Performance Evaluation of Sonar Signals using Fusion Technique

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Abstract

In active sonar systems, proper selection of the transmitted waveform is critical for target detection and parameter estimation. Each signal has its own diverse characteristics. Linear FM suffers from relatively high autocorrelation (ACF) side-lobes. The ACF sidelobes could be reduced by shaping the signal; other methods include Gaussian NLFM, Rayleigh NLFM and the combination of both these pulses. No single signal gives better result. To improve system performance there is a need to consider multiple signals and combine them to obtain better detection, especially with the existence of clutter (reverberation). In this paper we are going to combine multiple signals. Three commonly used signals in this are (i) Gaussian NLFM signal (ii) Rayleigh NLFM signal (iii) LFM. Comparison will be made with respect to their ambiguity plots, range resolution plots and parameters like PSLR, ISLR, Merit Factor and Discrimination for single signal and combined signals.

Key Words: Ambiguity plot, Range Resolution plot, Gaussian NLFM and Rayleigh NLFM.

1. Introduction

In LFM instantaneous frequency is linearly related to time, which is equivalent to changing the amplitude along the frequency axis. Indeed, the resultant shape is very close to the desired signal shape, yielding the expected ACF sidelobe pattern. Shaping the signal by amplitude weighting (LFM) pulse has a serious drawback. In a matched transmitter–receiver pair, it results in variable amplitude of the pulse transmitted. Variable amplitude requires linear power amplifiers, which are less efficient than saturated power amplifiers. This problem can be removed by performing amplitude weighting only at the receiver. The resulting mismatch causes SNR loss. In LFM the transmitter spends equal time at each frequency, hence the nearly uniform spectrum would be obtained. Another method of shaping the signal is to deviate from the constant rate of frequency change and to spend more time at frequencies that need to be enhanced. This approach was termed nonlinear FM (NLFM) [9]. Early works on NLFM suggest that the nonlinear frequency property may be used with the stationary-phase concept. i.e., the instantaneous frequency is related to time in a non linear fashion. The non linearity here in Gaussian NLFM is similar to the Gaussian distribution whereas in Rayleigh NLFM it is similar to the envelope of Rayleigh pulse, i.e., the frequency variations are similar to amplitude variations of these pulses. A comparative study between these signals with respect to their ambiguity functions and range resolution is done and is reported [6]. A new signal i.e., fusion of LFM, Gaussian NLFM and Rayleigh NLFM is generated. The performance in terms of range resolution and parameters like PSLR, ISLR, Merit Factor and Discrimination for fusion signal & individual signals are compared.

2. Ambiguity Function

The ambiguity function[5] (AF) represents the time response of a matched filter to a given finite energy signal when the signal is received with a delay 'τ' and a Doppler shift υ relative to the nominal values (zeros) expected by the filter.

$$\chi(\tau,\upsilon)=\left|\int_{-\infty}^{\infty}u(t)u^{*}(t+\tau)e^{j2\pi\upsilon t}dt\right| \quad (1)$$

Where 'u' is the complex envelope of the signal. A positive 'υ' implies a target moving toward the sonar. Positive 'τ' implies a target farther from the sonar than the reference (τ = 0) position. The ambiguity function is a major tool for studying and analyzing sonar signals.

3. Performance criteria for Signals

The following criteria have been used to compare signals and codes for range resolution.

3.1. Discrimination (D)

Discrimination (D) is defined as the ratio of main Peak in the Auto correlation function to the absolute maximum amplitude among the side lobes [10],

$$D=\frac{r(0)}{\underset{k\neq 0}{Max}|r(k)|} \quad (2)$$

3.2. Merit Factor (F)

Merit Factor 'F', is defined as the ratio of energy in the main lobe of Auto correlation function to the total signal energy in side lobes [1]

$$F = \frac{r^2(0)}{2\sum_{k=1}^{N-1} r^2(k)} \quad (3)$$

The factor 2 is used in the denominator, as ACF is an even function.

3.3. Peak to Sidelobe Level Ratio (PSLR)

This is similar to, D and is defined as follows [10]

$$PSLR(dB) = 20\log\left\{\frac{\text{Max(Sidelobe peak)}}{\text{Mainlobe peak}}\right\} \quad (4)$$

Smaller the PSLR value the better is the signal.

3.4. Integrated Sidelobe Level Ratio (ISLR)

This is similar to F and is defined as follows:

$$ISLR = 10\log\left\{\frac{\text{Energy in sidelobe}}{\text{Energy in mainlobe}}\right\} \quad (5)$$

Smaller the value the better is the signal.

