EMPIRICAL ANALYSIS ON DOPPLER TOLERANT RADAR CODES

Syed Sufiyan Ahmed Rafiuddin,Vinay Kumar Bhangdia

Abstract— Pulse compression has been used to improve radar resolution. Pulse compression combines the advantage of high energy of a long pulse with the high resolution of a short pulse. The ambiguity function χ (τ, f) of a radar signal is a two-dimensional correlation function in terms of delay (τ- time shift) and doppler (υ- frequency shift). The binary codes like barker code and conventional polyphase pulse compression codes including frank code, p1, p2, p3 and p4 code suffer severe signal loss in performance under doppler environment. Since p2 and p4 codes have the similar Doppler tolerance performance as p1 and p3 codes respectively , we omit these two codes and modulate the transmitted pulse using only frank, p1, p3 and HFM (hyperbolic frequency modulation) polyphase codes . HFM is polyphase pulse compression codes which are conceptually derived from the step appropriation of the face curve of the hyperbolic modulated chirp signal.This paper analysis the radar codes mentioned above for various values of delay and Doppler for better Doppler resolution.

Key words— Ambiguity Function, Barker Code, Doppler Tolerance Comparison, Hyperbolic Frequency Modulation, Polyphase Codes, Pulse Compression.

1 INTRODUCTION

PULSE compression techniques have been widely used in many modern radar systems. The transmitted pulse is modulated by using frequency (chirp) modulation or phase coding in order to get large time-bandwidth product TW. In receiver side, the target echo signal is passed through a filter matched with the transmitted waveform and results in an extremely narrow impulse with a large peak value, thus the transmitted pulse is compressed in time domain Pulse compression combines the advantage of high energy of a long pulse with the high resolution of a short pulse. However, when the relative velocity between the radar and the target is relatively large comparing with the velocity of signal propagation and is not negligible, the received signal is Doppler distorted and does not match with the matched filter. This mismatch will result in the signal loss and the side lobe increasing in the compressed pulse, therefore the Doppler-tolerant waveform with the minimum signal loss under different Doppler environments is always desired.

The pulse compression ratio can be expressed as the ratio of the range resolution of an un modulated pulse of length τ to that of the modulated pulse of the same length and bandwidth B is

$$PCR = \tau \cdot B$$

This term is described as time-bandwidth-product of the modulated pulse and is equal to the pulse compression gain ,PCG , as the gain in SNR relative to an un modulated pulse.

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2 POLYPHASE CODES

Polyphase sequences are finite length, discrete time complex sequences with constant magnitude but with a variable phase Øk. polyphae coding refers to phase modulation of the CW carrier, with a polyphase sequence consisting of a number of discrete phases. Increasing the number of elements or phase values in the sequence allows the construction of longer sequences, resulting in a high resolution waveform with greater processing gain in the receiver or equivalently a larger compression ratio.

Polyphase sequences that satisfy the barker criteria (so called barker codes) are currently under investigation in order to try and find longer sequences. Polyphase compression codes have also been derived from step approximation–to-linear-frequency modulation waveforms (frank, p1, p2) and linear frequency modulation waveforms (p3, p4).

The important of polyphase coding to the LPI community is that by increasing the alphabet size Nc, the autocorrelation side lobes can be decreased significantly while providing a larger processing gain.

3 AMBIGUITY FUNCTION

In pulsed radar and sonar signal processing, an ambiguity function is a two-dimensional function of time delay and Doppler frequency 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 . For a given complex baseband pulse , the narrowband ambiguity function is given by

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

4 HYPERBOLIC FREQUENCY MODULATION

The instantaneous frequency is the derivative of the phase term inside the cosine function which is a hyperbolic function of time, so it is called as hyperbolic frequency modulation. For non linear chirp waveform based Polyphase codes and HFM code has a much slower degradation ratio than Polyphase code and other codes. HFM codes also give the smallest signal loss almost over the entire Doppler shift range. The pulse width of HFM code does not increase very much when Doppler factor increase and is better than Polyphase codes.

