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Convolutional Windows for Side Lobe Reduction

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Abstract**: *A lot of applications in radar systems necessitate low range side-lobe performance which is achieved by pulse compression processing. Linear Frequency Modulation (LFM) signal is mainly used chirp signal for this processing. The paramount drawback in LFM is the first side-lobe level of -13dB at the receiver side. In this paper, LFM signal is modified by using simple two-stage piece wise linear frequency modulation (PWLFM) functions. The autocorrelation function of this PWLFM signal exhibited low peak sidelobe level ratio (PSLR) value compared to its counterpart LFM signal. An attempt is made to further reduce the side lobe values by using novel Convolutional windows. The simulation results confirm a significant side lobe reduction by the LFM signal designed using PWLFM functions when a more flexible Power of Cosine window function is applied compared to all other window functions.***

Index Terms**: *Convolution windows, LFM, PSLR, PWLFM***

I. INTRODUCTION

Assessment of target characteristics is still a significant research direction as moving targets and closely spaced targets are tough to perceive. Pulse compression is an approving technique which influences target parameter estimates by using different signal models such as Frequency modulation (FM) and Phase modulation (PM). The usual approach in pulse compression is to correlate the received signal with a delayed copy of transmitted signal in a matched filter (MF) [1]. Major considerable demand in the design of radar signals is to guarantee the lowest sidelobe levels to the response of MF. Linear Frequency Modulated (LFM) signal is the mainly used pulse compression waveform as it can be generated easily and bandwidth can be efficiently used as the frequency is linearly swept to cover up the total signal bandwidth. The compressed waveform at the receiver has a sidelobe at -13dB which can be a hindrance while detecting closely spaced targets [2]. So an important research direction refers to the design of improved methods to synthesize radio pulses with rectangular envelope but with suitable modified FM laws (non linear frequency modulation (NLFM) signals) so that the expected MF response is achieved [3]. NLFM signals have a vast applicability in radar systems with a good range resolution, good interference mitigation, better signal to noise ratio (SNR), low-cost, and has a spectral weighting function inherently in their modulation function which effectively which gives a pure matched filter output with low side-lobe levels [4]. This paper focuses on the design of a modified LFM signal and applying convolutional window functions to this signal to reduce the autocorrelation (ACF) sidelobes. In this paper, a modified LFM signal is generated using simple two-stage PWLFM functions which are described below.

$$f(\tau) = \begin{cases} \alpha_0\tau & 0 \le \tau \le T_1 \\ B_1 + \alpha_1(\tau - T_1) & T_1 \le \tau \le (T_1 + T_2) \end{cases} \qquad (1)$$

Equation (1) shows the instantaneous frequency variation of modified LFM signal formed by concatenating two piece wise LFM functions with a sweep rate of α_o in the first stage and α_1 in the second stage. The total pulse width of the chirp signal τ is divided into two time slots with respective pulse widths T_1 and T_2. If B_1 and B_2 are the corresponding bandwidths of the first and second stage LFM functions, then the corresponding sweep rates can be defined as

$$\alpha_0 = \frac{B_1}{T_1} \qquad \alpha_1 = \frac{B_2}{T_2}$$

The corresponding phase variation of this concatenated NLFM function can be obtained by integrating (1)

$$\varphi(\tau) = \int f(\tau) = \begin{cases} \alpha_0 \frac{\tau^2}{2} & 0 \le \tau \le T_1 \\ B_1\tau + \alpha_1(\frac{\tau^2}{2} - T_1\tau) & T_1 \le \tau \le T_1 + T_2 \end{cases}$$

(2)

Simulations were done for B = 20 MHz and T = 10 µs with different combinations of T_1, B_1, T_2, and B_2. All the possible combinations are examined by choosing different sweep rates. Amongst all the combinations, Fig. 1 shows the frequency variation of two-stage PWLFM function which achieved highest PSLR of -26.26dB at the output of matched filter (MF) as shown in Fig. 2. This is achieved at specific values of B_1=2.24MHz, T_1=2.71µs, B_2=17.76MHz and T_2=7.29µs.

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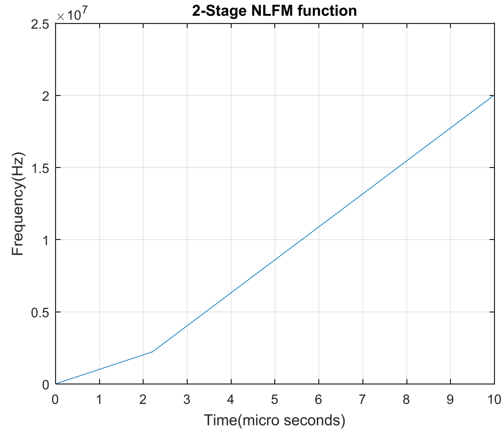

