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Scheme for nonlinear frequency modulated signal cancelling system

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ABSTRACT

A cancelling system for the four nonlinear frequency modulated (NLFM) signal (i.e. Taylor window, Tangent-based, Combination linear frequency modulation (LFM) and tan-FM, Stepped NLFM) is presented. It is mainly composed of a digital radio frequency memory (DRFM) and a field programmable gate array (FPGA) chip etc. The received signals are stored and reproduced by DRFM, and the system delay time is controlled by the FPGA chip. According to the target's radar cross section (RCS), the radar echo cancelling wave will be generated by the FPGA and DRFM on signal processing. The effect of error on the cancelling wave is analysed and the method for reducing nonlinear phase errors is presented. Theoretical analysis and simulation show that the system effectively reduces the signal power received by the radar receiver. Numerical simulation results show that about 11.3 dB target gain reduction can be achieved under the condition of large deviation.

1. Introduction

Nonlinear frequency modulation (NLFM) is a general class of continuous phase coding in which the sweep rate is not restricted to a constant as compare with linear frequency modulation (LFM). As a common pulse compression signal which can achieve fine range resolution, good signal to noise ratio (SNR) and good interference mitigation [1–3]. Also, NLFM has better detection rate characteristics and is more accurate in range determination than linear frequency modulation (LFM), dual apodization (DA), spatially variant apodization (SVA), or leakage energy minimization (LEM) [4]. With the development of electronic technology, NLFM signals are already used in many kinds of radar systems, such as laser detection and ranging (LADAR) system [5]. Therefore, the interference on NLFM radar has become an important content of modern electronic countermeasure.

The design of the NLFM signal waveform is a complex process. Several potentially suitable NLFM function families have been investigated with varying degrees of success. Four of the more popular candidates are Taylor window shape [6], Tangent-based waveform [7], Combination of LFM and tan-FM [8], Stepped NLFM waveform [9].

In this paper, we propose a cancelling system for the four NLFM waveforms. The cancelling system was designed based on the digital radio frequency memory (DRFM) and field programmable gate array (FPGA) chip.

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The paper is organized as follows: in Section 2, the scheme of the NLFM signal cancelling system is described, and the mathematical model of the cancelling signal is presented; and in Section 3, the effect of amplitude, frequency and phase errors on the cancellation result are discussed; in Section 4, numerical simulation of the cancelling system and finally make some useful conclusions through simulation analysis.

2. Scheme for NLFM signal cancelling system

2.1. NLFM function expression

A complex time domain chirp signal, $s(t)$, can be expressed as:

$$s(t) = a(t)\exp[j\varphi(t)] = a(t)\exp\left[j2\pi\int_0^t f(x)dx\right] \tag{1}$$

where $a(t)$ is the amplitude modulation function, $\varphi(t)$ is the phase modulation function, $f(t)$ is the instantaneous frequency function of the chirp signal. In this paper, we suppose envelope is rectangular, that is $a(t) = 1 (0 \le t \le T)$.

To generate such spectrum shape, it is necessary to determine the frequency function $f(t)$ that produces this type of spectrum. Four different NLFM waveforms are studied as follows:

(1) Taylor window shape

Here the Taylor weighting function $f(t)$ can be expressed in Fourier series as:

$$f(t) = \frac{Bt}{T} - \frac{B}{2} + \sum_{n=1}^{\infty} A(n)B\sin\frac{2\pi nt}{T} \tag{2}$$

Table 1
Optimal setting of α and γ.

Name	α	γ
$B \geq \frac{35}{T}$	$0.88 \leq \alpha \leq 0.94$	$1.42 \leq \gamma \leq 1.52$
For small bandwidth chirps	$0.88 \leq \alpha$ 1 or $0.66 \leq \alpha \leq 0.84$	$0.6 \leq \gamma \leq 1.08$ or $1.12 \leq \gamma \leq 1.44$

where B is the bandwidth, T is the pulse duration, $A(n)$ is the coefficient of the infinite series of sine terms. In fact, taking the sum of finite terms does not reduce the quality of waveform [10]. So the phase function is then as:

$$\varphi(t)=\frac{\pi Bt^2}{T}+2BT\sum_{n=1}^{N}\frac{A(n)}{n}\sin^2\left(\frac{\pi nt}{T}\right) \tag{3}$$

where $N = 10$.