5 RESULTS ANALYSIS

5.1 Figures :

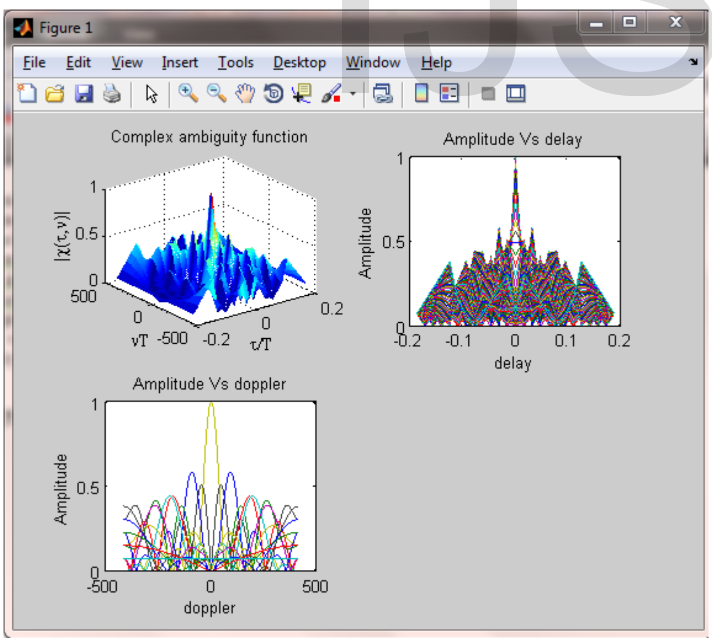

Figure 1: 13 Bit Barker Code

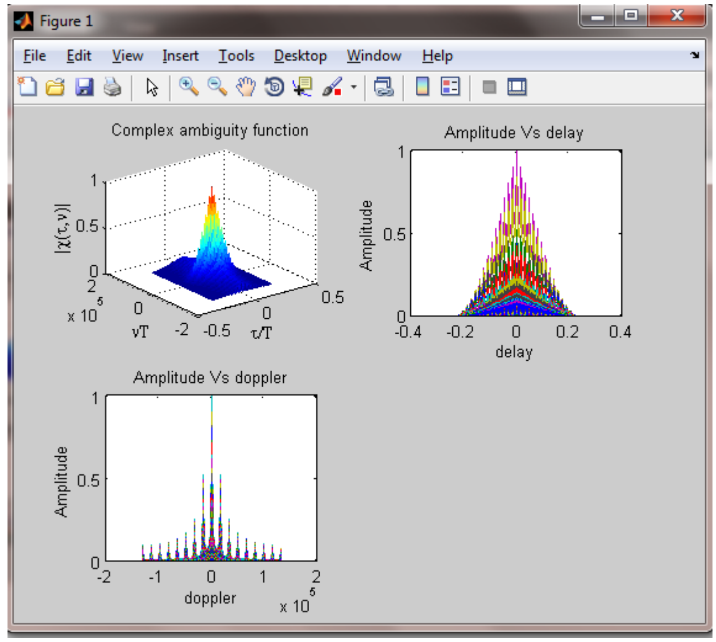

Figure 2 : 16 Bit Frank Code

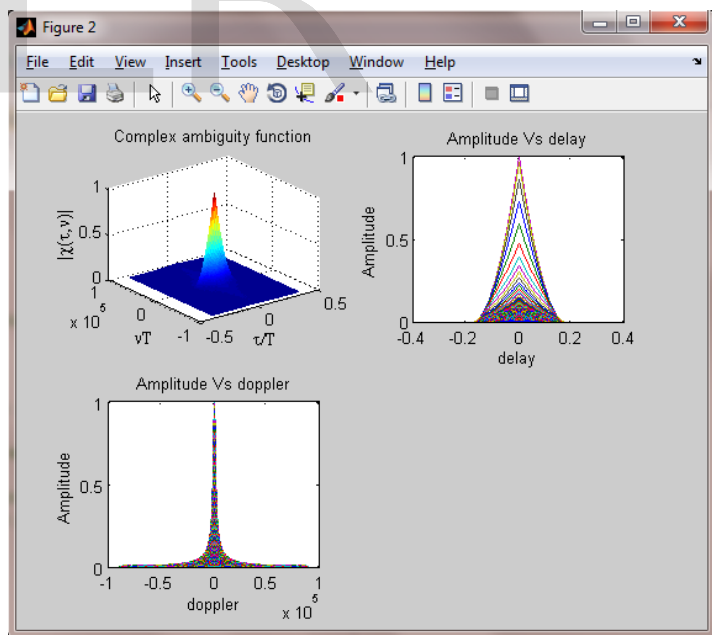

Figure 3 : 16 Bit P1 Code

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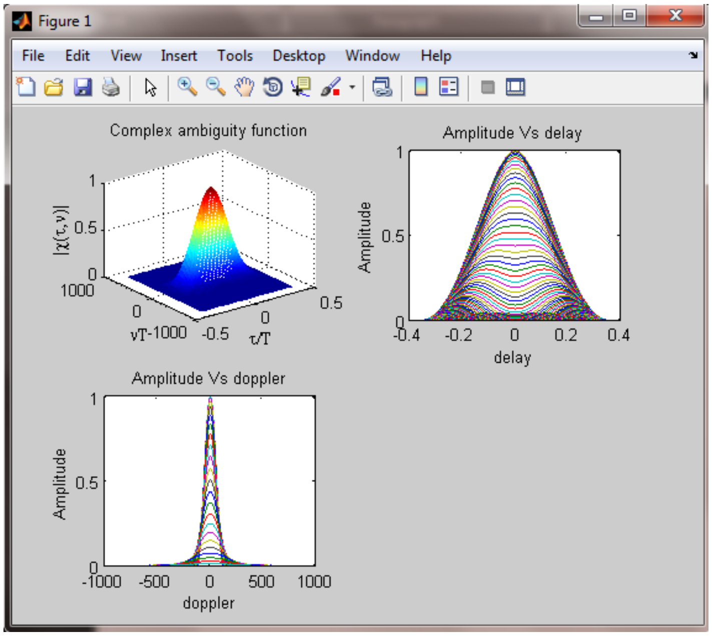

