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Performance Evaluation of Costas codes using Fusion Techniques

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***Abstract*-** The resolution is the important parameter of the radar. Here waveform design plays an important role in the radar applications. These waveform designs can be achieved by using signal processing tools like auto correlation and ambiguity function. In this project signal processing techniques have been developed by using above functions. These techniques are most useful in the multi target scenario of the radar. In this project the signals like burst signal, linear frequency modulated (LFM) and Non Linear Frequency Modulated (NLFM) signals are used for the determination of radar resolution and also these waveforms are implemented in popular codes like "COSTAS". The three dimensional plots are generated to evaluate both range and Doppler resolution by using ambiguity functions. The results are being presented for the COSTAS code by using LFM and COSTAS code by using NLFM signals. The performance of these waveforms is compared with the conventional waveforms.

***Index Terms*-** COSTAS, Ambiguity function, LFM, NLFM.

I. Introduction

The word radar is an abbreviation for Radio Detection and Ranging. In general, radar systems we use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search for targets. In this radar the target reflects back is the echo of the object [1, 2]. One fundamental issue in designing a good radar system is its capability to resolve two small targets that are located at long range with very small separation between them. This requires a radar system to transmit along pulse which will have enough energy to detect a small target at long range. However, a long pulse degrades range resolution. Hence, frequency or phase modulation of the signal is used to achieve a high range resolution when a long pulse is required.

A commonly used radar or sonar pulse is the linear frequency modulated (LFM) pulse (or "chirp"). It has the advantage of greater bandwidth while keeping the pulse duration short and envelope constant. A chirp is a signal in which the frequency increases ('up-chirp') or decreases ('down-chirp') with time. In some sources, the term chirp is used interchangeably with sweep signal. The linear-FM, or chirp, waveform is the easiest to generate. If a signal is Costas can be performed easily with the help of the difference matrix. The coding sequence, the order of frequencies used, is a concise way to describe the coding matrix. With regard to the difference matrix, note that the top row and the left most column are headings and not part of the matrix.

The element of the difference matrix in row i and column j, is

$$D_{i,j} = a_{i+j} - \alpha_{j}, \qquad i+j \leq M$$

Costas sequences are optimum discrete signals with good correlation characteristic. Coding with Costas is combined with LFM signal to generate LFM-Costas radar signal. The ambiguity function is analyzed. By using ambiguity function only we can plot the signals like LFM, COSTAS, and COSTAS WITH LFM. In the 3, 4, 5 sections we will discuss the above techniques.

II. AMBIGUITY FUNCTION

An ambiguity function is a two-dimensional function of time delay and Doppler frequency $\chi(\tau, f)$ showing the distortion of a returned pulse due to the receiver matched filter (commonly, but not exclusively, used in pulse compression radar) due to the Doppler shift of the return from a moving target. The ambiguity function is determined by the properties of the pulse and the matched filter, and not any particular target scenario. Many definitions of the ambiguity function exist; some are restricted to narrowband signals and others are suitable to describe the propagation delay and Doppler relationship of wideband signals. Often the definition of the ambiguity function is given as the magnitude squared of other definitions.

The radar ambiguity function is defined as the response of the matched-filter radar receiver to a target displaced in range delay T and Doppler frequency u from a reference target. The response is measured at the instant in time when the reference target is at its maximum value. The ambiguity function is therefore closely related to the matched filtered output waveform. In fact it is simply the squared magnitude of the time-reversed matched-filter response.

For a given complex baseband pulse s(t), the narrowband ambiguity function is given by

$$\chi(\tau, f) = \int_{-\infty}^{\infty} s(t)s*(t-\tau)e^{(-i2\pi ft)}\,dt.$$

Range Resolution: Is the ability of a radar system distinguished between two or more targets on the same bearing but at different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator. Pulse width is the primary factor in range resolution.

The theoretical range resolution of a radar system can be calculated from the following formula:-

$$s_r \geq c_0\tau/2$$

Doppler Resolution: Is the minimum separation in targets radial velocities that can be distinguished by the radar receiver. This resolution is fundamentally related to coherent integration time of radar

$$\Delta f_d = 2\Delta v_r / \lambda$$

Where Δv_r is the radial velocities, λ is the radar wavelength;

III. LFM

A **chirp** is a signal in which the frequency increases ('up-chirp') or decreases ('down-chirp') with time. In some sources, the term **chirp** is used interchangeably with **sweep signal**. It is commonly used in sonar and radar, but has other applications, such as in spread spectrum communications. In spread spectrum usage, SAW devices such as RACs are often used to generate and demodulate the chirped signals. In optics, ultra short laser pulses also exhibit chirp, which, in optical transmission systems interacts with the dispersion properties of the materials, increasing or decreasing total pulse dispersion as the signal propagates.

