be defined within a file. Each such function file contains a required primary function that appears first, and any number of sub functions that may follow the primary. Primary functions have a wider scope than

sub functions That is, primary functions can be called from outside of the file that defines them (e.g., from the MATLAB command line or from functions in other files) while sub functions cannot. Sub functions are visible only to the primary function and other sub functions within their own file.

7.8 Plotting in MATLAB

MATLAB provides a variety of functions for displaying vector data as line functions for annotating and that produce basic line plots. These functions differ in the way they scale the accepts input in the form of vectors or matrices and automatically scales the axes to accommodate the data. The mesh and surf commands create 3-D surface plots of matrix data. Surface object properties provide additional control over the visual appearance of the surface and also the edge line styles, vertex markers, face colouring, lighting, characteristics can also be specified.

7.8.1 Basic plot commands

- plot(x, y) : create a Cartesian plot of the vectors x & y
- plot(y) : creates a plot of y vs, the numerical values of the elements in vector
- semilogx(x, y) : plot log(x) vs y
- semilogy(x, y) : plot x vs log(y)
- loglog(x, y) : plot log(x) vs log(y)
- polar(theta, r) : creates a polar plot of the vectors r theta where theta is in radians
- bar(x) : creates a bar graph of the vector x. (Note also the command stairs(x))
- bar(x, y) : create a bar-graph of the elements of the vector y, locating the bars

Plot description:

grid : create a grid on the graphics plot
title('text') : places a title at top of graphics plot
xlabel('text') : writes 'text' beneath the x-axis of a plot
ylabel('text') : writes 'text' beside the y-axis of a plot

7.9 Data Types in MATLAB

By default, MATLAB stores most data in array of class double. The data in these arrays is stored as double precision (64-bit) floating-point numbers. All MATLAB functions and capabilities work with these arrays.

For images stored in one of the graphics file formats supported by MATLAB, however, this data representation is not always ideal. The number of pixels in such an image may be very large, for example, a 1000-by-1000 image has a million pixels. Since each pixel is represented by at least one array element, this image would require about 8 megabytes of memory if it were stored as class double. To reduce memory requirements, MATLAB supports storing image data in arrays of class uint8 and uint16. The data in these arrays is stored as 8-bit or 16-bit unsigned integer. These arrays require one eighth or one-fourth much memory as data in double arrays.

7.10 Applications of MATLAB

- Data Exploration, Acquisition, Analysing & Visualization
- Engineering drawing and Scientific graphics
- Analysing of algorithmic designing and development
- Mathematical functions and Computational functions
- Simulating problems prototyping and modelling
- Application development programming using GUI building environment.

CHAPTER-8
RESULTS AND DISCUSSIONS

Chapter-8

Results and Discussions

In this chapter simulation is carried out for Linear Frequency Modulated signal, Non-Linear Frequency Modulation, Two-stage NLFM and tri-stage NLFM.

8.1 LFM signal

A LFM radar waveform is generated with duration of pulse is $T=10\mu\text{sec}$, Bandwidth $B=20\text{MHz}$ with $BT=200$ as shown in Fig. 8.1.1

