Analog Pulse Compression Technique with Improved SNR and Reduced Sidelobes

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Abstract: **Pulse Compression is a signal processing technique used in radars to increase Signal to noise ratio and range resolution. In this paper we discuss about Linear frequency modulation (LFM) and Non-linear frequency modulation (NLFM). In this pulse compression can be done by using Matched Filter. In this paper we calculated the peak side lobe ratio. By using matched filter and transversal filter, order N like Hamming window, Hanning window, Kaiser window, Blackman window we increase the signal to noise ratio (SNR) and reduces the side lobe level. The Non-linear frequency modulation (NLFM) provides high signal to noise ratio compared to Linear frequency modulation (LFM).**

***Keywords*: Pulse compression, Linear frequency modulation (LFM), Nonlinear frequency modulation (NLFM), Matched Filter, Window techniques.**

1. INTRODUCTION

Radar is a system that uses electromagnetic waves to detect, locate and measure the speed of reflecting objects such as aircraft, ships, spacecraft, vehicles and terrain. Radar transmits that electromagnetic signals into free space and receives that echo signal reflected from the objects. Pulse compression is a technique used to convert long pulse into a short pulse. Because the energy content of long pulse with low peak power is same as the short pulse with high peak power. Linear frequency modulation or phase modulation increases the bandwidth of the transmitted signal. The long duration pulse strike with different number of targets and the echo is returned to the receiving antenna. Pulse compression techniques are used to

increase the range resolution and signal to noise ratio.

Range resolution is defined as the ability of the radar to distinguish between two or more targets which are placed close to each other with different ranges. In range resolution pulse width is the primary factor based on width of the transmitted pulse the degree of range resolution is defined. The amount of energy in the pulse is increased by decreasing the width of the pulse depends on the width of the transmitted pulse. hence get maximum range detection, depends on the strength of the received echo. For long distance transmission the transmitted pulse should have more energy to get high strength reflected echo since it gets attenuated during transmission.

$$R_{res} = \frac{C}{2B}$$

Where, c = speed of light and

B = bandwidth of the pulse

Signal to noise ratio is defined as ratio of signal power to the noise power and it is expressed in decibels(dB).

$$\text{SNR} = \frac{psignal}{pnoise}$$

1.1. Methods of pulse compression

M. I. Shkolnik, "Radar Handbook" 3rd edition, Mc-Graw Hill 2008 gives new idea about pulse compression method. In this we know pulse compression has been classified into both analog and digital methods. Analog methods are Linear LFM and NLFM. Digital methods are Barker code, Costas code and Frank code.

Generation of LFM and NLFM:

Linear frequency modulation is a technique in which frequency of the transmitted signal is changed with respect to pulse duration of T. The change of frequency from low to high or high to low is known as chirping. Chirping is classified in two types namely 'up-chirp' and 'down-chirp'. The change of frequency from low to high is known up-chirp or up sweep whereas change in frequency from high to low is known as down-chirp.

Input signal is $\mathrm{m}(t) = \mathrm{t}$

and carrier signal is $\mathrm{A}\cos(f_c t)$

The modulated signal is

$s = k\int t = k\frac{t^2}{2}$, where k=0.5

$\mathrm{f}(t) = \mathrm{A}\cos(f_c t - s)$ for downchirp.

$\mathrm{f}(t) = \mathrm{A}\cos(f_c t + s)$ for upchirp.

