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A New Biphase Coding LFM for Pulse Compression Radar

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Abstract— Linear Frequency Modulation (LFM) waveform becomes widespread in modern pulse compression radar systems in order to improve its target range resolution capability. Conventional LFM based on varying the waveform frequency linearly within the radar pulse width which leads to high Auto Correlation Function (ACF) with limited compression ratio (CR) and side lobe level (SLL). This paper proposed Optimized Biphase Pulse Compression Codes (OBPCC) with the LFM waveform. Frequency and phase coding have been used to achieve optimum (SLL) and (CR) using Genetic algorithm (GA). The results compare the ACF for both LFM and phase coded (PCLFM). Set of codes are generated for code length of 51 with frequency modulation index from 0.002 to 0.009. Peak sidelobe level from -18.89 dB to -19.33 dB is achieved. The results obtained show superiority of PCLFM over the conventional LFM which improves the compression ratio by 9.95 times the conventional LFM.

Index Terms— Radar Waveform, Pulsu Compression, LFM

1 Introduction

In radar terminology extraction the high resolution spatial profile from received signal is known as pulse compression. The problem matched filter output which makes the detection of weak echo signals accompanied by strong signals from target with high Radar Cross-Section (RCS) difficult or even impossible [1]. A very common pulse compression radar waveform is LFM chirp signal. Its utility is that it is fairly generated by a variety of technologies, and is easily processed by a variety of techniques that ultimately implement a matched filter. Large sidelobe level of the ACF causes a serious problem in detection of targets especially in presence of nearby interfering targets or other noise sources. Reducing the sidelobes at the matched filter output is typically accomplished by linear filtering, most often by applying window functions or data tapering. This additional filtering allows the matched filter to reduce the sidelobes as desired. However, since the cumulative filtering is no longer precisely matched to the signal, it necessarily reduces output Signal to Noise Ratio (SNR) as well, typically by 1-2 dB (depending on the filtering or weighting function used), also widening the main lobe leads to degradation on radar range resolution. It is well-known that NLFM can advantageously shape the Power Spectral Density (PSD) such that the autocorrelation function exhibits substantially reduced sidelobes[2].Consequently, no additional filtering is required and maximum SNR performance is preserved. The digital processing or SAW devices can be used to process nonlinear FM. NLFM technique gives better SNR performance, because no power is lost by windowing in the receiver. Different pulse compression techniques have been discussed [3-7], without decreasing the sidelobe level than -23 dB. This paper introduces group of OBPCC. The methodology of obtaining these codes depends on changing the waveform frequency and phase rather than the traditional methods which depends only on the frequency variation. GA has been used to achieve a set of optimized codes [8], but increasing the length of the code will often lead to an unacceptable slow convergence speed.

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2 Theoritical Description of LFM Waveform

The radar ambiguity function represents the output of the matched filter, and it describes the interference caused by the range and/or Doppler shift of a target when compared to a reference target of equal RCS. The ambiguity function evaluated at $(\tau, f_d) = (0,0)$ is equal to the matched filter output that is perfectly matched to the signal reflected from the target of interest. In other words, returns from the nominal target are located at the origin of the ambiguity function. Thus, the ambiguity function at nonzero τ and f_d represents returns from some range and Doppler different from those for the nominal target [9].

The general formula of the Ambiguity Function (AF) assuming a moving target with Doppler frequency f_d can be described as follows:

$$\left|\chi(\tau, f_d)\right|^2 = \left|\int_{-\infty}^{\infty} \tilde{x}(t)\tilde{x}^*(t-\tau)e^{j2\pi f_d t}\,dt\right|^2 \tag{1}$$

The radar ambiguity function is normally used by radar designers as a means of studying different waveforms. It can provide insight about how different radar waveforms may be

