Modified Radar Signal Model using NLFM

N. Adithya Valli, D. Elizabath Rani, C. Kavitha

Abstract— Intended to the setback of high side lobes of the linear frequency modulation (LFM) signal, we put forward a new signal model using nonlinear frequency (NLFM) signal to overcome the issue. NLFM is a promising way for achieving lower signal to noise ratio, good resolution and better interference mitigation. The novel signal model is designed to enhance the target range estimation and to reduce the side lobe levels. In this paper, a new signal model is designed based on the principle of fusion of two stages. First stage is exponential based nonlinear function and the second stage is a linear function. The simulations were performed for the designed signal model and are compared with the NLFM signal designed using two stage LFM functions. Simulation results show that the designed signal has significant reduction in side lobe levels of the matched filter response.

Keywords: LFM, NLFM, PSLR, side lobes.

I. INTRODUCTION

Estimation of target parameters using radar is still an active research area. As targets hidden and harder to detect accuracy of target parameters is difficult to achieve, options to improve the accuracy of parameter estimates are important. Signal model is the crucial radar system component that directly influences the parameter estimates [1]. Till date the available signal models are Phase modulation (PM) and Frequency modulation (FM). Linear Frequency Modulated (LFM) signal is extensively utilized from 1940 and is still the most used signal model for radar pulse compression because of its simple generation and effective bandwidth usage. The basic idea of LFM signal is to sweep the frequency linearly over entire range of signal bandwidth. However, the major drawback of LFM signal is its first side lobe at -13dB which can mask the echoes from nearby targets. Further optimization techniques and windowing functions are needed to reduce the side lobe level, at the cost of main lobe width and reduced signal to noise ratio [2]. Non-linear Frequency Modulation (NLFM) signal models were proposed to diminish the side lobe levels without utilizing extra filtering by avoiding the mismatch losses [3]. NLFM signals have a huge relevance in radar systems by a superior range resolution, improved signal to noise ratio (SNR) and good interference mitigation. They have a spectral weighting function essentially in their modulation function which in point of fact gives a pure matched filter output with fewer peaks to side lobe levels (PSLR) [4]. NLFM signals belong to the family of continuous modulation functions which holds major role in pulse compression radar systems [5]. An NLFM signal beneficially outlines the power spectral density (PSD) in a means that the autocorrelation function has reduced side lobes than its corresponding part LFM to a large extent. NLFM signal in addition provides an improved detection attribute and is more specific in determining the range compared to further methods existing in literature [6] such as dual apodization (DA), spatially variant apodization (SVA) and leakage energy minimization (LEM). On the contrary precise NLFM signal design and processing is still a tricky job as usually radar designer aim to have an effortlessly created and processed signal to get along the target performance characteristics, sidelobe reduction goals and the bandwidth constraints [7]. Research focus has been to improve methods to propose radar pulses with rectangular envelope with fitting FM laws in such a manner the matched filter output depicts constructive results. In radar systems theory many studies attempted to design most favorable (low side lobe levels) NLFM signals. So far available design of NLFM signals can be broadly classified into two directions. One is based on design by means of desired power spectral density function using different methods such as iterative methods, explicit functions cluster method and stationary phase principle method. Other is to design a NLFM signal using LFM signals introducing predistortion on small intervals into temporal domain or spectral domain and the other is the design [8]. In this paper, we have proposed side lobe reduction technique using novel single model using NLFM function. It mainly focuses on NLFM signal design by fusing piecewise NLFM and LFM functions and the resulting function is capable of generating an overall NLFM waveform. Two-stage LFM signal design is described in the first part of the paper and later the new NLFM signal design methodology is discussed followed by simulation results.

II. TWO-STAGE NLFM SIGNAL

A Non linear signal is designed using simple two-stage piece wise LFM functions which are described below.

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

Equation (1) represents the variation of instantaneous frequency of NLFM signal formed by concatenating two piece wise LFM functions with a sweep rate of αo and α1 in

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the first stage and second stage. The entire pulse width of the chirp signal τ is separated into two time slots with individual pulse widths T_1 and T_2.