UPCHIRP

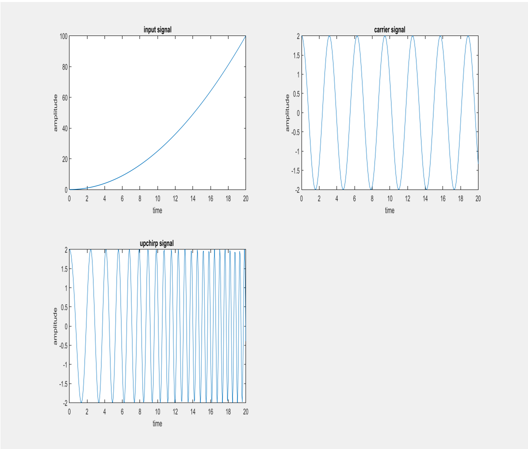


Fig (1): Up chirp

DOWNCHIP

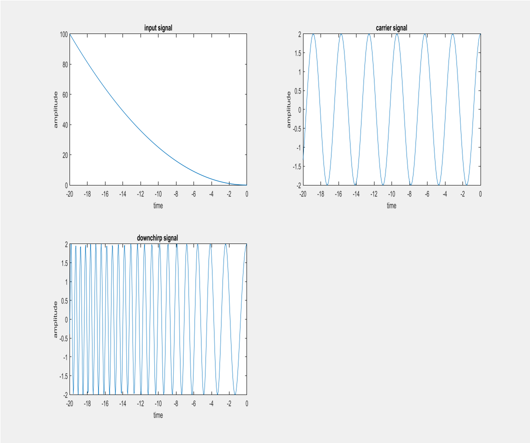


Fig (2): Down chirp

NLFM GENERATION:

It requires no frequency domain weighting for time sidelobe reduction. This shaping is accomplished by increasing the rate of change of frequency modulation near the ends of the pulse and decreasing it near the centre. [Doerry, A.W., 2006. *Generating nonlinear FM chirp waveforms for radar* (No. SAND2006-5856). Sandia National Laboratories].

$$s = \frac{t}{\boldsymbol{\tau}}\left[\boldsymbol{\beta}_{1+} + \boldsymbol{\beta}_2\left(\frac{\mathbf{1}}{\sqrt{\mathbf{1} - \mathbf{4}\frac{\boldsymbol{t}^2}{\boldsymbol{\tau}^2}}}\right)\right],$$

$$-\frac{\boldsymbol{\tau}}{\mathbf{2}} < t < \frac{\boldsymbol{\tau}}{\mathbf{2}}$$

$$f = Acos(f_c t + s)$$

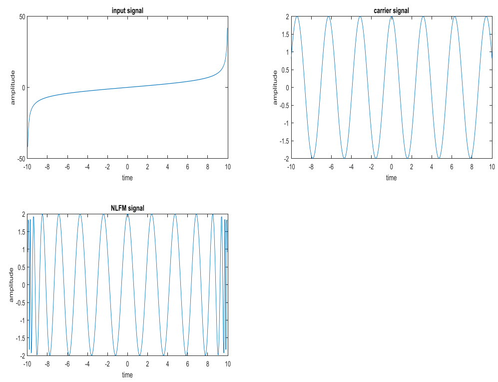
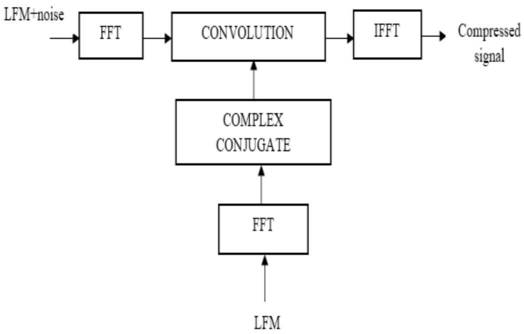


Fig (3): NLFM waveform

2. DESIGN OF MATCHED FILTER



Matched filter is a system used in initial stage of digital system receiver and it is used to improve the signal to noise ratio at the output of the receiver also reduce the probability of error.

The linear input signal is modulated by a frequency modulator in order to increase the bandwidth of the transmitted signal. Then this chirp signal and echo signal is given as input to the matched filter and then the convolution of replica of input signal and echo signal gives matched filter output.

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

where, x(t)→Received signal, h(t)→replica of Reference signal

x(t)=chirp + noise and h(t)=f(-t) = replica of chirp signal

From the output of the matched filter we can calculate the peak side lobe level. Here we observed that when the amplitude is increased at some interval and pulse width of noise is compressed. The matched filter technique is very important in communication as it is a good filtering technique which maximizes the signal to noise ratio (SNR). It is a linear filter and prior knowledge of the primary user signal is very essential for its operation.