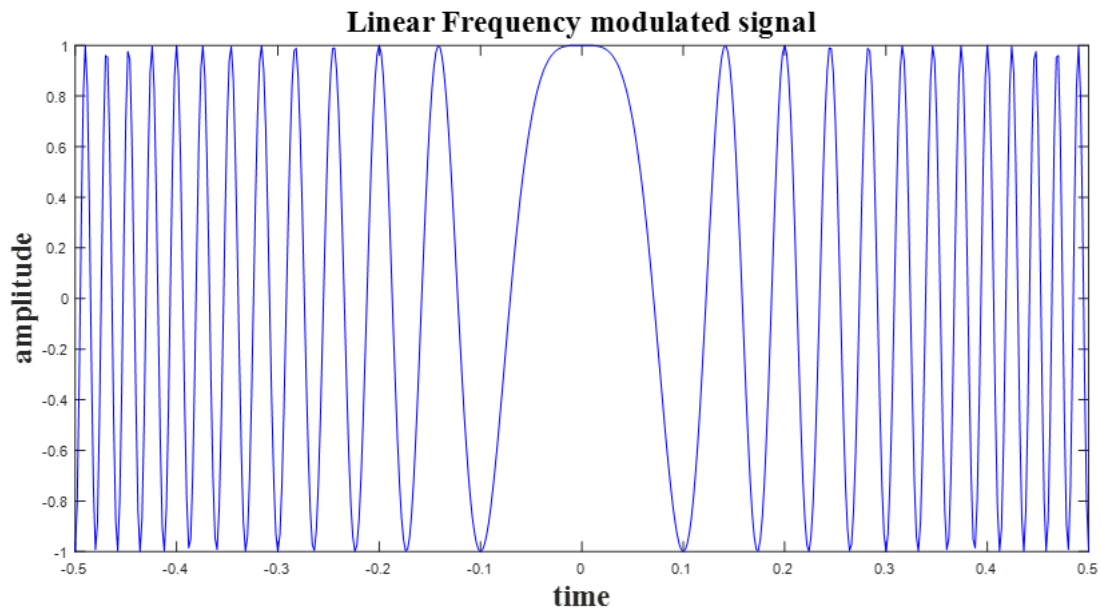


Fig 8.1.1 LFM Chirp Signal

The resultant output after passing the above LFM signal through matched filter is shown in Fig 8.1.2

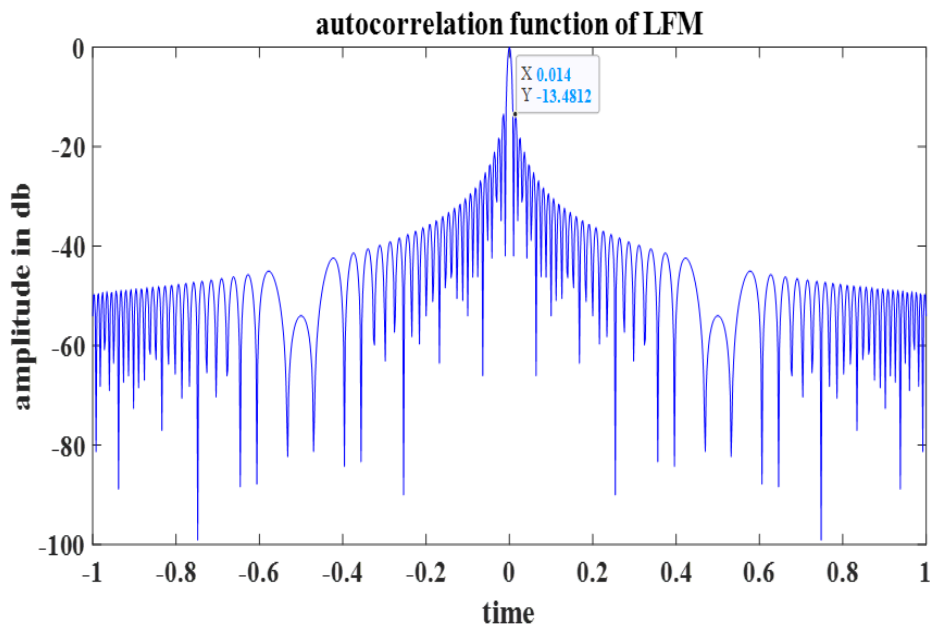


Fig 8.1.2 Auto Correlation of LFM signal

It can be observed from simulation results of Fig 8.1.2 that the PSLR = -13.48dB is obtained for LFM signal which is very high. To reduce PSLR more a NLFM signal is designed for different BT values.

As from the Fig. 8.1.2 obtained first side lobe level of -13.48 dB which is undesirable. NLFM signal is used to overcome the above problem. For different sweep rates the frequencies vary non-linearly.

8.2 NLFM Signal

A pulse width with time duration $T=10\mu\text{s}$ and band width $B =20\text{MHz}$ is used to simulate NLFM waveform. Fig.8.2.1 shows the simulated NLFM signal