Figure 4 : 25 bit P4 code

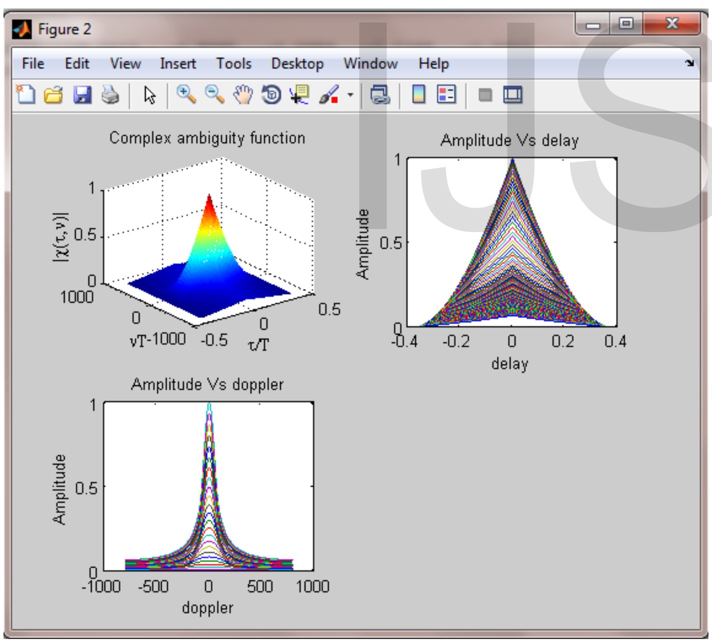

Figure 5 : 25 bit HFM code

In the above graphs as we can see there are three different plots the 3d plot in the top-left corner is the ambiguity function plot as mentioned above the ambiguity function is two-dimensional function of time delay and Doppler frequency, it helps us determine the response of the pulse for various values of delays and Doppler. The plot on the top-right is the amplitude vs delay plot and it is basically the one sided face view in the direction of the doppler axis. The graph plotted at the bottom left corner is the amplitude vs doppler graph and it is also a one sided view of the ambiguity function in the direction of the delay axis.

5.2 Table :

Doppler At (MHz)	13 Bit Barker Code	16 Bit Frank Code	16 Bit P1 Code	25 Bit P4 Code	25 Bit HFM Code
0	1.0000	1.0000	1.0000	1.0000	1.0000
50	0.0252	0.0769	0.0981	0.2072	0.6829
100	0.0200	0.1477	0.0430	0.0337	0.3468
200	0.0107	0.1621	0.0253	0.0031	0.1819
300	0.0090	0.1138	0.0165	0.0048	0.1251
400	0	0.0946	0.0158	0.0057	0.0985
500	0	0.0745	0.0136	0.0065	0.0837

Table 1 : Amplitude Vs Doppler Comparision Of All Codes

6 DOPPLER TOLERANCE COMPARISON

On thorough analysis of the ambiguity function of the mentioned codes, we have come to realize some specific properties of the codes that make them suitable for a given application and in the table given above we have noted the amplitude values for a set of Doppler values so as to give us a general idea of the Doppler tolerance of the code. The main things we look for in the ambiguity function is that the peak should be high and it must give high resolution i.e. the peak width of the code must b acceptably large so as to give an decent level of amplitude for wide range of Doppler values. Some of our main observations are :

1. Barker code is surrounded by much noises. We cannot transmit this code in applications that require a higher level of precision. Its highly unsuitable in higher Doppler environments.

2. Frank code is having good amplitude at zero and other selected Doppler values. Having a narrow peak width its not an ideal Doppler tolerant code. However, we can use this code for applications that have a small set of Doppler variations.

3. P1 code is having decent amplitude and wide band for better resolution compared to both frank and barker codes but, as it can be seen from the delay Vs amplitude plot it is not ideal for distant targets.

4. P4 code is having excellent results, its quiet Doppler tolerant in comparison to the above codes it may be used in Radars that are equipped to detect targets at a limited range of speeds as seen in the figure we can get good amplitude till 100 Doppler .Doppler resolution is more for better detection of targets.

5. HFM code is best among all the codes in terms of Amplitude and Doppler resolution. It can be put to use in radar applications where the variation in doppler is very large.

7 CONCLUSION

In this paper we design and analysis a new polyphase code based on the step approximation of the phase function of hyperbolic frequency modulated waveform. The numerical simulation illustrates that comparing with the variety of well-known polyphase codes, this HFM polyphase code has better Doppler resolution and fair amplitude, while the pulse width of the HFM are less affected by the Doppler effect. The desired Doppler tolerant property of the new HFM polyphase code makes it especially suitable for digital radar systems working under large Doppler environment.

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