2.1. Matched filter output waveform for LFM signal

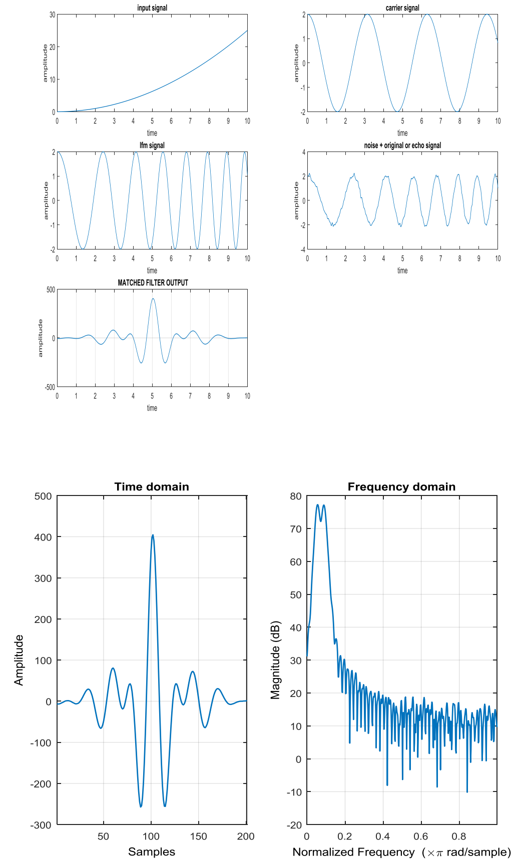


Fig (4): Matched filter output waveforms for LFM signal

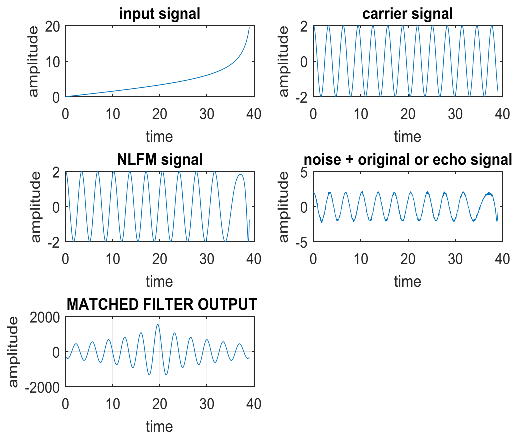
Signal to Noise ratio (SNR) =8.2548

Leakage factor = 0.1%

Relative Sidelobe attenuation = -0.8dB

Main lobe width (-3dB) =0.39844

2.2. Matched filter output waveform for nlfm signal



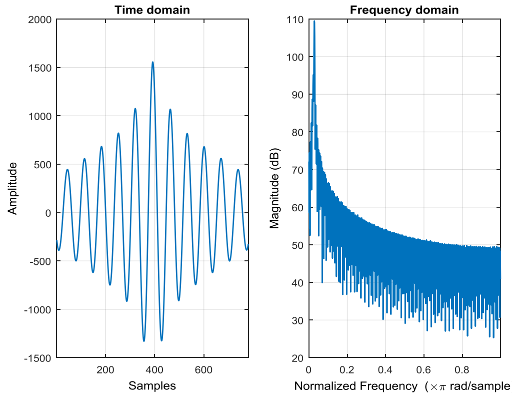


Fig (5): Matched filter output waveforms for NLFM signal

Signal to Noise ratio (SNR) =11.5799

Leakage factor = 0.09%

Relative Sidelobe attenuation = -0.8dB

Main lobe width (-3dB) =0.16211

2.3. Peak sidelobe ratio

Sidelobe level, usually expressed in decibels (dB), of the amplitude at the peak of the side lobe to the amplitude at the peak of a main lobe.

Peak sidelobe level is defined as the ratio of peak sidelobe level to the main lobe level.

$$\text{Peak side lobe Ratio}(PSR)\text{in dB} = 10\log 10\frac{peak\ sidelobe\ level}{main\ lobe\ level}$$

