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Comparative Analysis of Polyphase Codes for Digital Pulse Compression Applications

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Abstract **-Pulse compression permits us to trade-off between the average transmitted power of a reasonably long pulse and the range resolution corresponding to a short pulse. Polyphase codes viz., Frank, P1, P2, P3 and P4 have the ability to achieve low side lobes without amplitude weighting. Polyphase wave forms have the advantages of low main lobe width, high peak side lobe ratio and good Doppler tolerance.**

In this paper Digital Pulse Compression technique is analyzed using Polyphase codes and a comparison between different Polyphase codes (Frank, P1, P2, P3 and P4) is analyzed with respect to main lobe width, side lobe reduction, Doppler tolerance and pre-compression band-limiting effects.

IndexTerms - Pulse Compression, Barker sequence, Frank codes, Polyphase codes, side lobe reduction, auto-correlation, Doppler tolerance.

I. INTRODUCTION

Range resolution for Radar can be considerably improved by means of very short pulses. Utilizing short pulses reduces the average transmitted power, which can hamper the Radar's regular modes of operation. Because the average transmitted power is connected to the receiver SNR, it is often advantageous to increase the pulse width (thereby increasing the average transmitted power) while at the same time preserving adequate range resolution. Pulse compression [1] permits us to attain the average transmitted power of a reasonably long pulse, while acquiring the range resolution corresponding to a short pulse.

LFM signals are also often the waveform of choice for wideband systems, where the required bandwidth may be hundreds of megahertz. The ambiguity function of the LFM signal suffers from significant sidelobes, both in delay (range) and in Doppler. It is known, for example, that the first range sidelobe is approximately 13 dB below the main peak of the ambiguity function. Such sidelobes may be unacceptable in many applications due to system performance degradation caused by high sidelobes. To suppress the sidelobes some form of weighting can be applied to the matched filter response. The main drawbacks associated with conventional weighting functions (e.g., Hamming, Kaiser Windows) are the broadening of the main lobe of the ambiguity function cut along the time axis and an inevitable attenuation in the peak response which decreases the signal-to-noise ratio.

II. POLYPHASE CODES

Polyphase codes [2, 3] uses harmonically related phases based on a certain fundamental phase increment. In Polyphase codes, a particular pulse of time support τ is split into P equal parts; each part is subsequently partitioned into additional P sub-pulses each of chip width $\Delta\tau$. As a result, the total number of sub-pulses insideeach pulse is P^2, and the Pulse Compression Ratio (PCR) is P^2. The phase within each sub-pulse is maintained constant with regard to some continuous wave reference signal.

The phase coding methods of Frank, P1, P2, P3 and P4 are explained in the next section. The phase codes are selected so that the auto-correlation function of the coded waveform has the largest Peak signal to Side Lobe Ratio (PSLR) for a fixed code length.

A. Phase relationships in Polyphase codes

Polyphase codes are usually obtained from the phase variation of linear frequency modulated pulse. The Frank code, P1 and P2 codes are derived from the frequency stepped pulses. These threecodes are only appropriate for perfect square length of pulse compression ratio and can be stated as

Frank: $\varphi_{i,j} = \left(\frac{2\pi}{L}\right)(i-1)(j-1)$ ...(1)

P1: $\varphi_{i,j} = \left(\frac{\pi}{L}\right)[L-2(j-1)][(j-1)L+1]$ ...(2)

P2: $\varphi_{i,j} = \left(\frac{\pi}{L}\right)\left[\frac{(L+1)}{2} - j\right]\left[\frac{(L+1)}{2} - i\right]$ ...(3)

Two other Polyphase codes are P3 and P4 codes obtained from the linear frequency-modulated pulse. The length of P3 and P4 codes can be arbitrary. P3 and P4 codes can be expressed as

P3: $\varphi_i = \frac{\pi(i-1)^2}{M}$ ... (4)

P4: $\varphi_i = \frac{\pi(i-1)(i-1-M)}{M}$ ... (5)

III. AUTO-CORRELATION FUNCTIONS OF *POLYPHASE CODES*

The matched filter response of Polyphase waveforms can be studied using auto-correlation functions of Polyphase codes. The peak side lobe ratio and 6-dB time width (or compressed pulse width) can be calculated from the auto-correlation functions of the Polyphase codes.