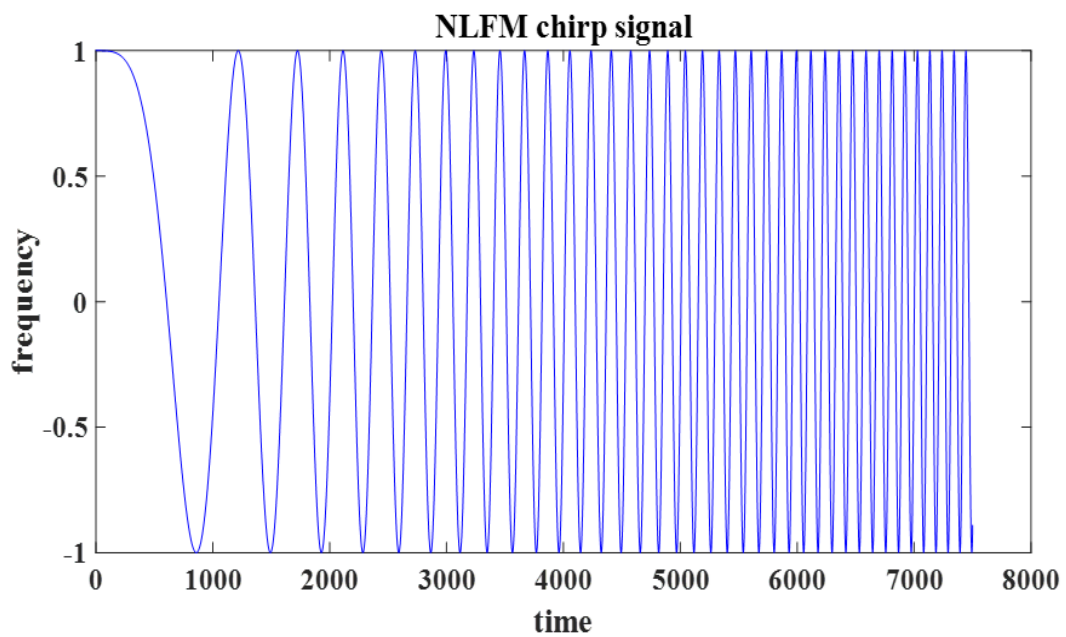


Fig 8.2.1 NLFM Chirp Signal

The output obtained after passing the above NLFM signal through matched filter is presented in Fig 8.2.2

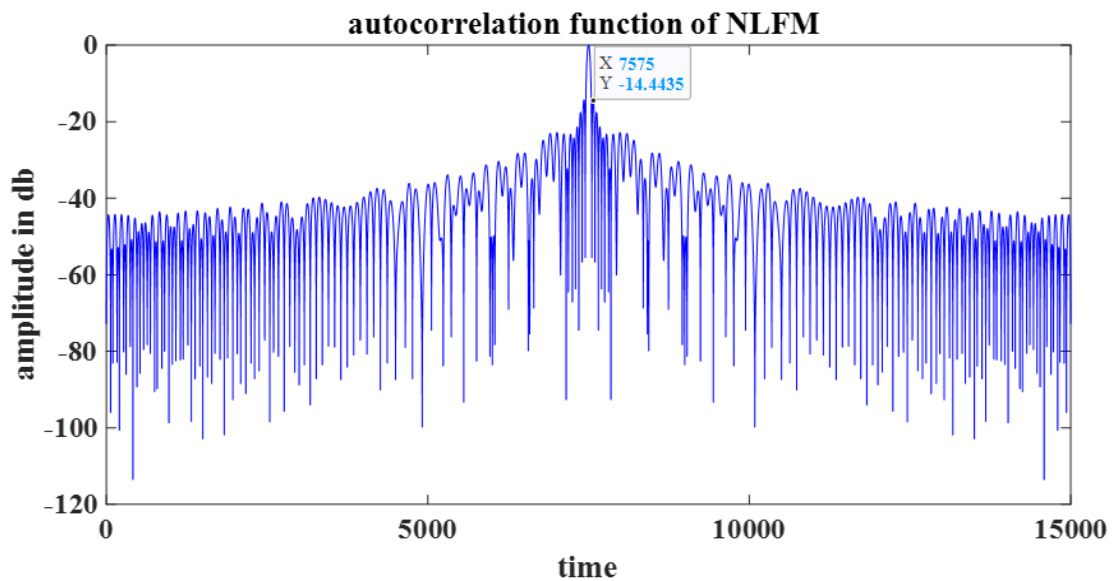


Fig 8.2.2 Auto Correlation of NLFM signal

which is low compared to LFM . To reduce PSLR more an Improved NLFM signal is designed for different values of BT .