- **For LFM signal:**

Main lobe level = 408.2

Peak side lobe level = 42.46

Peak side lobe ratio (in dB) = -9.8268dB

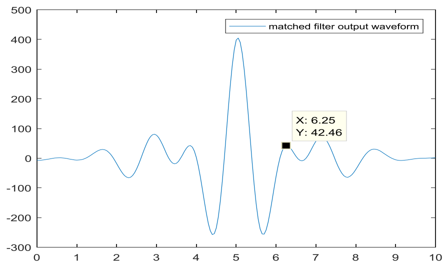


Fig (6): compressed signal peak side lobe ratio of LFM signal

- **For NLFM signal:**

Main lobe level = 1576

Peak side lobe level = 1083

Peak side lobe ratio (in dB) = -1.6292dB

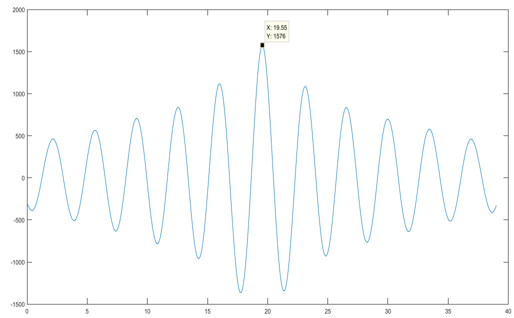


Fig (7): compressed signal peak side lobe ratio of NLFM signal

3. WINDOW TECHNIQUES

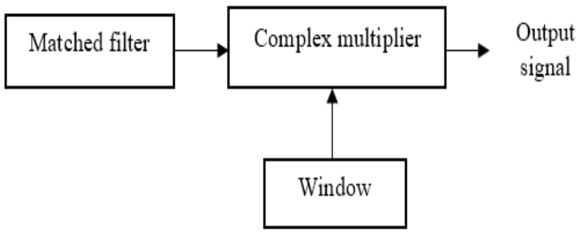


Fig (8): Block diagram of matched filter followed by Transversal filter, order N

The output of matched filter is given as input to the windows in order to increase the signal to noise ratio and relative side lobe attenuation. [Archana, M. and Gnana, M., 2014. Low power LFM Pulse Compression Radar with Sidelobe Suppression. International Journal of Advanced Research in

Electrical, Electronics and Instrumentation Engineering (IJAREEIE), 3(7), pp.10627-10679].

3.1. Applying window for LFM signal matched filter output

3.1.1. HAMMING window:

The hamming window reduces this ripple, giving you a more accurate idea of the original signal's frequency spectrum. Hamming Window is here to minimize the signal side lobe (unwanted radiation), and improves the quality of the signal, and reduces the sidelobe.

$$w(n) = 0.54 - 0.46\cos\left(\frac{2\pi n}{N-1}\right)$$

$$0 \le n \le N$$

HAMMING WINDOW OUTPUT WAVEFORMS

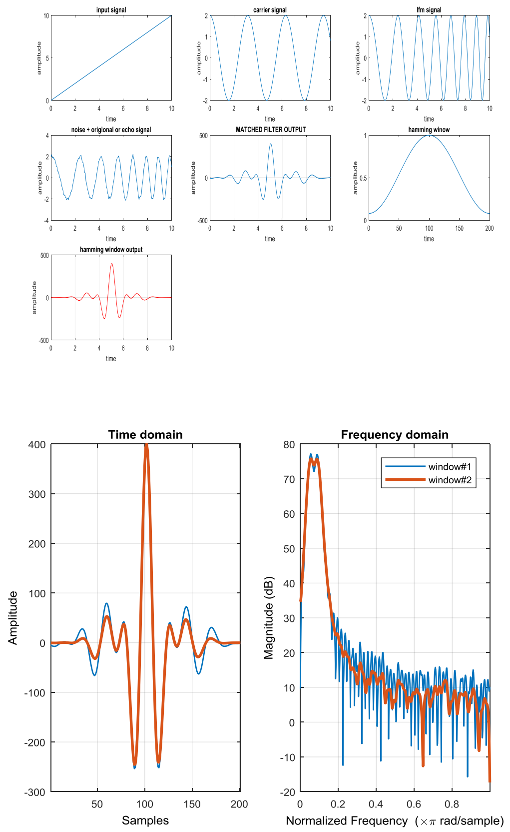


Fig (9): Hamming window output waveforms

3.1.2. HANNING window

Hanning windows are used with random data because they have a moderate impact on the amplitude accuracy and frequency resolution of the resulting frequency spectrum, especially when compared to the effects of other windows.