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suitable for the various radar applications[10]. It is also used to determine the range and Doppler resolutions for a specific radar waveform. The AF of a single pulse can be written as:

$$|\chi(\tau, f_d|^2 = \left|\left(1-\frac{|\tau|}{\tau_o}\right)\frac{\sin(\pi f_d(\tau_o-|\tau|))}{\pi f_d(\tau_o-|\tau|)}\right|^2 \quad |\tau| \le \tau_o \qquad (2)$$

where , τ is the pulse width while τ_0 is the compressed pulse width or effective pulse width. The LFM complex envelope signal is defined as:

$$\tilde{x}(t) = \frac{1}{\sqrt{\tau_o}} \mathrm{Rect}\left(\frac{t}{t_o}\right) e^{j\pi\mu t^2} \qquad (3)$$

The up-chirp ambiguity function cut along the time delay axis τ is :

$$|\chi(\tau, f_d|^2 = \left|\left(1-\frac{|\tau|}{\tau_o}\right)\frac{\sin\left(\pi\tau_o(\mu\tau-f_d)\left(1-\frac{|\tau|}{\tau_o}\right)\right)}{\pi\tau_o(\mu\tau-f_d)\left(1-\frac{|\tau|}{\tau_o}\right)}\right|^2 \quad |\tau| \le \tau_o \qquad (4)$$

Where, μ is the LFM coefficient and is equal to the bandwidth (B) divided by the pulse width. It is known that the LFM ambiguity function cut along the Doppler frequency axis is similar to that of the single pulse. This is the pulse shape has not changed (only frequency modulation was added). However, the cut along the time-delay axis changes significantly. It is much narrower compared with the un modulated pulse. On the other side, Stepped Frequency Waveforms (SFW) is a class of radar waveforms that are used in extremely wide bandwidth applications where very large time bandwidth product (or compression ratio) is requires [11]. The advent of high-speed Digital-to-Analog Converters (DACs) and high-speed large-scale Field Programmable Gate Arrays (FPGAs) currently facilitate generating high-performance precision digital LFM chirp waveforms. In LFM the transmitter spends equal time at each frequency, hence the nearly uniform spectrum. Another method for shaping the spectrum rather than amplitude weighting 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 NLFM .

The complex envelope of the NLFM signal is given by :

$$u(t) = g(t) \qquad (5)$$

where g(t) is the amplitude and $\phi(t)$ is the phase function. The Fourier transform can be described as follows:

$$U(f) = |U(f)| \exp[j\phi(f)] = \int_{-\infty}^{\infty} g(t) \exp\left[j\left(-2\pi ft + \phi(t)\right)\right] dt \quad (6)$$

In the Design process of the transmitted LFM radar signal ,the matched filter output signal is given by the input filter autocorrelation function. The signal autocorrelation function is determined by the Inverse Fourier Transform (IFT) of the energy spectral density. Frequency variation of LFM follows a first order equation as follows :

$$f(t) = bt + c \qquad (7)$$

changing the linear equation parameter (b) provides a different frequency distributions used in the designed LFM , Parameters used in our simulation is: 20 µ sec pulse width and chirp bandwidth of (0-50) MHz . The Matched filter output using Fast Fourier Transform (FFT) can be simply described as shown in Fig.1.

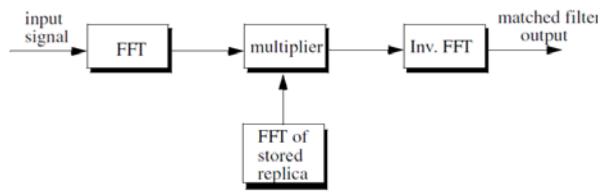

Fig.1. Matched filter output using FFT

The sidelobe suppression of the matched filter output using the designed LFM radar signal has been improved as well, but far less.