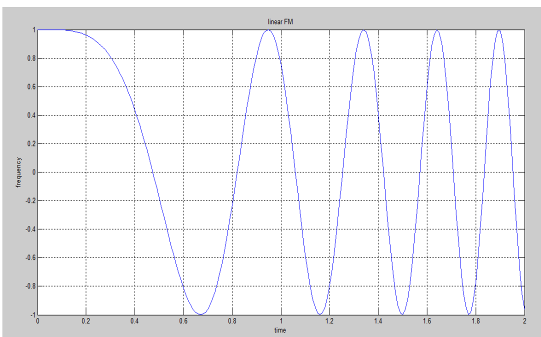

Fig 1: Linear Frequency Modulation

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

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

A complete description of a linear FM requires that at least three parameters be known: the duration and the FM's start and end frequencies. The change in over time ("t" in ms) defines the slope of a linear FM, such that slope=f(t2)-f(t1)/(t2-t1).i.e., frequency bandwidth/duration. In speech sounds, slope of the formant transition is equivalent to slope of an FM and may be measured in Hz/ms.

In this pulse compression technique the LFM signal are one of the techniques are used in the radar signals.

Pulse compression is a signal processing technique mainly used in radar, sonar and echography to increase the range resolution as well as the signal to noise ratio. This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse.

In this LFM the ambiguity plot is important because from the plot we can determine the range resolution, Doppler resolution and peak side lobe ratio.

The ambiguity plot is as shown in fig.

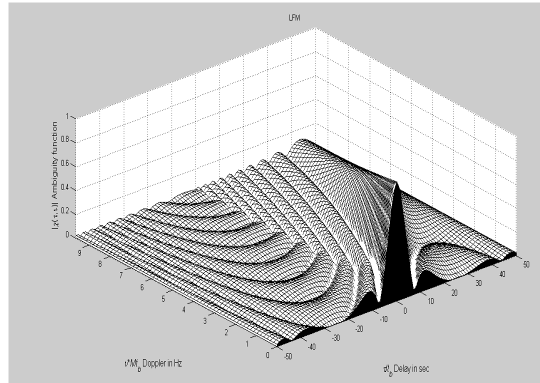

Fig 2: Ambiguity plot of LFM signal

IV. COSTAS

John P. Costas (1984) suggested a discrete frequency coding that is practically the opposite of the linear law used in LFM[4]. In this Costas we are having the binary matrix representation of both LFM and the Costas, for LFM it is linear in the matrix representation and for the Costas is represented in the frequency that we are taking.

If a signal is Costas can be performed easily with the help of the ***difference matrix***. The ***coding sequence***, the order of frequencies used, is a concise way to describe the ***coding matrix***. With regard to the difference matrix, note that the top row and the leftmost column are headings and not part of the matrix.

The element of the difference matrix in row *i* and column *j*, is

$$D_{i,j} = a_{i+j} - \alpha_{j,} \qquad _{i+j} \le M$$

Where a_i is the *i*th element of the coding sequence, the blanks at the remaining locations. Thus the first row is formed by taking differences between adjacent terms in the sequence, the second row by taking differences between next adjacent terms, and so on. The corresponding values in the difference matrix and side lobe matrix were marker with different colour circles.[5]

The difference matrix not only determines whether a sequence is Costas or not, but it also identifies the major side lobe locations in the positive delay slots of the ambiguity function. The side lobes in the negative delay slots are obtained by applying the rule of symmetry with respect with the origin. [5].

Difference matrix

a_j	4	7	1	6	5	2	3
i=1	3	-6	5	-1	3	1	
i=2	-3	-1	4	-4	-2		
i=3	2	-2	1	-3			
i=4	1	-5	2				
i=5	-2	-4					
i=6	-1						

The ambiguity function of the Costas signal

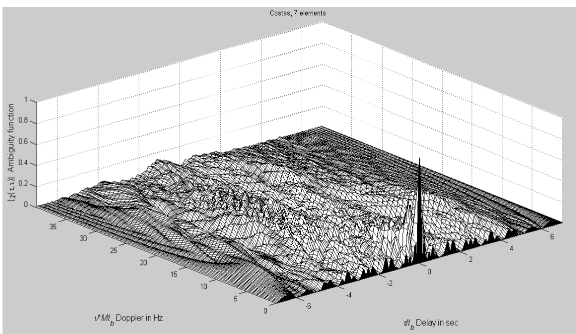

Fig 3: Ambiguity plot of COSTAS signal

By using thus plot we can calculate the range, Doppler resolution and peak side lobe ratio

V. COSTAS WITH LFM

Costas sequences are optimum discrete signals with good correlation characteristic. Coding with Costas is combined with LFM signal to generate LFM-Costas radar signal. The ambiguity function is analyzed.