If B1 and B2 are the equivalent bandwidths of the first and second stage LFM functions, then the resultant sweep rates can be defined as

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

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

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

III. MODIFIED NLFM SIGNAL

As an alternative to an NLFM signal designed using two LFM functions in both the stages, one stage can be altered by means of different modulation function. In the present paper, an exponential factor has been used to change the instantaneous frequency of the first stage of the signal. This new signal model comprises of one stage through NLFM sweep by using exponential function followed by the LFM sweep.

$$f(\tau) = \begin{cases} \alpha_0 \exp(\tau)\, \tau^2 & 0 \le \tau \le T_1 \\ B_1 + \alpha_1(\tau - T_1) & T_1 \le \tau \le (T_1 + T_2) \end{cases} \quad (3)$$

Equation (3) represents the variation of instantaneous frequency of the NLFM signal formed by concatenating one exponential NLFM slope with a sweep rate of α_o in the first stage and LFM slope with a sweep rate of α_1 in the second stage. The corresponding variation of phase of this concatenated NLFM function can be obtained by integrating (3)

$$\varphi(\tau) = \int f(\tau) = \begin{cases} \alpha_0 \exp(\tau) \frac{\tau^3}{3} & 0 \le \tau \le T_1 \\ B_1\tau + \alpha_1\left(\frac{\tau^2}{2} - T_1\tau\right) & T_1 \le \tau \le T_1 + T_2 \end{cases} \quad (4)$$

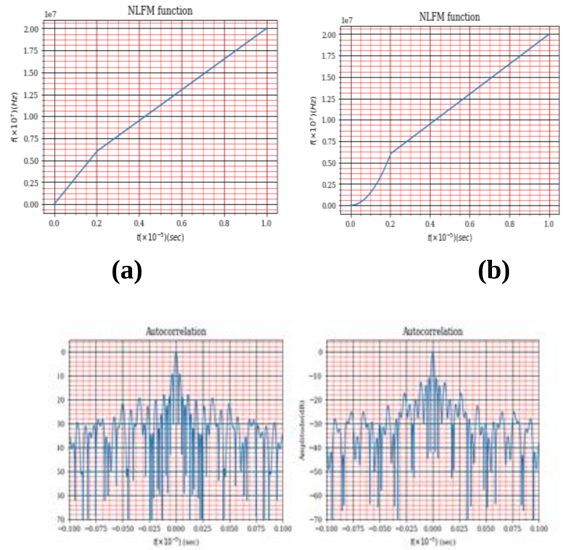
IV. SIMULATIONS AND RESULTS

Simulations were done for B = 20 MHz, T = 10 µs with various combinations of B_1, B_2 T_1, T_2. The possible combinations are examined by choosing different sweep rates α0, α1 for both two-stage NLFM function and proposed function. Break point B1 is kept constant at 6MHz and simulations were done for different T_1 values, the corresponding PSLR values are tabulated in the following Table 1.

Table 1. PSLR values when B1=6MHz and different T_1 values.

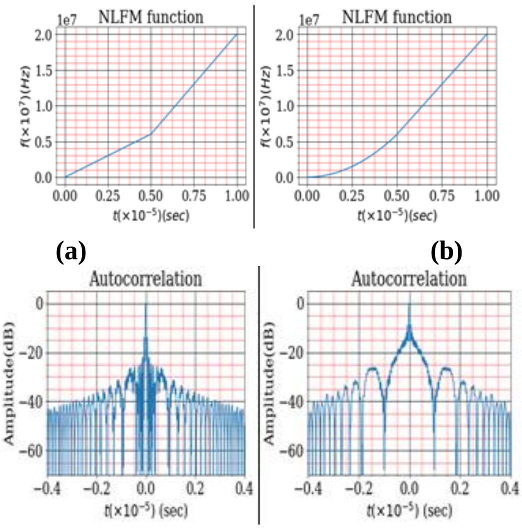
B_1(MHz)	T_1(µs)	Two stage NLFM signal PSLR(dB) values	Proposed signal PSLR(dB) values
6	2	-9.31	-10.98
	4	-15.57	-25.06
	5	-21.99	-25.96
	6	-20.55	-24.03
	8	-17.86	-23.11
	9	-16.24	-22.84