$$w(n) = 0.5 - 0.5\cos 2\pi nN - 1,$$

$$0 < n < N - 1$$

HANNING WINDOW OUTPUT WAVEFORMS

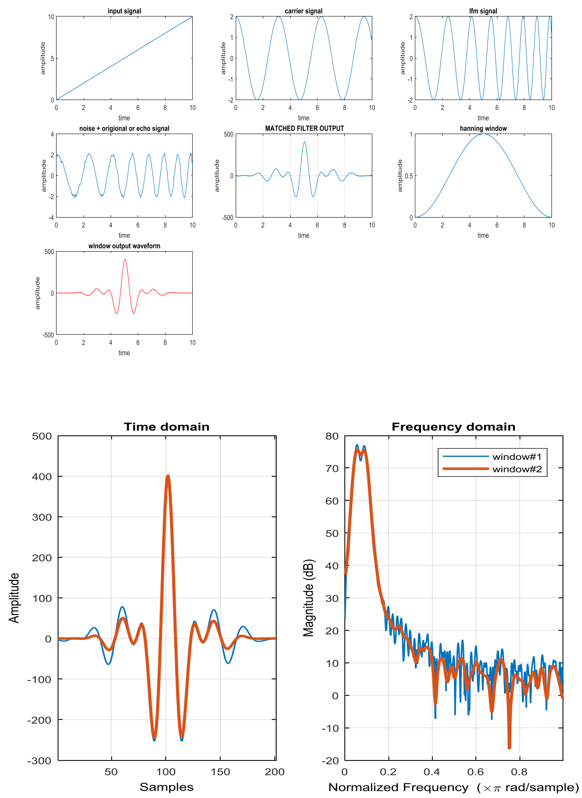


Fig (10): Hanning window output waveforms

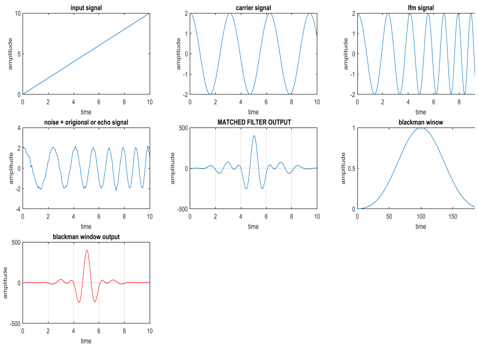
3.1.3. BLACKMAN window:

Blackman window is considered adequate for many audio applications.

$$w(n) = 0.42 - 0.5\cos\left(\frac{2\pi n}{N-1}\right) + 0.08\cos\left(\frac{4\pi n}{N-1}\right),$$

$$0 \leq n \leq N-1$$

BLACKMAN WINDOW OUTPUT WAVEFORMS:



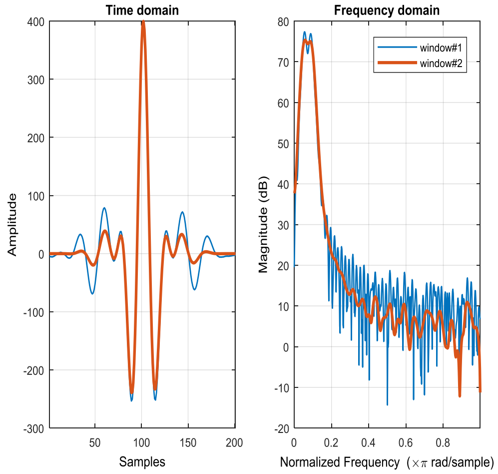


Fig (11): Blackman window output waveforms

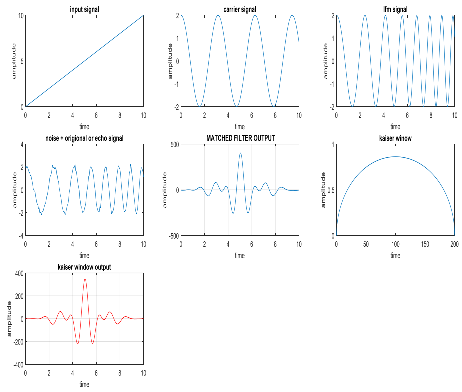
3.1.4. Kaiser window

$$\beta = 0.5842(\alpha - 21)^{0.4} + 0.07886(\alpha - 21), \quad 50 \geq \alpha \geq 21$$

$$\omega[n] = \frac{I_o\left[\beta\sqrt{1-\left(\frac{2n}{N-1}-1\right)^2}\right]}{I_o(\beta)}, \quad 0 \leq n \leq N-1,$$

Where, $I_0 = 0.3$, $\alpha = 23$

kaiser window output waveforms:



