Optimum Side Lobe Magnitude Estimation of Different Pulse Compression Techniques for RSP

Anil Kumar.A[1] Hanumanthappa.S.N[2]
[1]M.Tech. Student (DCN) [2]Assistant Professor
[1,2]Department of Electronics and Communication Engineering
[1,2]UBDT College, Davangere, Karnataka, India

Abstract— Pulse compression permits radar signal transmission to use long coded internal modulation waveforms in order to accomplish long range detection and concurrently gets the high range resolution by processing of the reflected echo to accumulate the long coded waveform energy in to narrow pulse. Range resolution is the ability to separate closely spaced targets. The shorter pulse width waveform transmission improved in the range resolution. But, if the pulse width is decrease, the quantity of energy in the pulse is decreased and maximum range finding gets reduced. Hence development of best PC technique to avoid this difficulty.

Key words: Pulse Compression (PC), Biphase Codes, Polyphase Codes, LFM, Matched Filter, Peak Side Lobe Level (PSL)

I. INTRODUCTION

Radar signal processing (RSP) is defined as the manipulation of the received echo signal from the object and represented in digital format to obtain the desired echo information while rejecting needless signals. Pulse compression signal processing acceptable the use of long waveform to achieve high energy at the same time achieves the resolution of a short pulse by internal modulation of a long time pulse with reduced transmitter peak power. The resolution is defined as capability of radar to differentiate between closely spaced targets [2]. When the transmitted signal is frequency or phase modulated waveform signal and received signal is processed using a exact filter called "matched filter". A filter is a linear network it maximizes the signal to noise ratio of radar receiver which in turn maximizes the detect ability of a target. In the matched filtering results in range or peak and side lobes which may be mask weak targets. In the frequency domain matched filtering Side lobes are the part of the pulse compression [5]. Comparison of Analog and Digital Pulse

Compression Techniques [1], in this they developed only two techniques to estimate side lobes. Hence in this paper, we development of optimum sidelobe magnitude estimation of different pulse Compression techniques for RSP, methods like linear frequency modulation and phase coded PC techniques. In this Comparison of PSL levels (magnitude) and then deciding best pulse compression technique.

II. PULSE COMPRESSION RADAR

Pulse compression is widely used in radar systems to increase the return energy (high strength reflected echo) without an increase in peak power through long duration pulse with sufficient time bandwidth otherwise it gets attenuated during the period of transmission. The energy content in the pulse is proportional to the product of duration (time) of the pulse and peak power of the pulse this product gives estimation of energy E=TB, where T is time, B is bandwidth. A low peak power pulse with long duration pulse provides the same energy as achieved in case of high peak power and short duration pulse $P_1\tau_1 \cong P_2\tau_2$. After pulse compression process shorter duration pulses achieves better range resolution R_{res} is given by

$$R_{res} = \frac{C}{2B} \quad (1)$$

Where, "C" is the speed of propagation of electromagnetic energy (speed of light) and "B" is band width of the pulse [2].

For un-modulated pulse, the time duration is inversely proportional to the bandwidth (TB=1or T=1/B). if the bandwidth is high then the time duration of the pulse is shorter, hence it offers a more resolution. In case of modulated pulse time band width product is greater than one (TB>>1). High peak power required for very short pulse to transmit a longer distance. However, to handle high peak power the radar equipment become bigger and cost of the system increases. This is the limitation of the transmitter. Pulse having a low peak power and longer duration pulse is modulated and transmitted at the transmitter for long range detection.