4. Linear Frequency-Modulated Pulse

The complex envelope of a linear-FM pulse is given by

$$u(t) = \frac{1}{\sqrt{T}} rect\left(\frac{t}{T}\right) e^{j\pi k t^2} \quad (6)$$

where $k = \pm\frac{B}{T}$ (7)

B is the bandwidth and T is the time period.

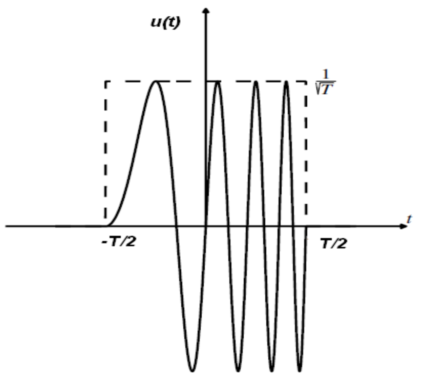

Figure 1. LFM signal u(t)

Fig.1 represents the LFM [1] signal u(t). The instantaneous frequency f(t) is obtained by differentiating the argument of the exponential.

$$f(t) = \frac{1}{2\pi}\frac{d\left(\pi k t^2\right)}{dt} = kt \quad (8)$$

The instantaneous frequency is indeed a linear function of time. The frequency slope k has the dimensions s^{-2}.

The ambiguity function (AF) of a linear-FM (LFM) pulse is given by

$$|\chi(\tau,\upsilon)| = \left(1-\frac{|\tau|}{T}\right)\frac{\sin\left[\pi T\left(\upsilon \mp B\left(\frac{\tau}{T}\right)\right)\left(1-\frac{|\tau|}{T}\right)\right]}{\left[\pi T\left(\upsilon \mp B\left(\frac{\tau}{T}\right)\right)\left(1-\frac{|\tau|}{T}\right)\right]} \quad (9)$$

for $|\tau \le T|$

= 0 elsewhere

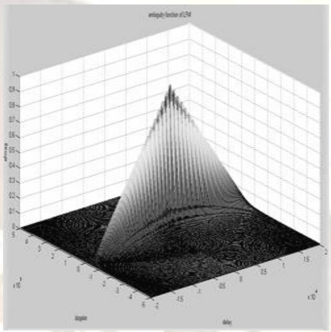

Figure 2. Ambiguity plot of LFM signal

5. Waveform Generation

5.1. Gaussian NLFM

The expression for a Gaussian pulse is given by

$$x(t) = \frac{1}{\sqrt{2\Pi\sigma}} e^{-\left(\frac{t^2}{2\sigma^2}\right)} \quad (10)$$

where 'σ' is known as the standard deviation. The Gaussian distribution is as shown in Fig.3. The corresponding NLFM signal is obtained as shown in Fig.4. It can be observed that in the Gaussian pulse the amplitude is increasing during the negative time axis and is decreasing during positive part of the time axis. Accordingly the NLFM signal that is

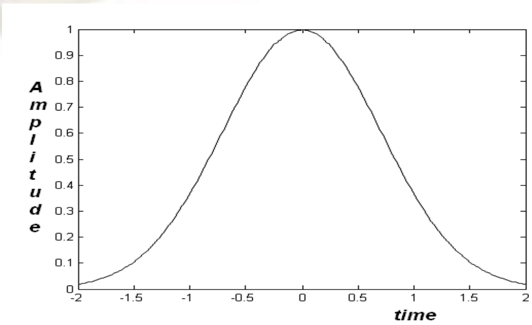

Figure 3. The Gaussian Pulse

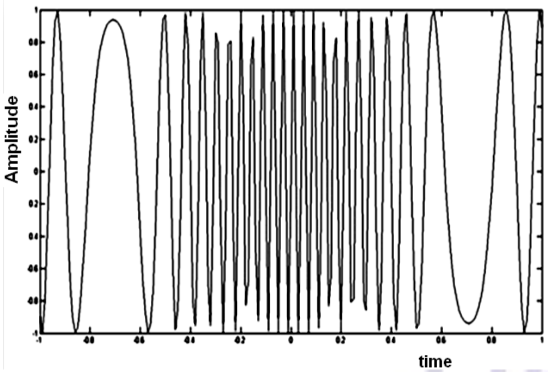

Figure 4. The Gaussian NLFM

obtained using the above Gaussian pulse will also vary its frequency in the similar manner. Fig.4 illustrates the increase and decrease of frequency.