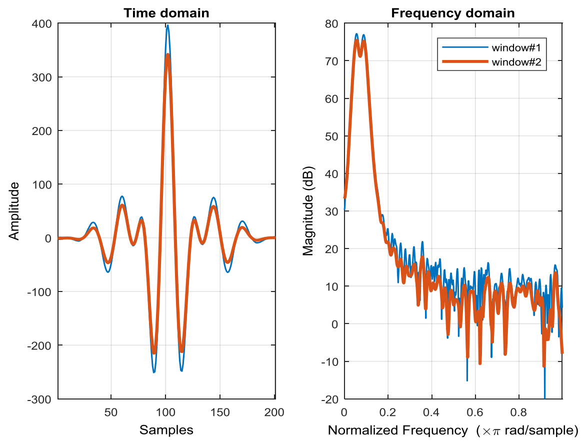
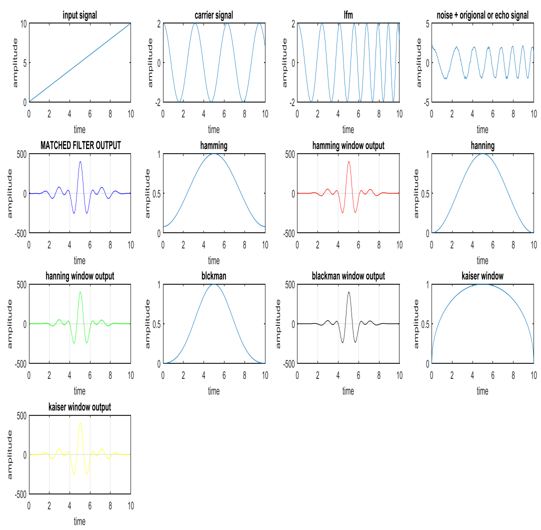


Fig (12): Kaiser window output waveforms

3.1.5. Comparison of all windows for LFM:



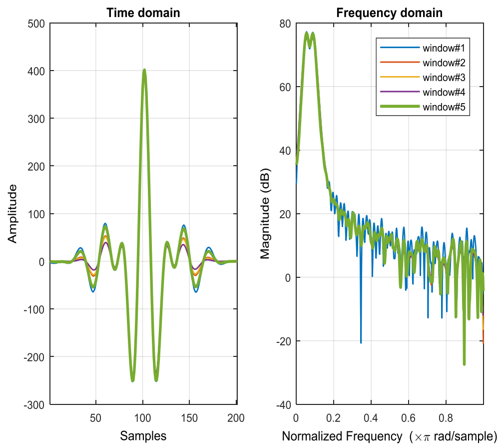


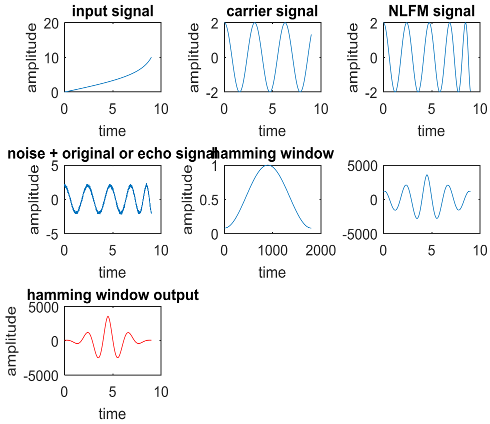
Fig (13): All windows output waveforms comparison

Table (1): Comparison of matched filter and window techniques for LFM signal

NAME	SNR	LEAKAGE FACTOR	RELATIVE SIDE LOBE ATTENUATION	MAIN LOBE WIDTH (-3dB)
Matched filter	11.5278	0%	-0.8dB	0.39844
Hamming window	92.1165	0%	-9.2dB	0.3252
Hanning window	56.6699	0%	-15.8dB	0.30957
Blackman window	91.8552	0%	-23.6dB	0.31055
Kaiser window				
Alpha=22	75.6902	0%	-2.4dB	0.36523
Alpha=23	88.9954	0%	-6.4dB	0.31836
Alpha=24	97.8243	0%	-5.3dB	0.32715