At the receiver output the pulse should have short width and high peak power to get better range resolution. "Fig.1" shows that two pulses have same energy with different pulse width and peak power and Long pulse for long range detection and short pulse for high range resolution

$$\tau_1 \ll \tau_2 \text{ and } P_1 \gg P_2$$

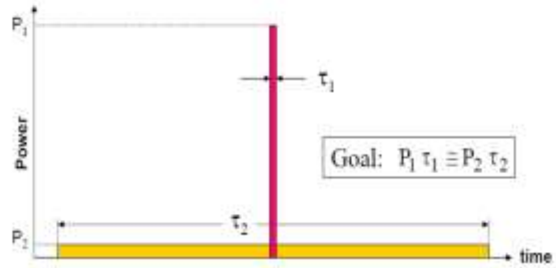

Fig. 1: Transmitter pulse and Receiver pulse ultimate signals

The range resolution depends on the bandwidth of a pulse but not depends on duration of the pulse. We have some modulation techniques such as LFM, barker code and polyphase codes are used to increase the bandwidth of a long duration pulse to obtain high range resolution having limited long pulse peak power. In pulse compression technique a pulse having long time duration and low peak power is modulated either in linear FM or phase coded signals before transmission and at the receiver side, received signal is passed through a matched filter to accumulate (convert) the energy in a short duration pulse. The pulse compression ratio is defined as

$$PCR = \frac{\text{width of the pulse before compression}}{\text{width of the pulse after compression}}$$

Or, pulse compression ratio (PCR), $N = T/\tau \approx BT$, where B=1/ τ=bandwidth [2].

III. DIGITAL MATCHED FILTER

The matched filter is a pulse compression process in radar digital signal processing at receiver. The digital Compressor employs fast convolution and takes the advantages of fact that convolution in time domain equivalent multiplication in frequency domain.

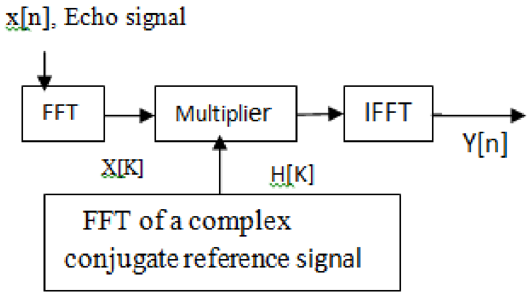

Fig. 2: Digital matched filter

Where, x(n) is a received echo signal after digitization

$$X[K]=FFT\{x(n)\}, \quad H[k] = FFT\{x^*(-n)\}$$

$$Y[k] = X[k]H[k], \quad y(n)=IFFT\{Y[K]\} \qquad (2)$$

Where, the FFT and IFFT operations are used to shorten the correlation function. Frequency domain matched filter involves the multiplication in frequency domain of spectrum of received echo and a use of complex conjugate of time delay of transmitted reference waveform [4].

IV. LINEAR FREQUENCY MODULATION

Practically in the radar system employs LFM Signals to track and detect the target objects. LFM chirp signals easer to generate and its PC output shape and SNR are fairly insensitive to Doppler shifts [3]. Real and imaginary parts of LFM equation is given by

$$\exp[j\emptyset(t)] = \cos\emptyset(t) + j\sin\emptyset(t) \qquad (3)$$

Therefore, the real and imaginary parts of linear FM transmitted signal in time domain is given by $S(t) = e^{j\emptyset(t)}$, where, the instantaneous phase of the chirp signal is $\emptyset(t) = 2\pi(f_o t + \frac{1}{2}kt^2)$

Where, f_o = carrier frequency, K= frequency sweep rate related to pulse duration 'T_P or T' and$K = \frac{B}{T_P}$,

B= band width, T_P=pulse width duration [6]

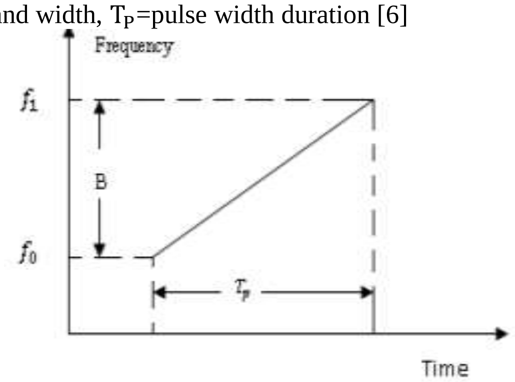

Fig. 3: Instantaneous frequency of Linear FM over Time

The real and imaginary parts of Linear FM transmitted waveforms in time domain will be