Fig 1(a) to 4(a) show the frequency variation of two-stage NLFM function and Fig 1(b) to 4(b) show the frequency variation of proposed NLFM function when B1 is kept constant and T1 is varied as 2µs, 5µs ,6µs and 9µs, and the corresponding matched filter output for two-stage NLFM function is shown in Fig 1(c) to 4(c) and for proposed NLFM function is shown in Fig 1(d) to 4(d).



(a) (b) (c) (d)

Fig 1. (a) two-stage NLFM function (b) Proposed NLFM function with B_1=6MHz, T_1=2µs (c) and (d) Corresponding Matched filter outputs.



(a) (b) (c) (d)

Fig 2. (a) two-stage NLFM function (b) Proposed NLFM function with B_1=6MHz, T_1=5µs (c)

and (d) Corresponding Matched filter outputs.

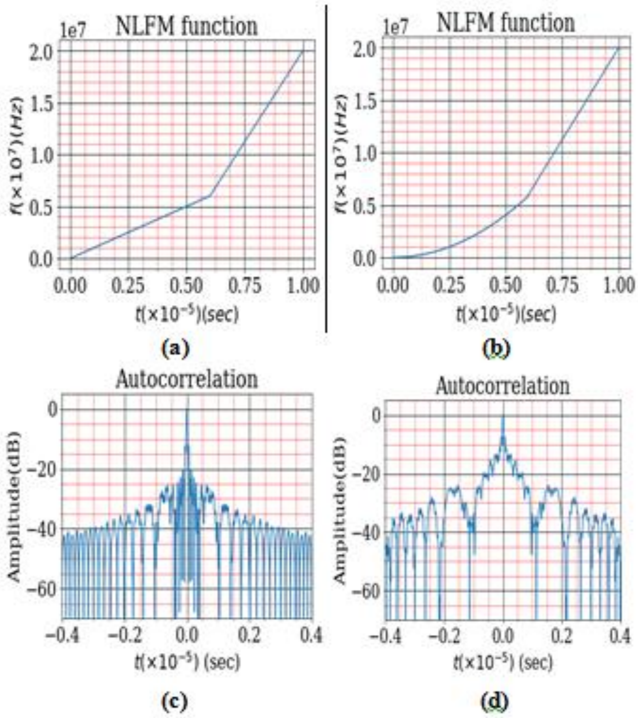


Fig 3. (a) two-stage NLFM function (b) Proposed NLFM function with B_1=6MHz, T_1=6µs (c) and (d) Corresponding Matched filter outputs.