3.2. applying window for nlfm signal matched filter output

3.2.1. HAMMING window:



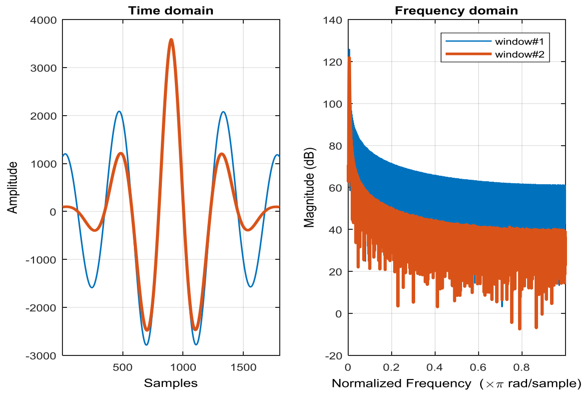
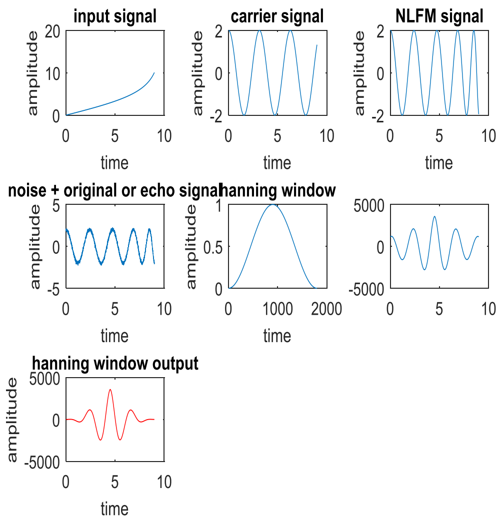


Fig (14): Hamming window output waveforms

3.2.2. HANNING window:



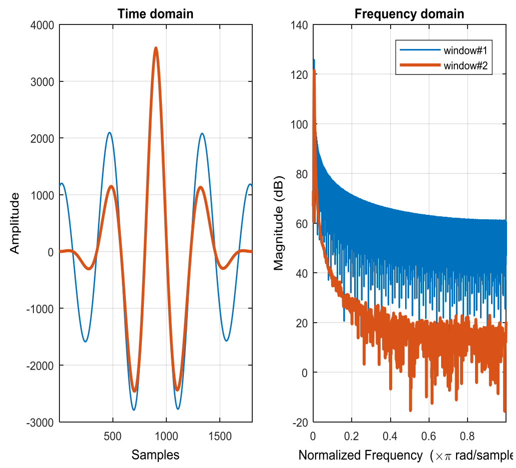
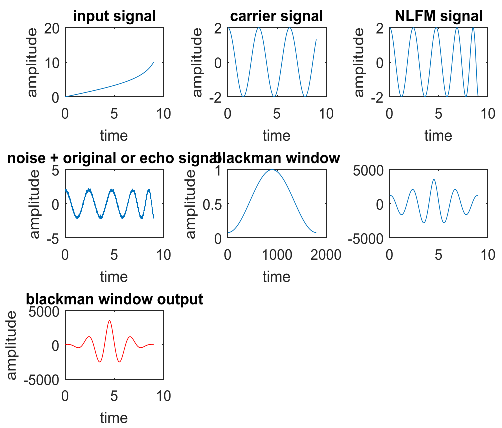


Fig (15): Hanning window output waveforms

3.2.3. BLACKMANN window



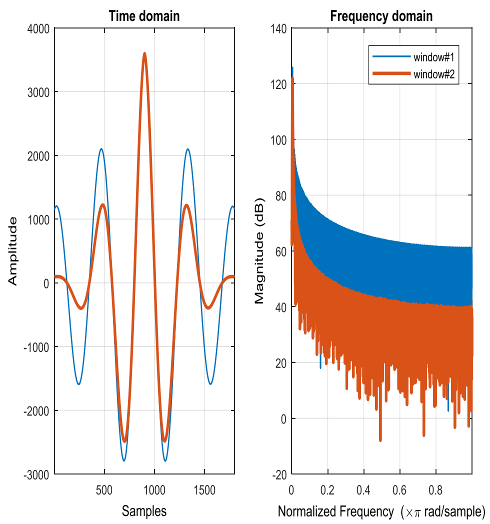
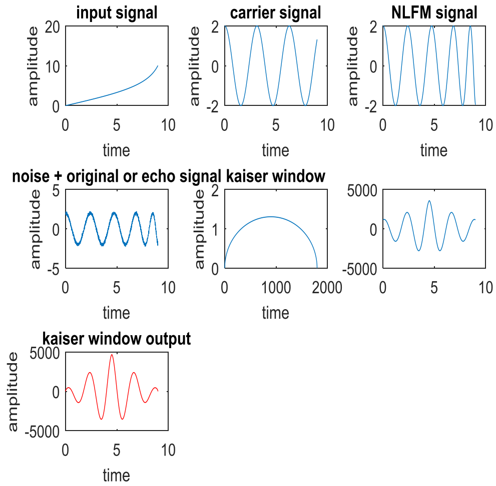