3 Theoritical Description of Biphase Codes

The most widely used phase coded waveform employs two phases and is called binary, or biphase, coding. One family of biphase codes that produced compressed waveforms with constant sidelobe level equal to unity is Barker codes. The complex envelope of the phase coded pulse is given by [12],

$$u(t) = \frac{1}{\sqrt{T}}\sum_{m=1}^{M} u_m rect\left(\frac{t-(m-1)t_b}{t_b}\right) \qquad (1)$$

where

$$u_m = \exp(j\phi_m)$$

the set of M phases, $\{\phi_1, \phi_2, \ldots\ldots, \phi_m\}$ is the phase code associated with u(t) and T is the pulse duration. The biphase codes consist of a sequence of either 0 and 1 or +1 and -1. code element (l) means amplitude (1) and phase shift (0^o) while (-1) means amplitude (1) and phase shift (π^o). If a transmitted pulse u(t) with M_u phase elements defined by um($1 \le m \le M$) and a reference pulse v(t) with M_v elements defined by $v_n(1 \le n \le M_v)$. The cross-correlation function of two phase-coded pulses is defined as [13]:

$$R_{uv}(\tau) = \int_{-\infty}^{\infty} u(t) v^*(t+\tau) d\tau = \int_{-\infty}^{\infty} \frac{1}{\sqrt{M_u t_b}} \sum_{m=1}^{M_u} u_m rect\left(\frac{t-(m-1)t_b}{t_b}\right). \qquad (2)$$
$$\frac{1}{\sqrt{M_v t_b}} \sum_{m=1}^{M_v} v_n rect\left(\frac{t+\tau-(n-1)t_b}{t_b}\right).d\tau$$

Phase coded signal using five bits [1 1 1 -1 1] biphase pulse compression Barker code is shown in Fig.2. where the phase of the waveform changes according to the code elements.

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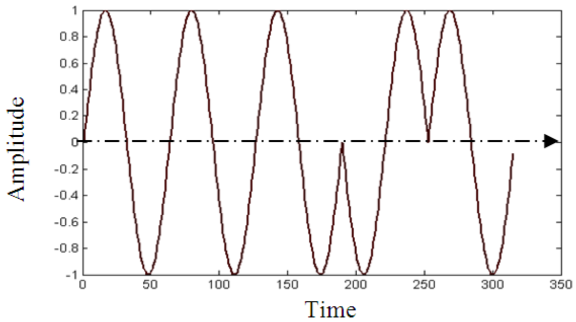

Fig.2. Phase coded signal using Five bits biphase pulse compression code

4 Optimization Process

Genetic algorithm has been used to optimize the pulse compression codes parameters by changing The code value .Binary encoding scheme is used in this algorithm to encode the code elements [13-15]. The chromosome contains the bi-phase pulse compression code elements, each gene encoded as 1 bit to represent the code element . Elitism is used to save the best solution to improve the performance of genetic algorithm. The algorithm started with a set of solutions called population solutions, one population is used to form a new population, this is motivated by hope that the new population will be better than the old one .Solutions that are selected to form new off springs are selected according to their fitness .The fitness of pulse compression codes is determined according to two main parameters the PSL and MSL levels. The crossover rate used is randomly selected between 10-90 % , the mutation rate is equal to 3% , the population size is selected to be 64 . The optimization process proceeds to obtain the minimum PSL and MSL of the biphase pulse compression codes.

5 Optimization Results

Fig.3. show a comparison between ACF of LFM and OBPCC LFM with 0.002 modulation slope which reflects a significant improvement in compression ratio exceeded 9 times that achieved from traditional LFM without any degradation in SLL. With 0.003 modulation slope significant compression ratio CR achieved with additional SLL reduction by more than -4 dB over the normal LFM as shown in Fig.4. The same conclusion can be achieved from Figs. (5 to 10) with modulation slopes from 0.004 to 0.009. Fig.11. demonstrate the ambiguity function of LFM signal while OBPCC LFM ambiguity function shown in fig.12. Table (1) illustrates the optimized Biphase codes for each modulation slope.