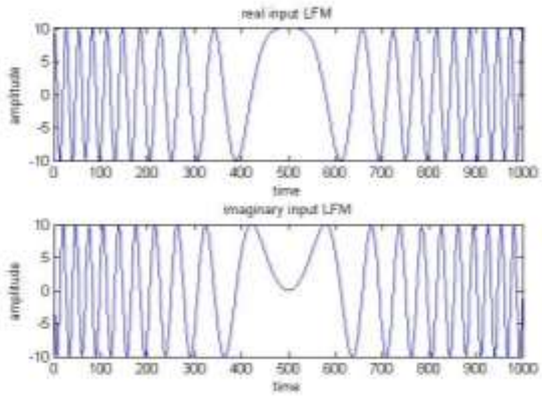

Fig. 4(a): Real and Imaginary part of LFM

The spectrum of radar received echo and LFM transmitted signal as a reference signal spectrum fig.4 is achieved by Fast Fourier Transform (FFT) [4]

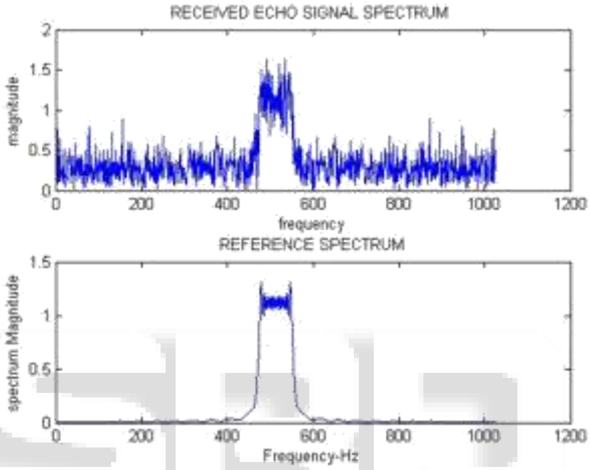

Fig. 4: Received echo spectrum with noise and frequency reference spectrum

V. BARKER CODE PULSE COMPRESSION

Barker code is one of the special types of pulse compression technique, this code is also known as phase coded signal

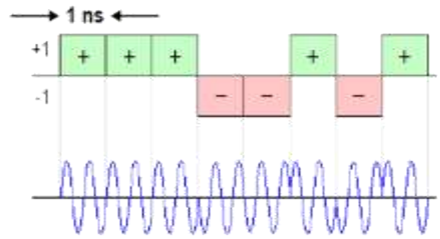

Fig. 5: Barker code with BPSK modulation

Biphase code consists of a sequence of sub-pulse that has +1 and -1 .the phase of the transmitted waveform is 0° phase (amplitude of +1 volt) as either "1" or "+"and alternatively, a sub pulse with phase is equal to180° or π (amplitude of -1 volt) characterized either "0" or "–''. The phase coded signal is discontinuous at the point of phase reversal [7] shown in fig.5.

In Biphase Codes the selection of random phase 0 or π is a difficult task. The phases are selected so that the matched filter output of the Code has lower side lobes. Barker Codes are the special type of binary Codes having side lobes of unity magnitude. Exhaustive computer based search reveals that the Barker Codes are available for the length of 2, 3, 4, 5, 7, 11 and 13 only.

Sl No	CODE LENGTH	CODE ELEMENT	PSR in (dB)
1	2	1 -1,1 1	-6.0
2	3	1 1 -1	-9.5
3	4	1 1 -1 1, 1 1 1 -1	-12.0
4	5	1 1 1 -1 1	-14.0
5	7	1 1 1 -1 -1 1 -1	-16.9
6	11	111-1-1-11-1-11-1	-20.8
7	13	11111-1-111-1111	-22.3

Table 1: Barker code table for different lengths

The Barker Codes along with their side lobe reduction values are given in Table 1. The Barker Code have maximum compression ratio 13 and highest PSL magnitude is -22.3dB PSL= $20\log_{10}(N)$. Barker codes are the sequence of bits used to generate the BPSK signal.