Two-stage NLFM is examined to further decrease the level of first side lobes. This NLFM modulation function has two LFM stages as shown in fig 8.3.1. It has two distinct LFM sweep rate with $B_1=5\text{MHz}$, $T_1=1\mu\text{sec}$ and $B_2=15\text{ MHz}$, $T_2=9\mu\text{sec}$ for total BT of $B=20\text{MHz}$, $T=10\mu\text{sec}$. Modulation Function graph with different sweeps is shown in Fig 8.3. It can be observed from simulation results of Fig 8.2.2 that the PSLR = -14.27dB is obtained for NLFM signal 1

8.3 Simple Two-Stage NLFM

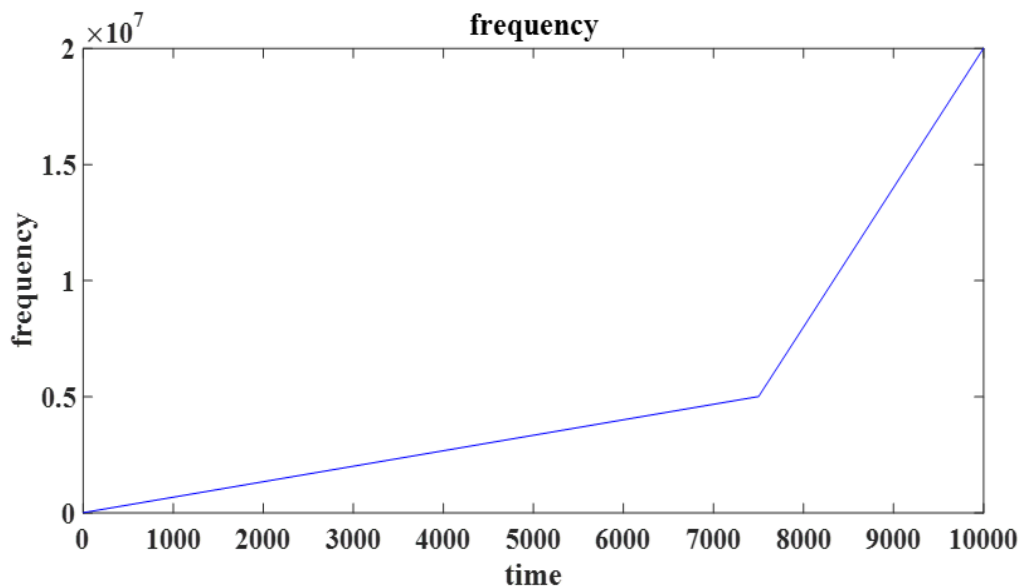


Fig 8.3.1 Modulation Function in simple two-stage NLFM

A simple two stage NLFM signal with Pulse width $T=10\mu\text{s}$ and Bandwidth $B=20\text{MHz}$ is generated as depicted in fig 8.3.2.