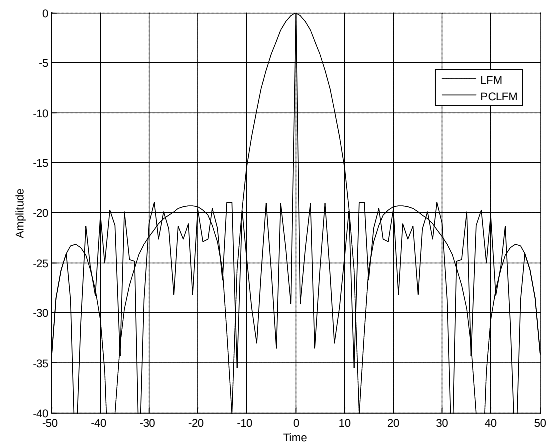

Fig. 3. PCLFM ACF with 0.002 LFM slope compared with conventional LFM

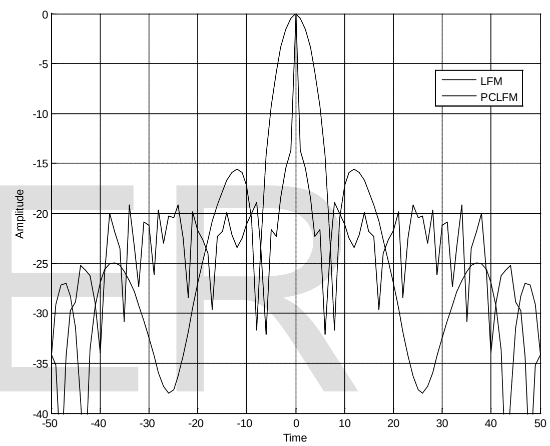

Fig.4. PCLFM ACF with 0.003 LFM slope compared with conventional LFM

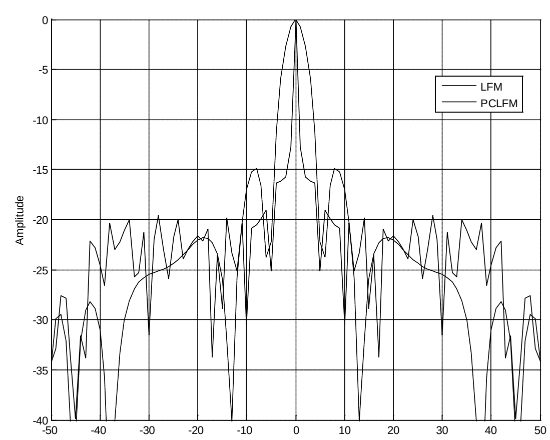

Fig.5. PCLFM ACF with 0.004 LFM slope compared with conventional LFM

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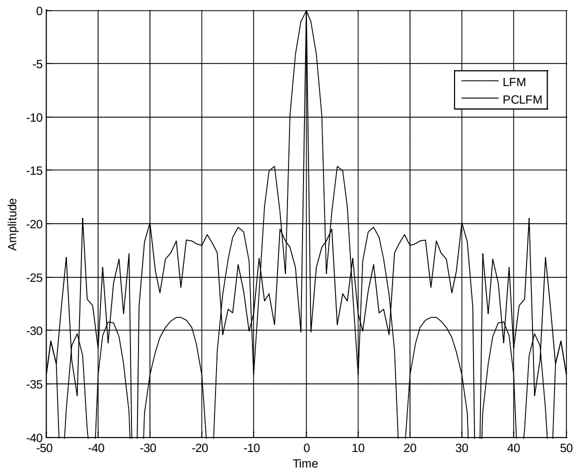