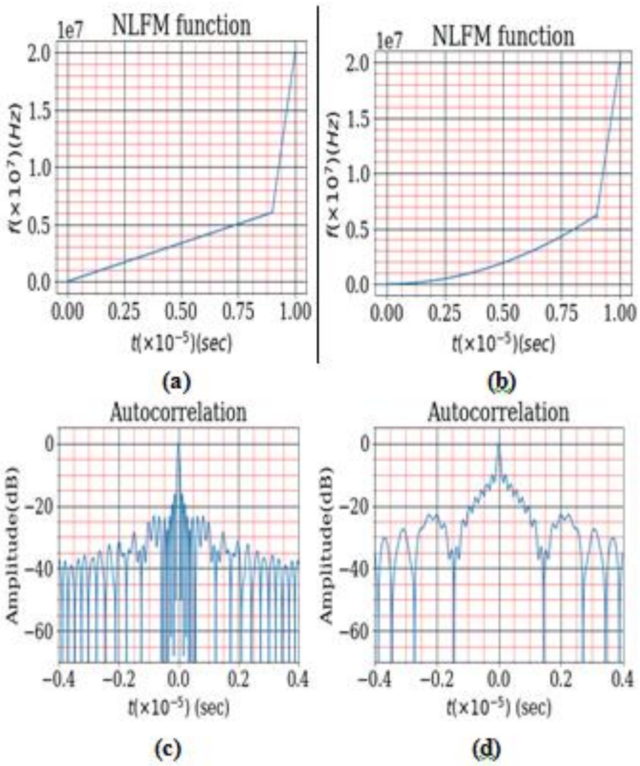


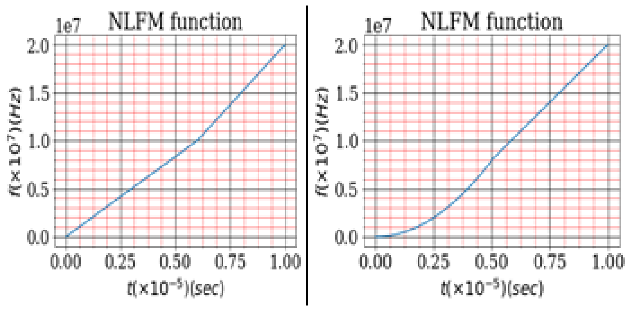
Fig 4. (a) two-stage NLFM function (b) Proposed NLFM function with B_1=6MHz, T_1=9µs (c) and (d) Corresponding Matched filter outputs.

From the above Table 1 and Figs it is observed that the PSLR values are increasing when the break point (T_1) value is increasing in the leading edge region and reached maximum value of -21.99dB for two-stage NLFM function and -25.96dB for proposed NLFM function exactly at T_1=5µs, then from there again PSLR value is decreasing when the break point (T_1) value is approaching the trailing edge region.

Similarly simulations were performed by changing the values of B_1 and T_1 simultaneously and an attempt is made to observe the PSLR variations based on various sweep rate ratios. Table 2 shows the variation of PSLR values depending upon the sweep rate ratio. It is observed that there is a significant increase in PSLR value when the sweep rate ratio α_0 has a lower value and sweep rate ratio α_1 has a higher value. Fig 5(a) and 5(b) show the frequency variation of two stage NLFM function and proposed NLFM function with B_1=10MHz and T_1=6µs and corresponding PSLR values achieved are -20.70dB and -25.58dB as shown in Fig 5(c) and 5(d). Fig 6(a) and 6(b) show the frequency variation of two stage NLFM function and proposed NLFM function with B_1=14MHz and T_1=7µs and corresponding PSLR values achieved are -14.04dB and -23.82dB as shown in Fig 6(c) and 6(d). Fig 7(a) and 7(b) show the frequency variation of two stage NLFM function and proposed NLFM function with B_1=18MHz and T_1=7µs and corresponding PSLR values achieved are -10.42dB and -7.71dB as shown in Fig 7(c) and 7(d).

Table 2. PSLR values of proposed signal and the two stage NLFM signal based on the Sweep Rate Ratios.

$\alpha_0=B_1/T_1$	$\alpha_1=B_2/T_2$	Two stage NLFM signal PSLR(dB) values	Proposed signal PSLR(dB) values
1.2	2.8	-21.99	-25.96
1.6	2.5	-20.70	-25.58
1.7	2.4	-18.27	-24.85
2	2	-14.04	-23.82
2.25	1	-12.42	-23.78
2.57	0.66	-10.42	-7.71
3	0.5	-8.28	-5.26



(a) (b)