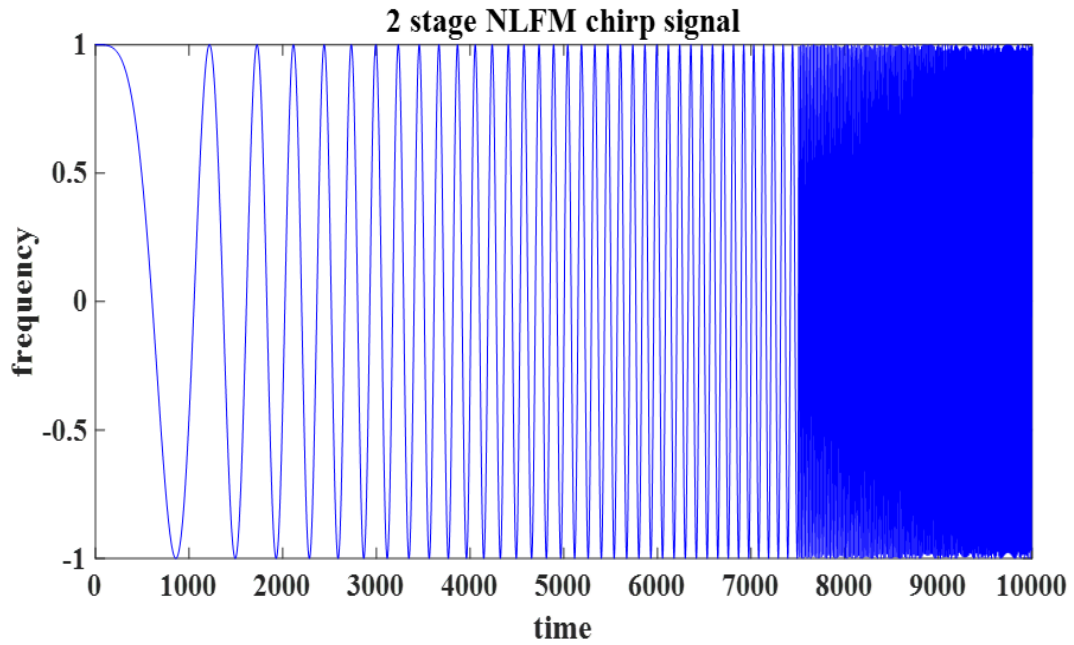


Fig 8.3.2 Two Stage NLFM Chirp Signal

The resultant output after passing the above two-stage NLFM signal through matched filter is shown in fig 8.3.3

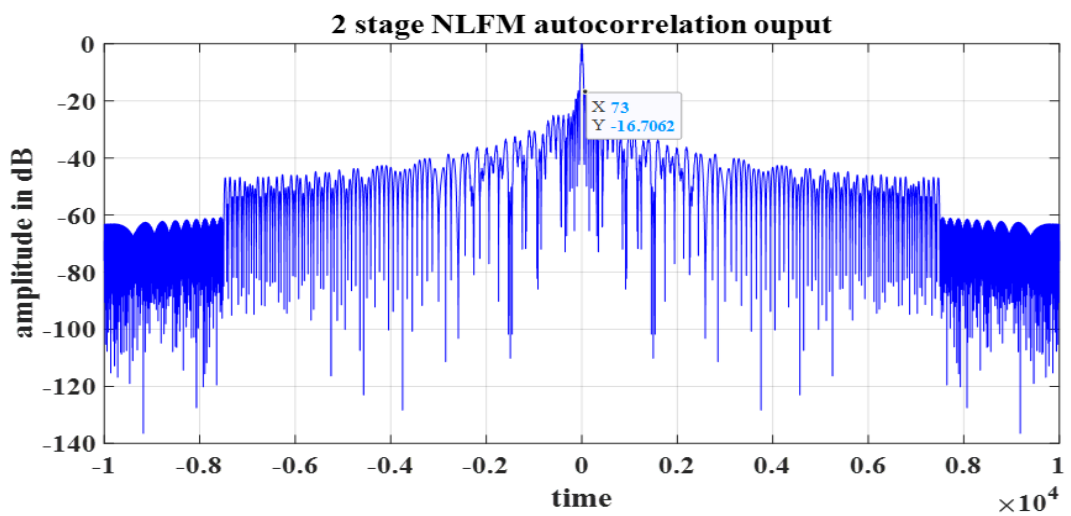


Fig 8.3.3 Auto Correlation of two stage NLFM signal

It can be observed from simulation results of Fig 8.3.3 that the PSLR = -16.77dB is obtained for Two stage NLFM signal which is low compared to NLFM . To reduce PSLR more an Improved Tri stage NLFM signal is designed for different values of BT. A further reduction of first side lobe level can be observed in Tri Stage NLFM besides NLFM and Two-stage NLFM.

This NLFM modulation function has three LFM stages as shown in Fig 8.4.1 It has three distinct LFM sweep rate with $B_1=10\text{KHz}$, $T_1=2.5\text{msec}$, $B_2=5\text{KHz}$, $T_2=5\text{msec}$ and $B_3=5\text{KHz}$, $T_3=2.5\text{msec}$ for total BT of $B=20\text{KHz}$, $T=10\text{msec}$. Modulation Function graph with different sweeps is shown in Fig 10. At three different time stages the linearity of increase in frequency varies and it is depicted in the fig 8.4.1