Fig.6. PCLFM ACF with 0.005 LFM slope compared with conventional LFM

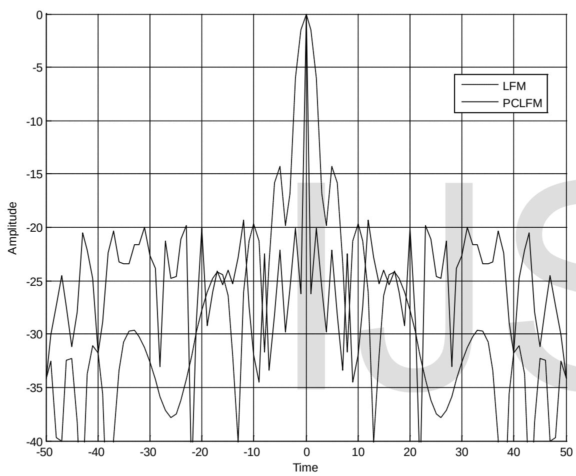

Fig.7. PCLFM ACF with 0.006 LFM slope compared with conventional LFM

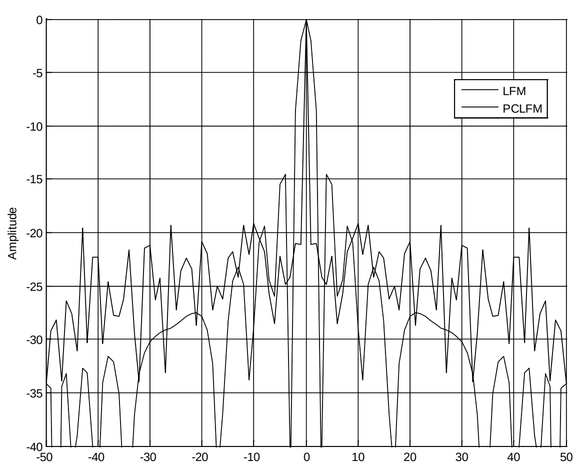

Fig.8. PCLFM ACF with 0.007 LFM slope compared with conventional LFM

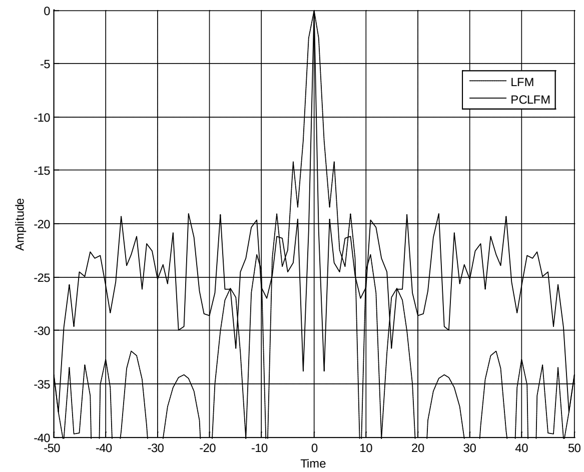

Fig.9. PCLFM ACF with 0.008LFM slope compared with conventional LFM

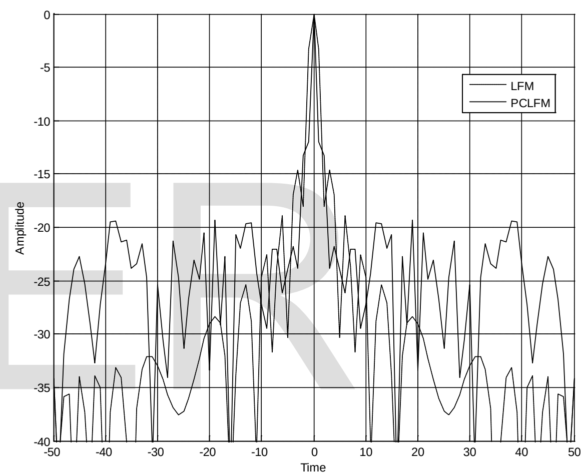

Fig.10. PCLFM ACF with 0.009 LFM slope compared with conventional LFM

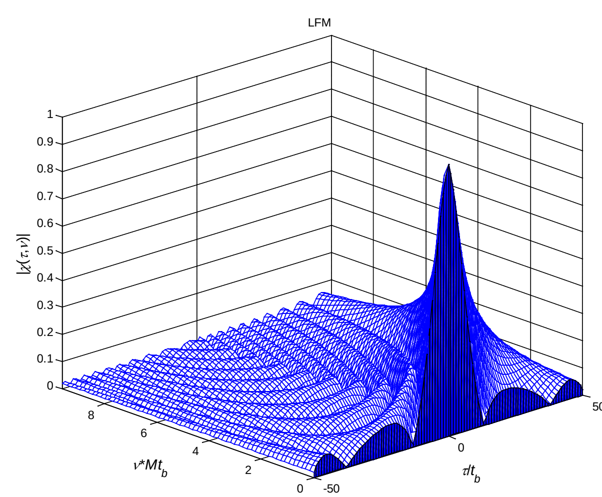

Fig.11. Ambiguity function of the 51-element LFM.