For Polyphase Barker sequences, very good Integrated Sidelobe Levels (ISL), defined as

$$ISL = 10 * Log10 \sum_{i \neq 0} \frac{Ri^2}{Ro^2} \qquad \dots (6)$$

where the Ri are the elements of the auto-correlation sequence, i = 1 to N-1, and R_0 is the auto-correlation peak. This is done because long codes cannot have Barker-level sidelobes without also having good ISL. With this in mind good ISL codes are found, and then used as starting points for local searches for low-PSL codes [4].

The following Polyphase auto-correlation functions simulations are carried out with Matlab© for Pulse-Doppler radar with Pulse Repetition Frequency (PRF) = 1000Hz, PCR = 100, and range resolution of 50m (chip width of 33 ns).

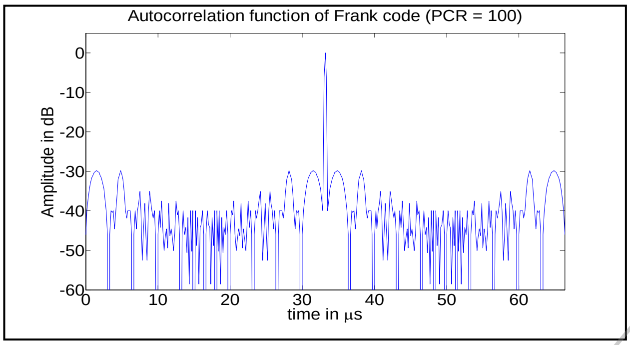

Fig 1. Auto-correlation function of Frank code

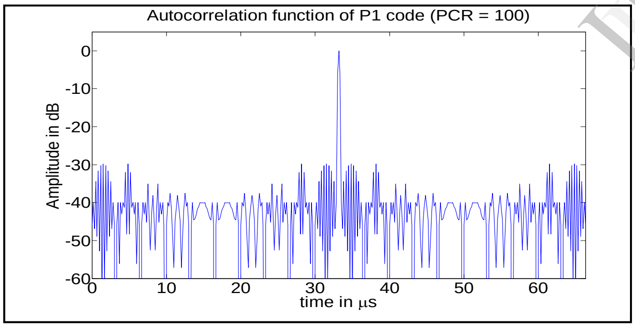

Fig 2. Auto-correlation function of P1 code

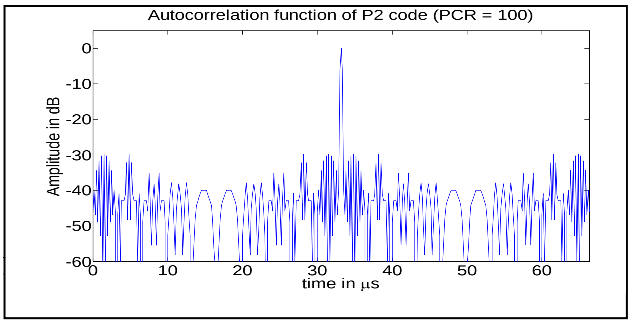

Fig 3. Autocorrelation function of P2 code

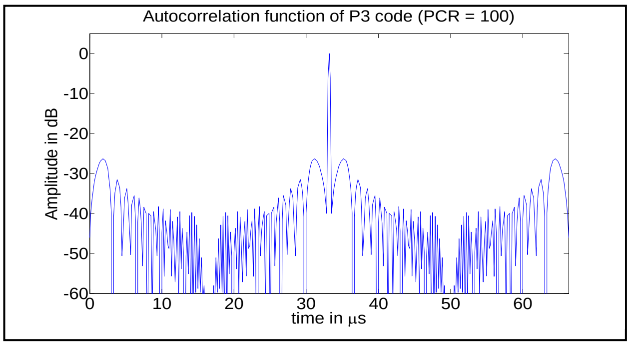

Fig 4. Auto-correlation function of P3 code

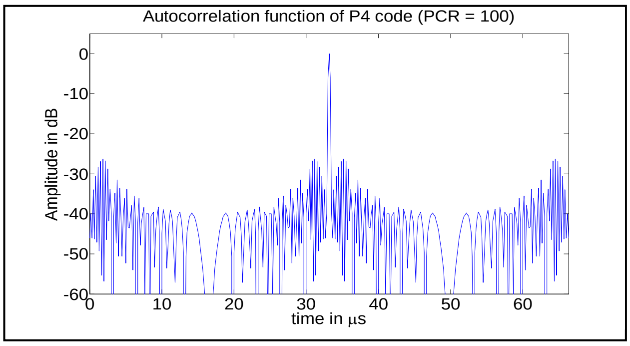

Fig 5. Auto-correlation function of P4 code

Peak Side Lobe Ratio (PSLR) for a PCR = 100				
Frank	P1	P2	P3	P4
-30 dB	-30 dB	-30 dB	-26.3 dB	-26.3 dB