Fig (16): Blackman window output waveforms

3.2.4. KAISER window:



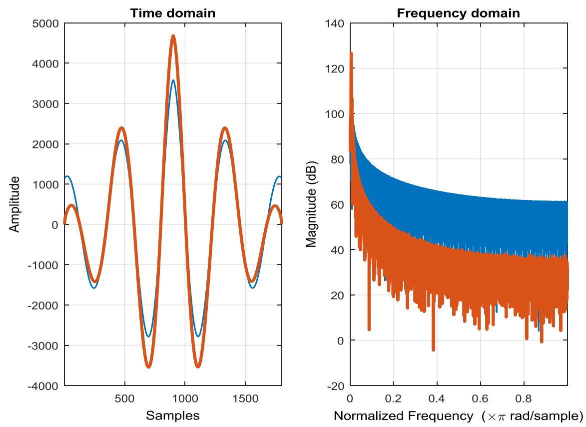
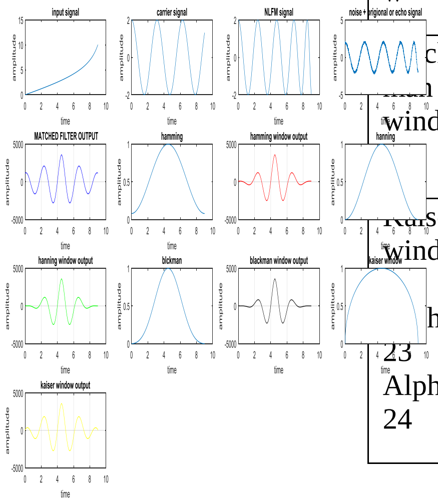


Fig (17): Kaiser window output waveforms

3.2.5. Comparison of all windows of nlfm signal

w				
ck n windo	132.2756	0%	-14.3dB	0.063599
ser windo ha= 23 Alpha= 24	130.7162 137.9464	0.02% 0.02%	-1.2dB -1dB	0.024414 0.024536



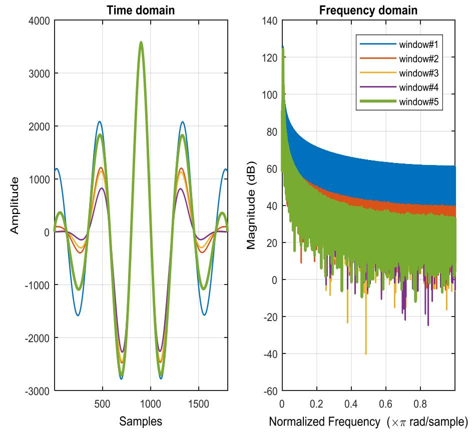


Fig (18): all windows and matched filter output waveforms comparison

Table (2): Comparison of matched filter and window techniques for NLFM signal

NAME	SNR (dB)	Leakage FACTOR	RELATIVE SIDE LOBE ATTENUATION	MAIN LOBE WIDTH (-3dB)
Matched filter	11.5799	0.09%	-0.8dB	0.1621
Hamming window	150.4544	0%	-14.4dB	0.067871
Hanning windo	150.4728	0%	-7.5dB	0.050659

4. CONCLUSION

Pulse compression for LFM radar signal can be implemented and simulated using MATLAB. Digital pulse compression can be performed by matched filter with the help of Matlab software programming. In this paper we generated LFM and NLFM radar signals. The signal to noise ratio can be increased by using matched filter and window techniques. The higher side lobe level is reduced and signal to noise ratio is increased by using different window techniques. The parameters like leakage factor, relative sidelobe reduction, main lobe width and signal to noise of hamming window, Hanning window, Kaiser window and Blackman window are calculated in this paper. The SNR of matched filter is 11.57dB and it is increased up to 150dB. SNR of NLFM signal is high compared to SNR of LFM signal. The relative sidelobe attenuation and SNR of NLFM Hamming window is -14.4dB,150.4544 respectively is high compared to LFM Hamming window relative sidelobe attenuation and SNR i.e.; -9.2dB and 92.1165.

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