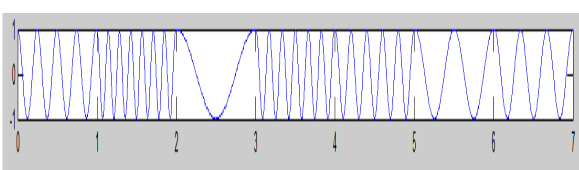

Fig 4: Costas with LFM signal

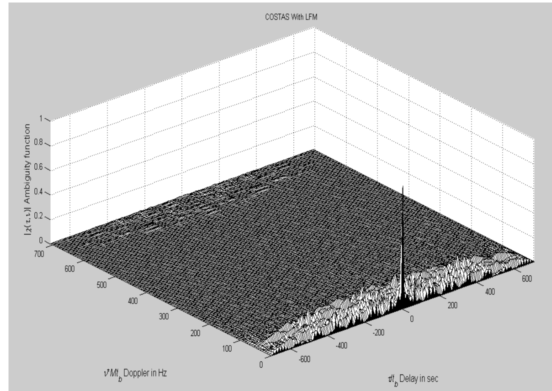

Fig 5: Ambiguity plot of COSTAS with LFM signal.

Costas code with LFM is having the 2 different sweep rates, their ambiguity plot are

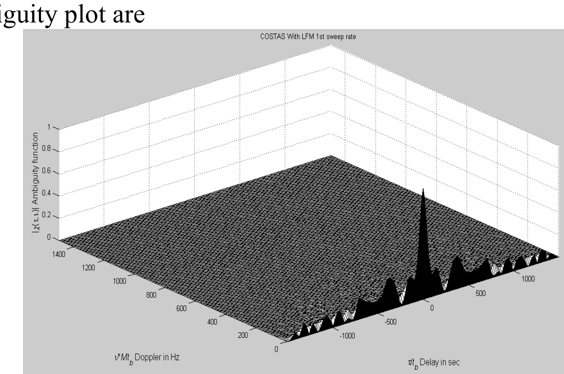

Fig 6: Ambiguity plot of Costas with LFM signal with 1st sweep rate

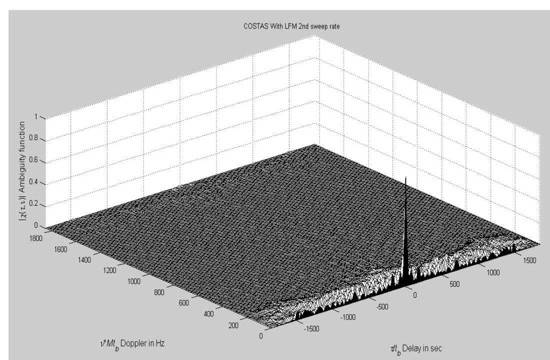

Fig 7: Ambiguity plot of Costas with LFM signal with 2nd sweep rate

NLFM

Another method for shaping the spectrum 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).

COSTAS WITH NLFM

Coding with Costas is combined with NLFM (Non Linear Frequency Modulation) signal to generate NLFM-Costas radar signal. The ambiguity function is analyzed.

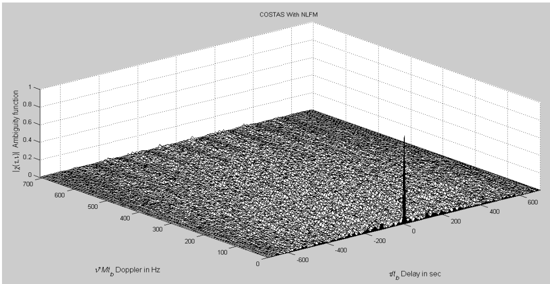

Fig 8: Ambiguity plot of Costas with NLFM

VI. CONCLUSION

In this work the waveform design of radar by using different signal processing techniques like burst signal, LFM signal, and Costas signal, Costas with LFM and Costas with NLFM. Costas is a frequency coding technique multiple frequency signals are transmitted according to the code that we are using.LFM signal is a Linear Frequency Modulation signal even it has the great resolution but power is lost due to the ridges.

Presently Costas code and Costas with LFM is being implemented using un-modulated sine wave with different sweep rates.

By calculating the above parameters, Costas with NLFM signal is having the low range resolution, low Doppler resolution and high peak side lobe ratio. Hence it is concluded the Costas with NLFM is preferable signal for low range resolution and Doppler resolution when compared to Costas with LFM.

parameter / Waveform	RR in cm	DR in m/s	PSLR
SINE	0	0.182	undefined
LFM	300	0.48	6.02
COSTAS	211.5	0.2115	10.7
COSTAS WITH LFM	105.75	0.0423	19.09
COSTAS WITH LFM 1ST SWEEP RATE	898.2	0.4991	3.424
COSTAS WITH LFM 2ND SWEEP RATE	1105.2	0.5526	7.35
COSTAS WITH NLFM	72.03	0.0216	50

Table 1: Performances of different signal in range resolution, Doppler resolution and peak side lobe ratio.

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