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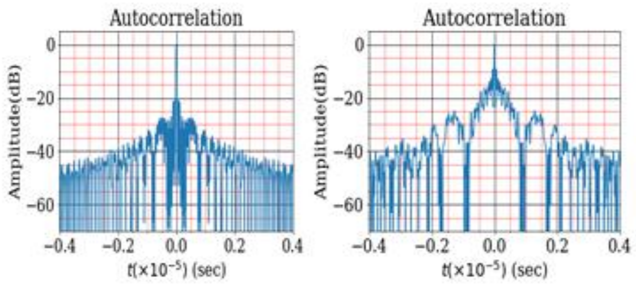
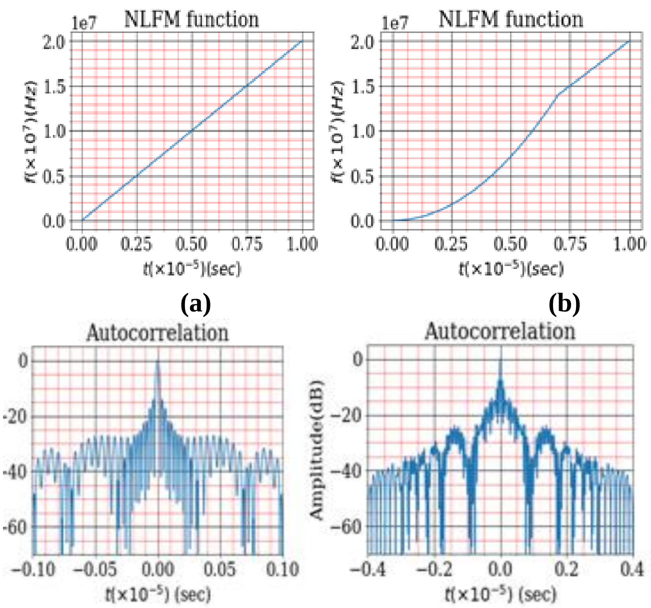


(c) (d)

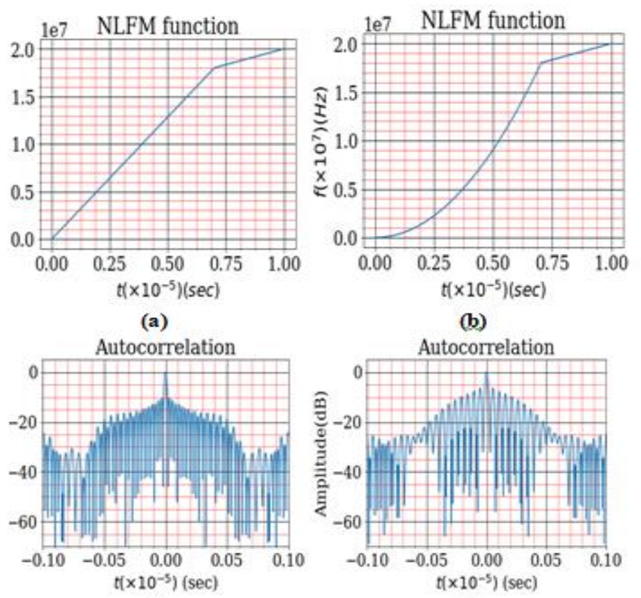
Fig 5. (a) two-stage NLFM function (b) Proposed NLFM function with α_0=1.6, α_1=2.5 (c) and (d) Corresponding Matched filter outputs.



(a) (b)

(c) (d)

Fig 6. (a) two-stage NLFM function (b) Proposed NLFM function with α_0=2, α_1=2 (c) and (d) Corresponding Matched filter outputs.



(a) (b)

(c) (d)

Fig 7. (a) two-stage NLFM function (b) Proposed NLFM function with α_0=2.57, α_1=0.66 (c) and (d) Corresponding Matched filter outputs.

V. CONCLUSION

Even though NLFM signals have better characteristics, they have not been given adequate consideration and hence not applied to the radar systems widely. The constraint is the difficulty to progressively produce a desired NLFM signal. The proposed NLFM signal in this paper is generated by concatenating one NLFM function and one LFM function. The NLFM signal designed using this method exhibited enhanced PSLR values than the NLFM signal designed using two LFM functions.

Practical range side lobes can be accomplished using proposed NLFM signal without the use of additional filtering to reduce the side lobes as generally used in LFM signal. However the drawback appears to be a marginal increase in main lobe width.

This may be overcome by using optimization of piecewise NLFM signal.

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