(2) Tangent-based waveform

For this class, the NLFM waveform uses a tangent function to generate frequency:

$$f(t)=\frac{B\tan\left(2\beta\frac{t}{T}\right)}{2\tan(\beta)}\qquad -T/2\leq t\leq T/2 \tag{4}$$

where β is defined by: $\beta=\tan^{-1}(\alpha_1)$. The degree of nonlinearity increases with the parameters α_1, for $\alpha_1\in[0,\infty)$. When $\alpha_1 = 0$, it is the LFM case. Integrating Eq. (4) and multiplied by 2π to find $\varphi(t)$ gives

$$\varphi(t)=-\frac{\pi BT}{2\beta\tan\ \beta}\ln\left|\cos\left(2\beta\frac{t}{T}\right)\right| \tag{5}$$

(3) Combination of LFM and tan-FM

The combination of LFM and tan-FM function yields the frequency modulation function in radians like

$$\varphi'(t)=\pi B\left[\frac{\alpha}{\tan\ \gamma}\tan\left(\frac{2\gamma t}{T}\right)+\frac{2(1-\alpha)}{T}t\right] \tag{6}$$

where the constant γ controls the proportion of the tan x curve which is used and α controls the balance between tan-FM and LFM, the optimal setting of α and γ for various range bandwidth chirps are shown in Table 1 [11], $-T/2\leq t\leq T/2$.

Integrating Eq. (6) to find $\varphi(t)$ gives

$$\varphi(t)=\frac{\pi B}{T}(1-\alpha)t^2-\frac{\pi B\alpha T}{2\gamma\tan\ \gamma}\ln\left|\cos\ \frac{2\gamma}{T}t\right| \tag{7}$$

(4) Stepped NLFM waveform

The evaluated signal can be produced by combining LFM and NLFM, the corresponding frequency modulation function is given by

$$f(t)=\frac{t}{T}\left[B_L+B_C\frac{1}{\sqrt{1-4t^2/T^2}}\right],\qquad -\frac{T}{2}\leq t\leq\frac{T}{2} \tag{8}$$

where B_L is the total frequency sweep of the LFM part and B_C is the total frequency sweep of the NLFM part. The phase modulation function can be described

$$\varphi(t)=\frac{\pi B_L}{T}t^2-\pi B_C\sqrt{\left(\frac{T}{2}\right)^2-t^2} \tag{9}$$

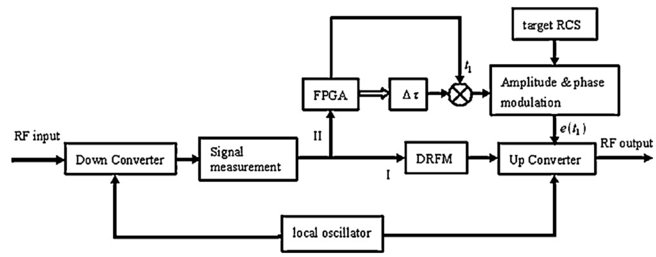

Fig. 1. Block diagram of NLFM signal cancelling system.

2.2. NLFM signal cancelling system programm

The block diagram of the NLFM signal cancelling system is shown in Fig. 1. The received radio frequency (RF) signal pass through the down converter and its parameters can be measured by the signal measuring equipment [12]. Then the signal is divided into two branches: In branch I, the signal is fed into a digital radio frequency memory (DRFM) storage. In branch II, the delay time τ_1 at a particular instant of time t_1 is controlled by the field programmable gate array (FPGA) chip. And the received signal is multiplied by the conjugation of its delayed version (the jammer processing delay time $\Delta\tau$ is controlled by FPGA). Finally, let the two branch of the results are multiplied to obtain the jamming signal. According to the target's radar cross section (RCS) [13], phase and amplitude modulation are made in order to get the signal having the same frequency and amplitude as the echo pulse but with the opposite phase [14]. This signal cancels the radar echo signals.

2.3. Model of cancelling signal

The jamming signal $e(t_1)$ can be expressed as:

$$e(t_1)=s(t_1)\times s^*(t_1-\Delta\tau)\cdot a_{RCS}\cdot\exp[j(\varphi_{RCS}+\pi)] \tag{10}$$

where a_{RCS} and φ_{RCS} representing the target's RCS amplitude and phase characteristic, respectively. "*" indicates the complex conjugate of the function. Let $s(t_1)=s(t-\tau_1)$, so the baseband jamming signal can be shown that:

$$S_J(t)=s(t-\Delta\tau)s(t-\tau_1)\times s^*(t_1-\tau_1-\Delta\tau)\cdot a_{RCS}\cdot\exp[j(\varphi_{RCS}+\pi)] \tag{11}$$

Therefore, the baseband jamming signal for Taylor window can be get by substituting Eq. (3) into Eq. (11), the simplified formula form is

$$S_J(t)=s(t)\exp\left(j\frac{B\pi}{T}\tau_1\Delta\tau\right)\exp\left[jBT\sum_{n=1}^{N}\frac{A(n)}{n}\cos\ \frac{n\pi}{T}(\Delta\tau-\tau_1)\right]\cdot\exp\left[jBT\sum_{n=1}^{N}\frac{A(n)}{n}\cos\ \frac{n\pi}{T}(\Delta\tau+\tau_1-2T)\right]\cdot a_{RCS}\exp(j(\varphi_{RCS}+\pi)) \tag{12}$$