Table 1. PSLR of Polyphase codes

It is evident from the simulation that, the Peak Side Lobe Ratio (PSLR) of P3 and P4 codes are higher than that of Frank, P1 and P2 codes by 3.7 dB at a PCR = 100.

IV. DOPPLER TOLERANCE OF POLYPHASE CODES

Any pulse compression code will exhibit some sensitivity to Doppler and to the number of bits used to represent elements of the sequence. In pulse Doppler Radars matched filtering is performed in receiver which involves the computation of cross-correlation of the received waveform and reference signal for signal detection. Because of the Doppler shift introduced by the moving targets matched filter performance will decrease. Doppler tolerance describes the maximum obtainable Doppler shift for a known waveform such that still a correlation peak bigger than threshold is achieved.

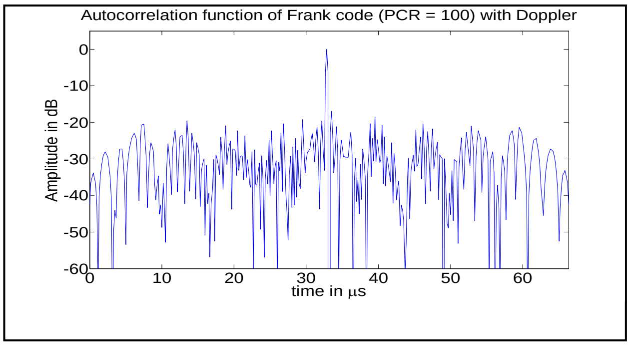

Fig 6.Doppler tolerance of Frank code

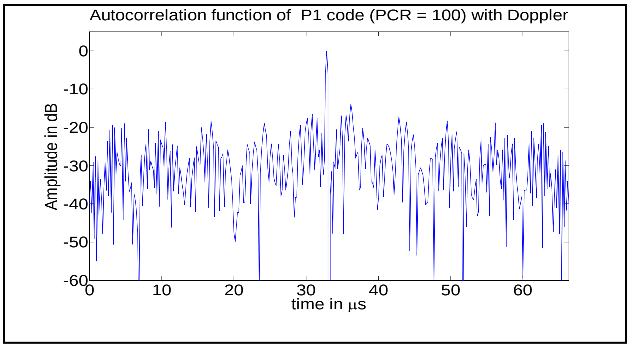

Fig 7. Doppler tolerance of P1 code

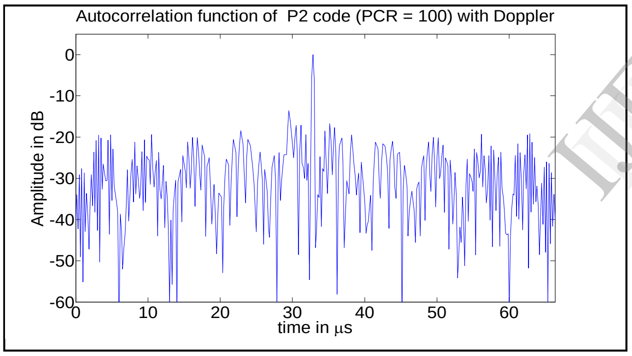

Fig 8. Doppler tolerance of P2 code

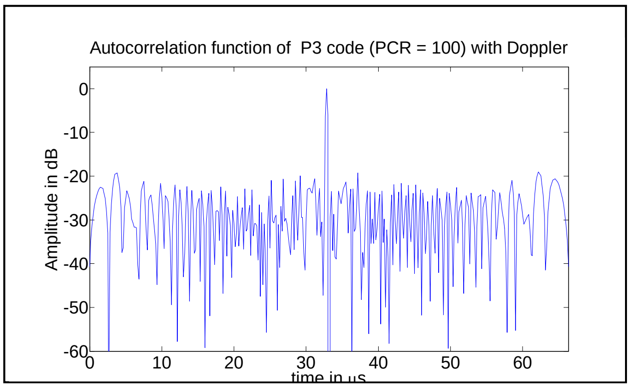

Fig 9. Doppler tolerance of P3 code

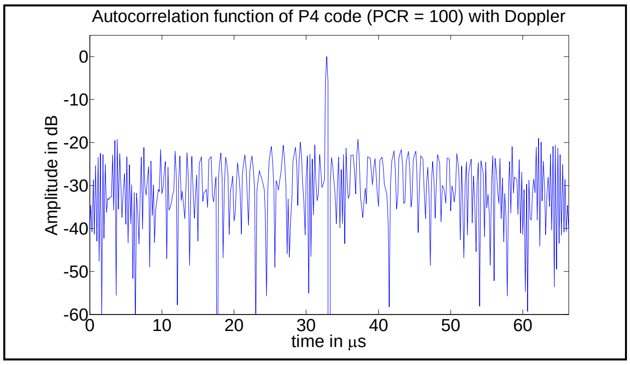

Fig 10. Doppler tolerance of P4 code

Figures [6-10] shows the matched filter response by auto-correlation of Polyphase codes in the presence of Doppler frequency shift of 30 KHz.

PSLR with Doppler for a PCR = 100				
Frank	P1	P2	P3	P4
-16.9 dB	-13.9 dB	-13.6 dB	-19.3 dB	-19.3 dB

Table 2. PSLR of Polyphase codes with Doppler

It is evident from the above Table 1 and 2 that P3 and P4 codes have better Doppler tolerance compared to Frank, P1 and P2 codes.

V. PRE-COMPRESSION BAND-LIMITING EFFECTS ON POLYPHASE CODES

Before the application of pulse compression algorithm, the base band signal will be undergoing band-limiting to minimize the effect to out-of-band noise. If a receiver designed so that it has an approximate rectangular bandwidth with respect to 3-dB bandwidth of the received waveform, the received waveform contains errors and mismatch occur later in the pulse compression stage. This band-limiting would normally occur before sampling process in order to prevent noise and aliasing effects. The result of any band-limiting is to smooth the vectors constituting the coded waveform. This weighing causes an unwanted mismatch with the pulse compressor which results in a degradation of the sidelobe level.