Table.1 listed of different types of barker code sequences available for the generation of BPSK signal [7].

VI. POLYPHASE CODING

If the pulse is allowed to take more than two phase values, it is known as polyphase codes. In this section the polyphase codes namely Frank code, P1, P2 and P3, P4 codes and their properties are described [4].

A. Frank Code

Frank code is derived from a step approximation to a linear frequency modulation waveform using N frequency steps and N samples per frequency. Hence length of frank code is $N^2 = M$. The phases of the frank code are obtained by multiplying the elements of the matrix "A" by phase $(2\pi/N)$ and by transmitting the phases of row1 by row2 and so on [5].

$$A = \begin{bmatrix} 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 2 & \cdots & (N-1) \\ 0 & 2 & 4 & \cdots & 2(N-1) \\ 0 & 3 & 6 & \cdots & 3(N-1) \\ \cdot & & & & \\ \cdot & & & & \\ 0 & (N-1) & 2(N-1) & \cdots & (N-1)^2 \end{bmatrix}$$

If "i" is the number of the sample in a given frequency, the phase of the ith sample of the jth frequency is

$$\emptyset i,j = 2\pi/N(i-1)(j-1) \qquad (4)$$

Where, i=1, 2,……, N and j=1, 2,…,N.

$$\mathrm{PSL} = 20\log_{10}\left(\frac{1}{N\pi}\right)$$

$$\mathrm{PSL} = 20\log_{10}\left(\frac{1}{10\pi}\right) = -29\mathrm{dB} \qquad (5)$$

B. Polyphase Code One (P1code)

The P1 code also consists of $N \times N$ eliments

$$\emptyset_{i,j} = -\left(\frac{\pi}{N}\right)[N-(2j-1)]\begin{bmatrix}(j-1)N + \\ (i- \quad 1)\end{bmatrix} \qquad (6)$$

Where, i and j =1,2,3,…………,N. PSL in dB of P1code is same as prank code [5]

C. Polyphase Code Two (P2 Code)

P2 polyphase code has the same phase increments within each group (segment) as the p1 code except that the starting phase are different.

P2 code hase N^2 =M eliments and the phase of i_{th} eliment of the j_{th} group is represented as

$$\emptyset_{i,j} = \left(\frac{\pi}{2N}\right)[N-2i+1][N-2j+1] \qquad (7)$$

Where, i and j =1,2,3,…………,N. PSL in dB is same as frank, P1 and P2 code and It offers Doppler intolerance and low PSL [5].

D. Polyphase Code Three (P3code)

P3 and P4 codes have been derived from approximation to linear frequency modulation waveform. The doppler intolerance of the frank code, P1 and P2 codes. Next of this to dovelope the P3 and P4 codes, which exhibits a doppler tolerance similar to LFM waveform

$$\emptyset_i = \pi/N(i-1)^2 \qquad (8)$$

Where, i=1,2,..,N and N is sequence length [5].

$$\mathrm{PSL} = 20\log_{10}\sqrt{\frac{2}{N\pi^2}} \quad (\mathrm{dB}) = -26\mathrm{dB}$$

E. Polyphase Code Four (P4 Code)

P4 code phase sequence is given by

$$\emptyset_i = \pi/N(i-1)(i-N-1)$$

Where, i=1,2,3,……….,N and The peak sidelobe levels in dB of P3 and P4 code is a bit smaller than the frank, P1, P2 codes listed in table 2. P3 and P4 code is more intolerant [5].