Fig.1 Two-stage PWLFM function

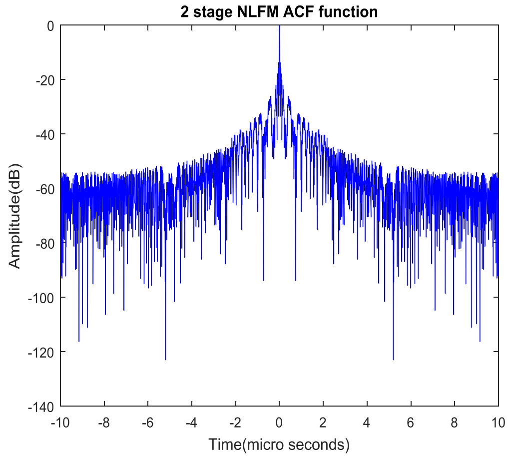

Fig.2 MF output of two-stage PWLFM function

II. CONVOLUTIONAL WINDOWS

Fundamentally window is a mathematically limited function which exist inside given interval and is zero valued everywhere else and is used to decrease the well known Gibbs oscillations formed by the rapid truncation of a Fourier series [5]-[7]. A window function is a basic signal processing tool that is needed in many signal processing fields such as radar/sonar. Convolutional windows are produced by convolving the window with itself. High side lobe attenuation and flat top spectrum is obtained by time convolution of classical windows [8]. These windows are appropriate for harmonic amplitude evaluation in non synchronous sampling case. The convolutional windows from second to eighth order for rectangular window are derived in [9], [10]. In this paper both the fixed and flexible convolutional window functions in time domain are used to reduce the side lobe values of the modified LFM signal designed using PWLFM functions. The windows used are below, Cauchy and Power of cosine are flexible window functions whose matched filter characteristics depends upon the variables α and p. Papoulis (Bohman) and Parzen are the fixed window functions. Table I shows the spectral characteristics of windows namely; leakage factor which determines the ratio of power in the sidelobes to the total window power and it is always desirable to have leakage factor as low as possible, relative side lobe attenuation which is the difference in height from the mainlobe peak to first highest sidelobe peak. Side lobe roll off ratio depends on this value, as better the sidelobe attenuation better the PSLR values but from below table it is observed that there is always a tradeoff between main lobe width and PSLR values.

1) Cauchy

$$w(n) = \frac{1}{1+\left(\alpha\frac{n}{N/2}\right)^2} \qquad 0 \le |n| \le N/2$$

$$\alpha = 2,3,4$$

2) Power of Cosine

$$w = cos^p\left(\frac{\pi n}{N}\right) \qquad n = -\frac{(N-1)}{2} : \frac{(N-1)}{2}$$

$$p = 2,5,7$$

3) Papoulis

$$w(n) = \left(1 - \frac{|n|}{N/2}\right)\cos\left(\frac{\pi n}{N/2}\right) + \frac{1}{\pi}\sin\left(\frac{\pi|n|}{N/2}\right)$$

$$0 \le |n| \le N/2$$

4) Parzen

$$w(n) = \begin{cases} 1 - 6\left(\frac{n}{\frac{N}{2}}\right)^2\left(1 - \frac{|n|}{\frac{N}{2}}\right) & 0 \le |n| \le \frac{N}{4} \\ 2\left(1 - \frac{|n|}{\frac{N}{2}}\right)^3 & \frac{N}{4} \le |n| \le \frac{N}{2} \end{cases}$$

Table I
Spectral characteristics of Convolution window functions

Windows		**Leakage factor (%)**	**Relative Side lobe Attenuation (dB)**	**Main lobe width(-3dB)**
Cauchy	α=3	0	-62	0.003
	α=4	0	-52	0.004
	α=5	0	-62.7	0.004
Power of Cosine	p=2	0	-62.9	0.003
	p=5	0	-107.9	0.005
	p=7	0	-135.7	0.006
Papoulis		0	-92	0.004
Parzen		0	-106.1	0.005

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III. SIMULATION AND RESULTS

Simulations were done for two-stage PWLFM functions using aforesaid window functions. The subsequent figures represent the matched filter output with and without window functions. It's obvious from the figures that the windowed signal output yields lesser PSLR values. Fig.3 shows the MF output of two-stage PWLFM without window function which yielded a PSLR value of -26.26dB and MF output when convolution Cauchy window is applied which yielded a PSLR value of -46.58dB for α=3, -52.18dB for α=4 and -57.05dB for α=5. Fig. 4 shows the MF output with convolution Power of cosine window with PSLR values of -49.12dB when p=2, -73.56dB when p=5 and -91.12dB when p=7. Fig. 5 and Fig. 6 shows the MF output when Papoulis and Parzen window function is applied which yielded PSLR values of -58.72dB and -62.89dB.