5.2 Rayleigh NLFM

The expression for a Rayleigh pulse is given by

$$x(t)=\frac{t}{\sigma^2}e^{-\left(\frac{t^2}{2\sigma^2}\right)} \quad (11)$$

Where 'σ' is known as the standard deviation.
The Rayleigh distribution is as shown in fig.5.

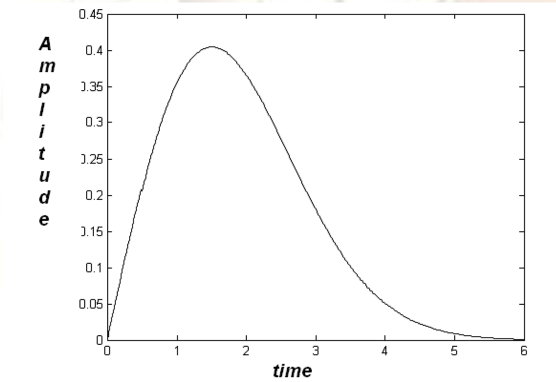

Figure.5 The Rayleigh Pulse for σ = 1.5

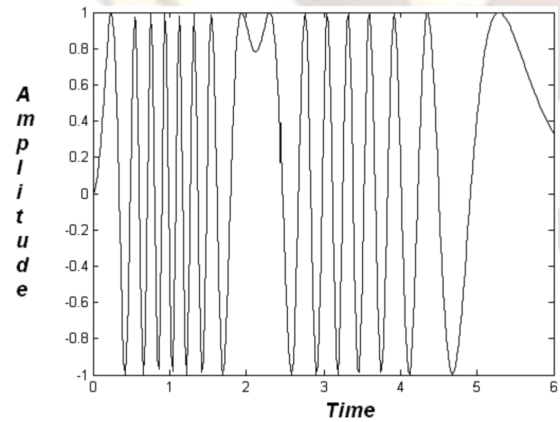

Figure 6. Rayleigh NLFM

The corresponding NLFM is as shown in Fig.6. It can be observed that in the Rayleigh pulse the amplitude is increasing first and then decreases. Accordingly the NLFM signal that is obtained using the above Rayleigh pulse will also vary its frequency in the similar manner. Fig.6 illustrates the increase and decrease of frequency.

6. Ambiguity Functions of Gaussian NLFM, Rayleigh NLFM & fusion signal

The ambiguity functions of Gaussian Nonlinear Linear modulated frequency pulse, Rayleigh Nonlinear Linear modulated frequency pulse and fusion of these signals (LFM, Gaussian NLFM and Rayleigh NLFM) is given in Fig.7.

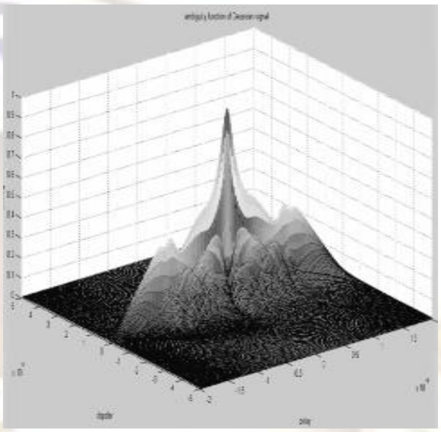

Figure 7(a). Ambiguity plot of Gaussian NLFM

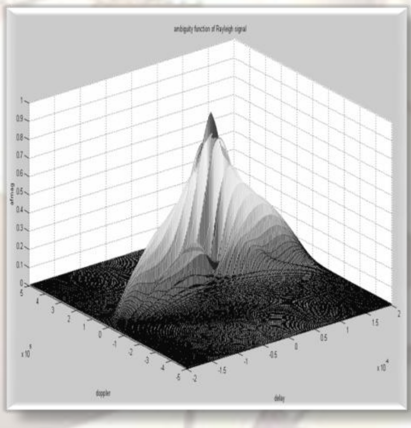

Figure 7(b). Ambiguity plot of Rayleigh NLFM

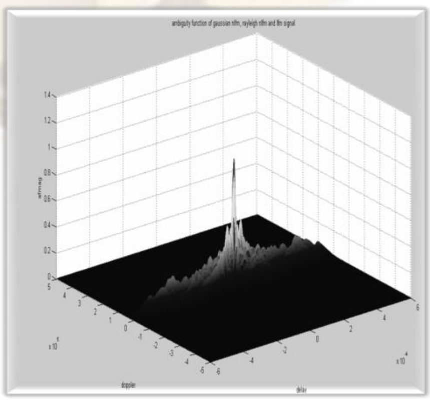

Figure 7(c). Ambiguity plot of fusion signal

7. Range Resolution Plot of Gaussian NLFM, Rayleigh NLFM & fusion signal

The range resolution plot of LFM, Gaussian NLFM, Rayleigh NLFM and fusion signal are obtained by considering zero Doppler of ambiguity function.