VII. RESULTS AND DISCUSSIONS

The purpose of a Pulse Compression technique is to accomplish considerable low PSL and suitable range sidelobes in an inexpensive way. The types of waveforms used in the technique choose the cost and complexity of the Radar system. Using MATLABR2013a as simulator tool to develop code and simulation to study the three techniques.

A. LFM Simulation

The PSL achieved here is -13.45dB and the main lobe width is very large shown in fig.7. Such a wide PSL can affect masking of weaker targets. Also the mainlobe is relatively wide. The narrower the pulse width the superior is the range resolution.

So it shows that the range resolution of LFM Code is set up to be very poor and very high side lobs.

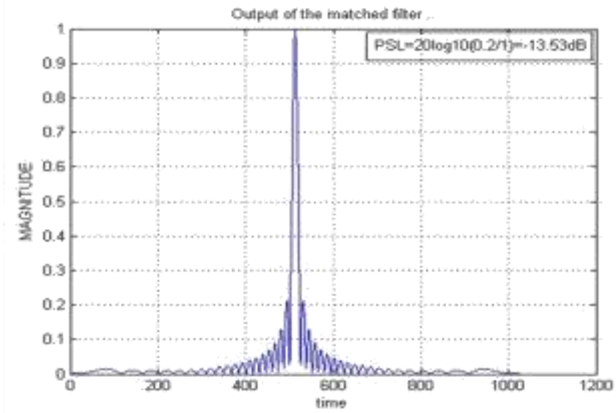

Fig. 6: Compressed output for LFM Code.

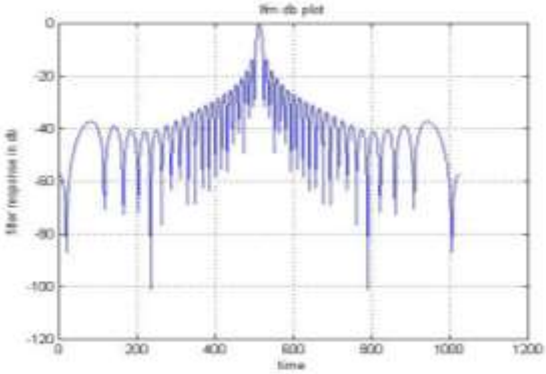

Fig. 7: shows dB plot for LFM Code

B. Barker Code Simulation

It shows from this fig.8 that the PSL of Biphase Code is -22.28dB which is lesser than that of Linear FM Code and mainlobe width of Biphase Code is decreased and is comparatively narrow. This shows that the Biphase Code has superior range resolution compared to LFM Code. Barker code 13 has high compression ratio $PSL = 20\log_{10}(N) = -22.3\text{dB}$ it is theoretical value.

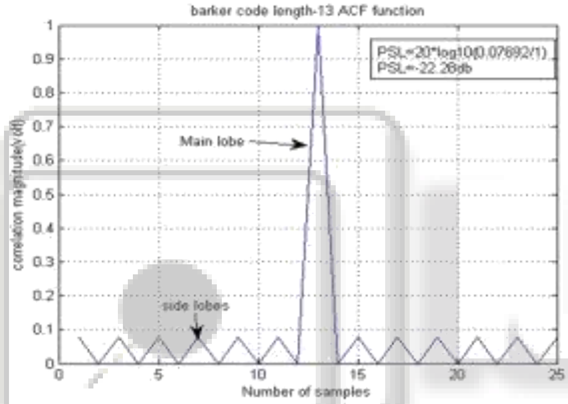

Fig. 8: PSL for Barker Code length N=13

C. Polyphase Code Simulation

Polyphase codes below figures shows that fig.9, 10, 11 which is -27.56dB these polyphase codes has very narrow mainlobe width similar to P3 and P4 Codes, but difference in PSL in dB, PSL in dB of frank, P1 and P2 codes are more, compared to P3 and P4 code. Hence Frank, P1 and P2 Codes contain good range as a result weaker targets are also Prevented from masking and increased resolution but this codes process Doppler intolerance however P3 and P4 codes process Doppler tolerance.