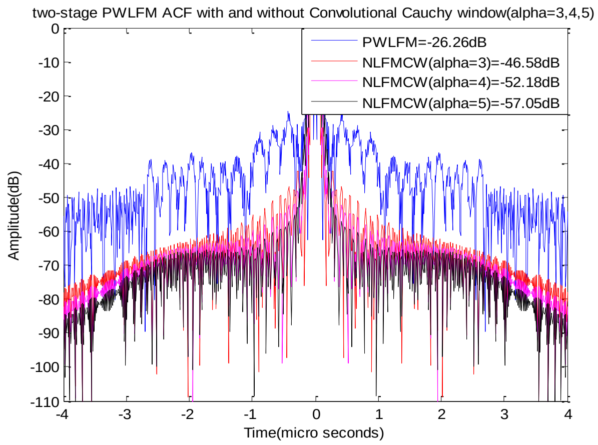

Fig. 3 Matched Filter Output With Convolution Cauchy Window

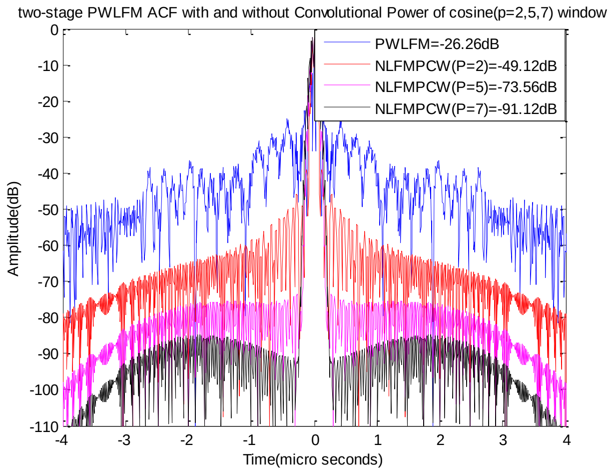

Fig. 4 Matched Filter Output With Convolution Power Of Cosine Window

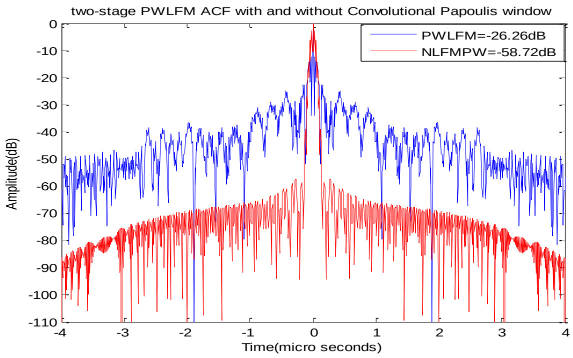

Fig. 5 Matched filter output with Convolution Papoulis window

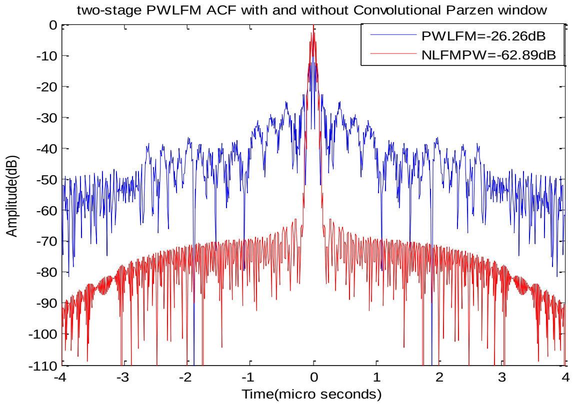

Fig. 6 Matched filter output with Convolution Parzen window

Table II shows the list of PSLR values of two-stage PWLFM signal with all the fixed and flexible Convolution window functions discussed. Among all the fixed and variable window functions used in this paper, a drastic reduction in PSLR values can be seen with a variable window (power of cosine, P=7) having spectral characteristics of zero leakage factor and a high relative sidelobe attenuation of -135.7dB, which yielded lowest PSLR value of -91.12dB.

Table II
PSLR values of two-stage PWLFM signal with different Convolution windows

Windows		Two-StagePWLFM PSLR(dB)
Cauchy	α=3	-46.58
	α=4	-52.18
	α=5	-57.05
Powerof Cosine	p=2	-49.12
	p=5	-73.56
	p=7	-91.12
Papoulis		-58.72
Parzen		-62.89

IV. CONCLUSION

The two-stage PWLFM function intended is attractive as it is able to reduce the sidelobe levels better than their counterparts. A maximum sidelobe suppression around -26.26 dB is achieved.

The higher sidelobe level introduced by two-stage PWLFM function is suppressed using different convolutional window functions. A radical suppression from -26.26dB to -91.12dB is achieved by using a variable window function Power of cosine (P=7). Based on the inference drawn from Table II, this signal can be used in the range of applications where low sidelobe levels are preferred.

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N. Adithya valli was born in 1988, she completed her under-graduate studies in electronics and communications engineering (ECE) at Gudlavaleru engineering college (affiliated to jntu Kakinada), Vijayawada (India) in 2010 and she received her dual degree (M.Tech/m.sc) in electrical engineering with emphasis on signal processing at jntu Kakinada and Blekinge institute of technology (BTH) Sweden in 2013. She worked as assistant professor in Lingaya's engineering college Vijayawada (India) from 2014 to 2015. Now she is pursuing her full time PhD in Gitam University Visakhapatnam.

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