8.4 Tri-Stage NLFM

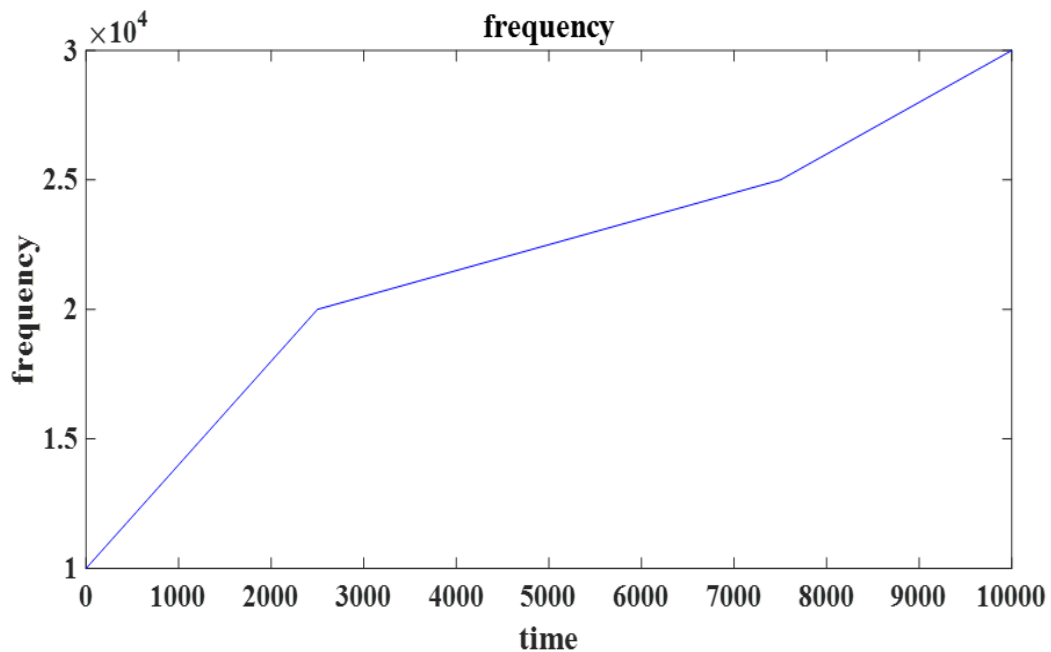


Fig 8.4.1 Modulation Function of Tri-Stage NLFM

A Tri-stage NLFM signal of pulse width $T=10\text{ms}$ and Bandwidth $B=20\text{KHz}$ is simulated and is depicted in Fig 8.4.

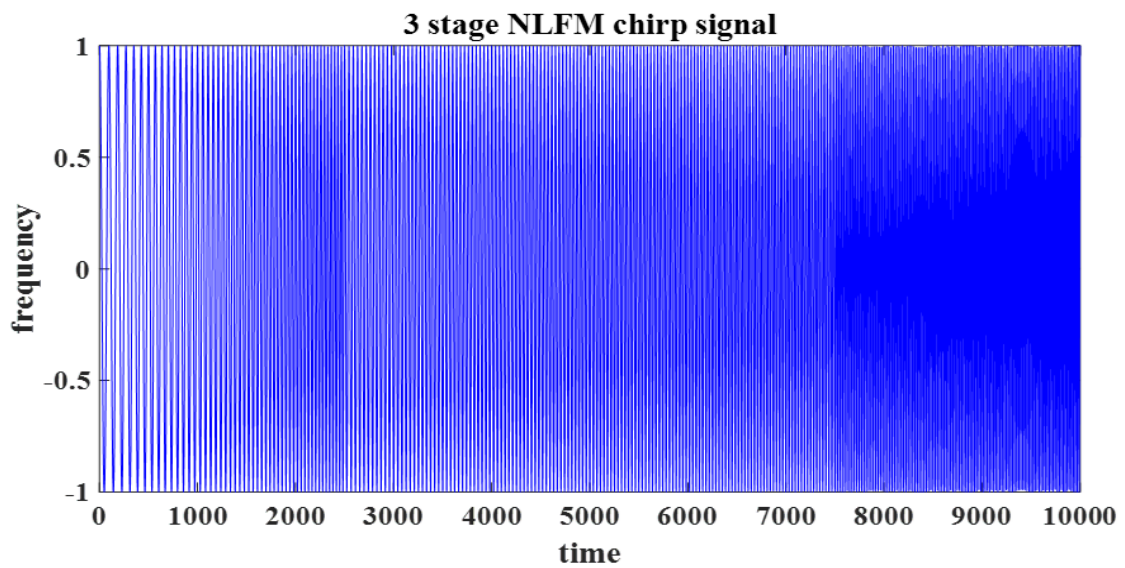


Fig 8.4.2 Tri-Stage NLFM Chirp Signal

The resultant output generated after passing the above tri-stage NLFM chirp signal through matched filter is shown in Fig 8.4.3