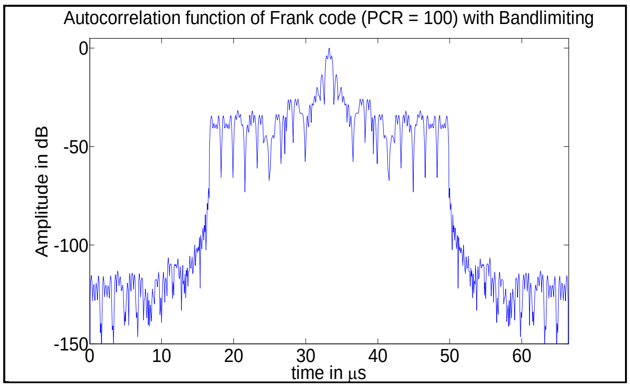

Fig 11. Bandlimiting effects on Frank code

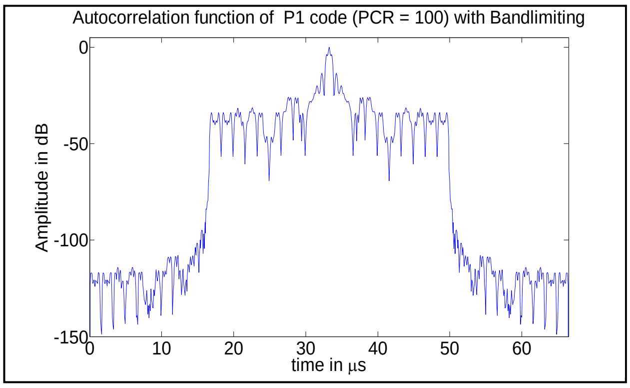

Fig 12. Bandlimiting effects on P1 code

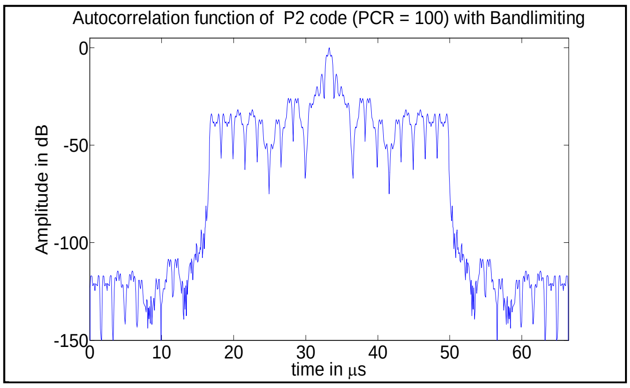

Fig 13. Band-limiting effects on P2 code

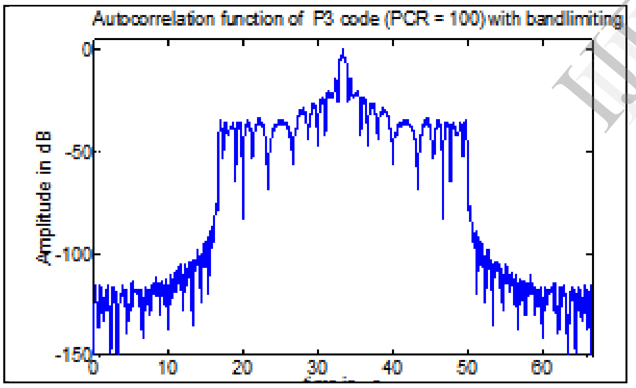

Fig 14. Band-limiting effects on P3 code

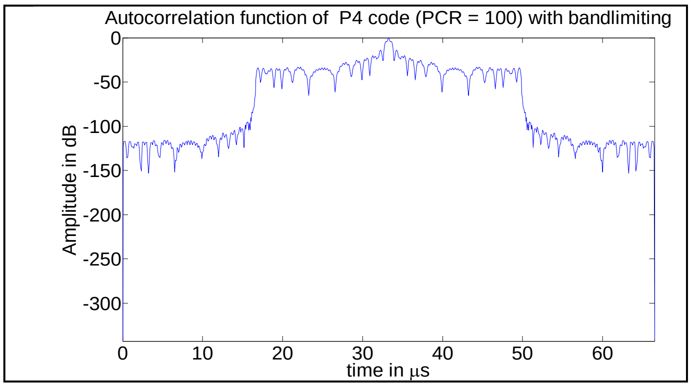

Fig 15. Band-limiting effects on P4 code

Figures [11-15] shows the matched filter response of Polyphase codes in the presence of pre-compression bandlimiting. Sampling rate chosen was 4 times the bandwidth to improve the time resolution.

Bandlimiting effects for a PCR = 100					
	Frank	P1	P2	P3	P4
PSLR (dB)	-13.4	-13.5	-13.5	-13.8	-13.8
Range Resolution (m)	125	125	125	125	125

Table 3.Band-limiting effects on Polyphase codes

The band-limiting filter carries out a smoothing process that combines the slower varying phase terms resulting in the increased side lobes close to the end of the code. Band-limiting also widens the main lobe, which reduces the range resolution. Polyphase codes given in the Table 3 are designed for a range resolution of 50 m, but due to bandlimiting process the actual range resolution resulted is 125 m.

VI. SUMMARY

Pulse compression permits us to trade-off between the average transmitted power of a reasonably long pulse and the range resolution corresponding to a short pulse. Polyphase codes for pulse compression applications are investigated and a comparison between different Polyphase codes (Frank, P1, P2, P3 and P4) is analyzed with respect to main lobe width, side lobe reduction Doppler tolerance and pre-compression band-limiting effects are analyzed by means of simulation.

It is clear that Peak Side Lobe Ratio (PSLR) of P3 and P4 codes are higher than that of Frank, P1 and P2 codes by 3.7 dB at a PCR = 100, range resolution of 50m.

It is evident from the Table 1 and 2 that P3 and P4 codes have better Doppler tolerance compared to Frank, P1 and P2 codes. The better Doppler tolerance of P3 and P4 codes allows large time-bandwidths to be effective even in the presence of high Doppler shifts on received signal.

Pre-compression band-limiting widens the main lobe, which reduces the range resolution. Pre-compression band-limiting results in the increased side lobes close to the end of the code.

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