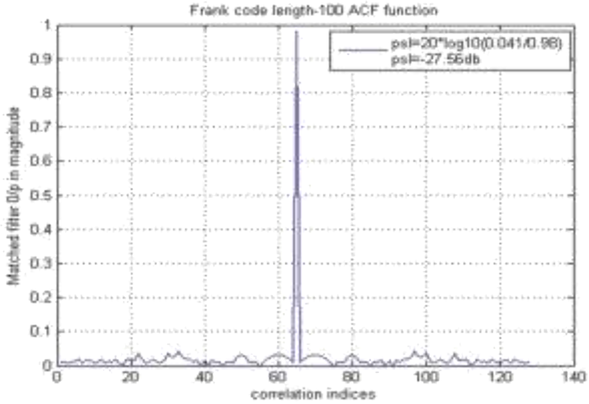

Fig. 9: PSL for Frank Code N=10, M=100

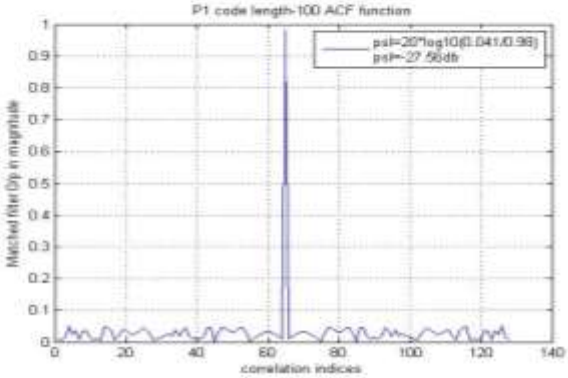

Fig. 10: PSL for P1 Code N=10, M=100

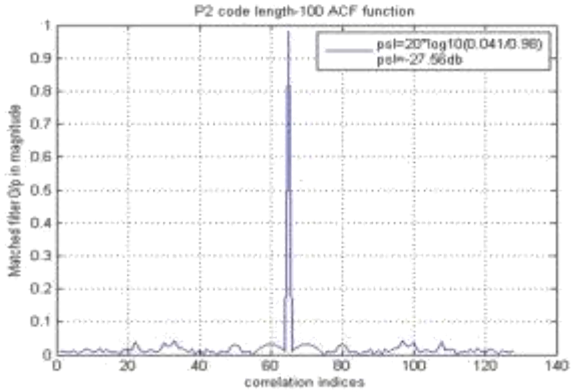

Fig. 11: PSL for P2 Code N=10, M=100

Fig.12 and 13 shows narrow main lobe width similar to Frank, P1 and P2 Codes, PSL in dB is obtained from P3 and P4 code is -25.45dB less than that of Frank, P1 and P2 Codes and also PSL is very small compared to first three polyphase techniques listed in table.2.