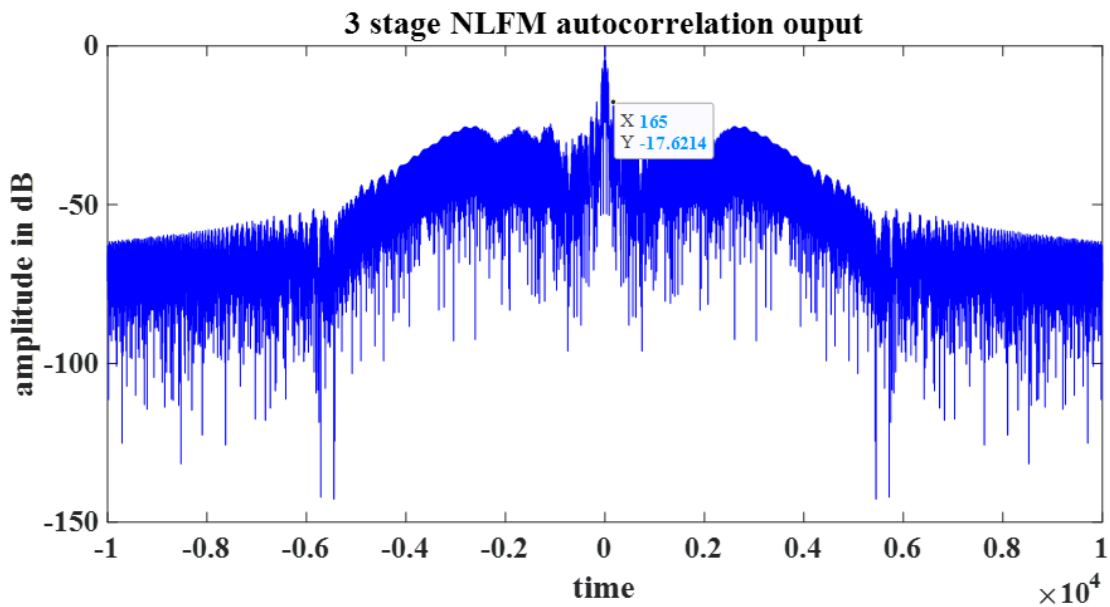


Fig 8.4.3 Auto Correlation of Tri-Stage NLFM signal

The first side lobe level of -17.62dB is obtained after the auto correlation of tri-stage NLFM signal. Therefore, a further decrease in first side lobe level can be observed.

Table 9.1 Comparison of First Side Lobe Levels of various modulated signals for BT value of 200:

| BT | LFM | NLFM | Two-Stage NLFM | Tri-Stage |
|-----------|------------|-------------|-----------------------|------------------|
| 200 | -13.48db | -14.27db | -16.77db | -17.62db |

CHAPTER-9

CONCLUSION AND FUTURE SCOPE

CHAPTER-9

Conclusion and Future Scope

In this project, designed and generated an LFM, NLFM and Improved NLFM radar signals. To overcome the problem of increased side lobe levels while using conventional LFM signal in a radar, a NLFM signal and improved NLFM signals are designed. An increased side lobe level would result in decreased Range resolution and wastage of energy. It is observed that by using Two stage and Tri-stage NLFM radar signals we can reduce the side lobe levels up to -17.62dB. Because of non-usage of any weighting techniques there would be less amount of loss in the transmitted signal's energy and the Range resolution which is the ability to track closely spaced objects more clearly would be immensely increased. There is still a scope to decrease the side lobe levels and get clearer and more precise main lobe through a different approach of using polynomial based NLFM equation. Thus, using NLFM signal in a RADAR as an alternative to LFM signal could result in reduced side lobe levels and increased SNR. There is still a scope to decrease the side lobe levels and get clearer and more precise main lobe through a different approach of using polynomial based expressions. Thus, using NLFM signal in a RADAR as an alternative to LFM signal could result in reduced side lobe levels and increased SNR.

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