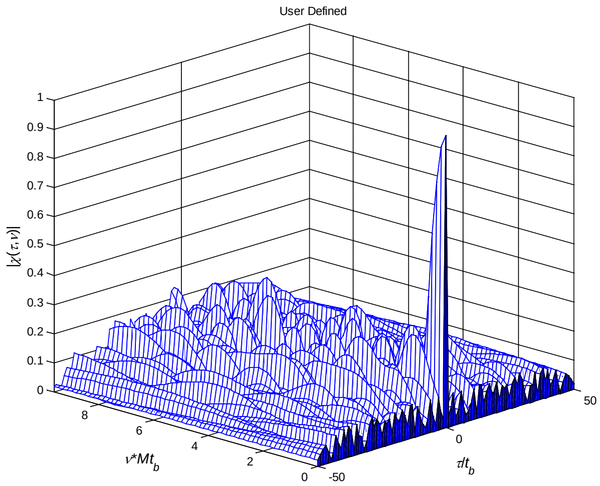

Fig.12. Ambiguity function of the 51-element GA OBPCC LFM., with 0.002 LFM slope

M.S	Biphase Code	SLL(dB)
0.002	[0,1,0,1,1,0,1,1,0,0,1,0,0,0,1,1,0,0,0,0,1,1,1,0,0,0, 1,0,1,0,1,1,1,0,0,0,0,0,0,1,0,0,0,1,1,0,1,1,0,1,0;]	-18.95
0.003	[0,0,0,0,0,0,1,0,1,0,1,1,0,0,1,1,1,1,0,0,0,0,1,0,1,1, 1,0,1,0,1,0,1,1,0,0,1,0,1,0,0,1,0,1,0,1,0,0,0,1,0;]	-18.89
0.004	[1,1,0,0,0,1,1,1,1,0,1,0,0,1,0,1,0,0,1,0,1,1,0,0,0,1, 0,0,1,0,0,0,0,0,0,1,0,1,1,0,1,0,1,0,1,1,0,1,0,1,0;]	-19.06
0.005	[0,0,0,0,1,0,1,1,0,0,0,1,1,0,0,0,1,1,1,1,0,1,1,0,1,0, 1,1,1,0,0,0,1,0,0,1,0,1,0,0,1,1,0,1,0,0,0,0,0,1,1,1;]	-19.49
0.006	[0,0,0,0,1,1,0,1,0,0,1,1,0,0,0,0,1,0,0,1,0,1,1,0,0,1, 0,1,1,0,0,0,0,1,0,1,1,0,0,1,1,1,1,1,0,0,1,0,1,1,0;]	-19.34
0.007	[0,0,1,1,0,1,0,0,1,1,0,0,1,0,0,1,0,0,0,0,0,1,0,0,1,0, 0,0,1,0,0,1,0,1,1,0,0,0,1,0,0,1,0,0,0,0,1,0,0,1,0;]	-19.15
0.008	[1,1,0,1,0,0,0,1,1,1,0,0,1,1,1,1,0,1,0,0,0,0,0,0,1,1, 0,0,0,1,0,0,1,0,1,1,1,0,0,0,0,1,0,0,0,1,0,0,1,1,1;]	-19.08
0.009	[1,1,1,1,1,0,0,0,0,0,0,0,0,1,0,1,1,1,0,1,1,1,0,0,0,0, 0,0,0,0,1,1,1,0,1,1,0,0,1,1,1,0,0,0,1,0,0,1,0,1,1;]	-19.33

5 Conclusion

This paper proposed Optimized Biphase Pulse Compression Codes (OBPCC) with the LFM waveform. Frequency and phase coding have been used to achieve optimum (SLL) and (CR) using Genetic algorithm (GA). The results compare the ACF for both LFM and phase coded (PCLFM). Set of codes are generated for code length of 51 with frequency modulation index from 0.002 to 0.009. Peak sidelobe level from -18.89 dB to -19.49 dB is achieved. The results obtained show superiority of PCLFM over the conventional LFM which improves the compression ratio by 9.95 times the conventional LFM.

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