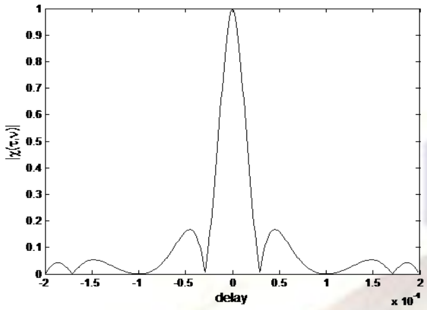

Figure 8(a). Range Resolution plot of LFM

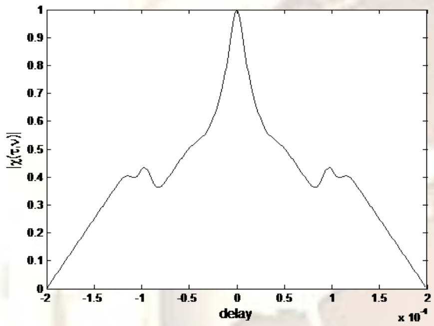

Figure 8(b). Range Resolution plot of Gaussian NLFM

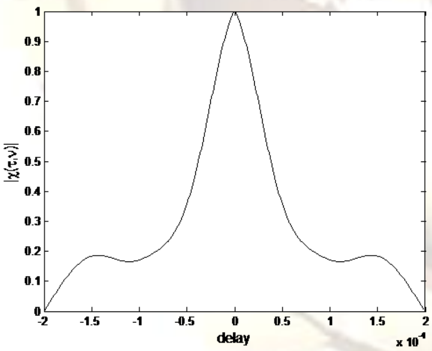

Figure 8(c). Range Resolution plot of Rayleigh NLFM

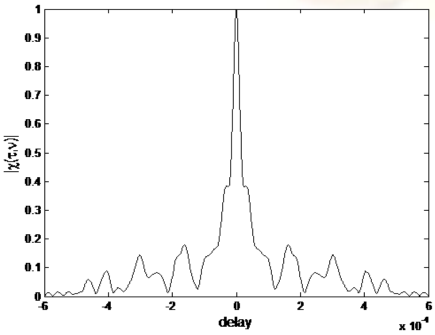

Figure 8(d). Range Resolution plot of fusion signal

9. Parameters of Signals

We have calculated the parameters Discrimination, Merit Factor, PSLR, ISLR for both individual signals and for fused signals.

Table 1.Parameters of Individual signals

Parameter	LFM	Gaussian NLFM	Rayleigh NLFM
Discrimination	5.5825	2.3070	5.3672
Merit Factor	0.0277	0.0128	0.0163
ISLR(dB)	15.577	18.943	17.879
PSLR(dB)	-14.93	-7.2609	-14.587

Table 2.Parameters of fused signals

Parameter	Gaussian NLFM & Rayleigh NLFM	Rayleigh NLFM & LFM	Gaussian NLFM, Rayleigh NLFM & LFM
Discrimination	4.2231	3.9427	**18.7132**
Merit Factor	0.0142	0.0263	**0.0431**
ISLR(dB)	18.4765	15.8057	**13.6505**
PSLR(dB)	-12.5126	-11.9159	**-25.4429**

From Figs.8 (a), (b), (c) and (d) it is observed that fused signal has better range resolution as it has narrow main lobe and low sidelobe level compared to range resolution plot of LFM, Gaussian NLFM & Rayleigh NLFM. From the table The parameters of fusion signal compared to the parameters of individual signal are better.

9. Conclusion

In this paper we have generated LFM, Gaussian, Rayleigh NLFM and fusion of Gaussian NLFM, Rayleigh NLFM & LFM. The ambiguity plots & Range resolution plots are compared for the individual signals and fusion signal. The characteristics of these signals are verified using the parameters Discrimination, Merit Factor, PSLR & ISLR. It is also concluded that the fusion signal provides good range resolution. Hence signal fusion plays a vital role in sonar scenario in improving system performance and providing better detection.

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