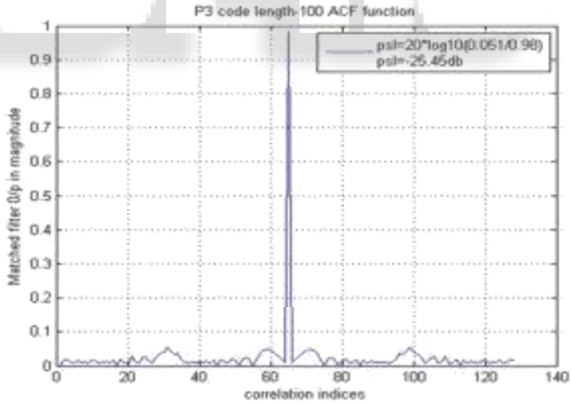

Fig. 12: PSL for P3 Code N=10, M=100

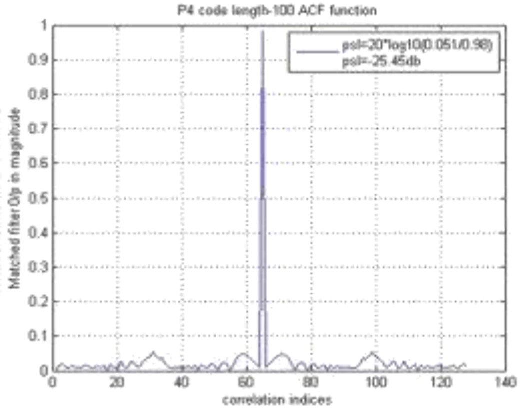

Fig. 13: PSL for P4 Code N=10, M=100

Table.2 shows results obtained for PSL in dB and side lobe voltage levels for Polyphase Codes, Biphase and LFM codes. Pulse Compression Codes in the table peak side-lobe ratio (PSR) in dB value decreases then the sidelobe levels increases or side lobe voltage levels will increase.

Sl no	PC Techniques	PSL in volts (Magnitudes)	PSL or PSR in dB
1	Frank code	0.041	-27.56
2	P1 code	0.041	-27.56
3	P2 code	0.041	-27.56
4	P3 code	0.051	-25.45
5	P4 code	0.051	-25.45
6	Barker code	0.077	-22.21
7	LFM code	0.2	-13.45

Table 2: Comparison of PSL (dB) and side lobe voltages for different Pulse Compression Codes

VIII. FUTURE SCOPE

PC of LFM and P3, P4 codes through matched filter produces high level side lobes which mask the weak targets but this codes is better in Doppler tolerance and easy to generation and widely used codes. Hence in this future work will be minimizing these side lobes by using different types of windowing techniques.

IX. CONCLUSION

In this paper, we proposed PC allows utilizing a reduced transmitter power and still achieving the preferred range resolution. The dissimilar Pulse Compression techniques called LFM, Barker code and Polyphase Codes are recognized and pleasing into consideration the significant parameters that is mainlobe width, range resolution and PSL. All the results of the simulations demonstrated (listed in table.2) that Polyphase Codes have lowest Peak Sidelobe Level (PSL) compared to Barker Codes, LFM Codes. Barker code is eliminated because of limited number of code length. Polyphase Codes contain improved range resolution compared to LFM and the mainlobe width is wider for LFM but the quantity of range sidelobes are less compared to the other Codes. So Polyphase Codes are preferable in Radar Pulse Compression suitable to superior range resolution and lowest PSR and Doppler tolerance.

REFERENCES

[1] Md. Maynul Islam[1], Md. Roman Sarker[2], Md. Tanjilul Alam[3] and Gp Capt Dr Mohammed Hossam-E-Haider[4], "Comparison of Analog and Digital Pulse Compression Technique and Reduction of Side lobes Using Transversal Filter", 978-1-4799-4819-2/14/$31.00 ©2014 IEEE
[2] ThinThin Mar[1], Su Su Yi Mon[2], "Pulse compression method for radar signal processing" international Journal Of Science and Engineering Applications, volume 3 Issue 2, 2014, ISSN-2319-7560.
[3] K.L.priyanka[1], Sujatha Ravichandran[2], N.Venkatram[3], "pulse compression techniques for target detection" International Journal Of computer applications, volume 96-No.22, June 2014.
[4] Mark A, Richards[1], James A.Schees[2], William A. Holm[3], "principles of modern radar" Vol. 1: Basic principles, copyright @ 2010 by scitech publishing.
[5] Phillip E. Pace, "Detecting and Classifying Low Probability of Intercept Radar", second edition Artech House, 2009
[6] M. Archana[1], M. Gnana priya[2] "Low Power LFM Pulse Compression RADAR
[7] With Sidelobe suppression" IJAREEIE Vol. 3, Issue 7, July 2014
[8] Bassem R.mah "Radar Signal Analysis and Processing Using Matlab" 2009 by chapman & hall/crc.