International Journal Of Advance Research, Ideas And Innovations In Technology

ISSN: 2454-132X
Impact factor: 4.295
(Volume 3, Issue 6)
Available online at www.ijariit.com

Phase Coded Radar Signals – Frank Code & P4 Codes

B. Shubhaker
Assistant Professor
Electronics and Communication Engineering,
St. Martin's Engineering College, Hyderabad, Telangana
shubhaker.subbu@gmail.com

Abstract: ***This dissertation presents an overview of phase coded radar signals based on frank codes and p4 codes used in target detection techniques. For good range detection, high SNR is required. So matched filter is used in the processing of radar signals which maximizes the peak signal power to mean noise ratio. In this analysis, the ambiguity function plays an important role. Using ambiguity diagrams and auto correlation functions, various waveforms are compared in terms of PSL (peak side lobe level). Ambiguity diagrams are obtained by using MATLAB code. Primarily simple pulse has been taken but it has some drawbacks like poor range resolution, poor Doppler resolution, so pulse burst waveforms were taken and it has given better Doppler resolution than simple pulse with some range resolution.***

To improve the range resolution further, LFM (Linear Frequency Modulation) is used. The idea here is to sweep the frequency band B linearly during the pulse duration T. It provides better range Resolution. To reduce the side lobe levels further Weighting techniques are used for LFM, the presented weighting techniques are Hamming and Hanning. Because of these weighting techniques, PSL is reduced by -14.4 dB but the resultant is range doppler coupling and side lobes, as it is a drawback, NLFM (non-linear Frequency Modulation) is used which provides lower side lobes when compared to LFM.

In NLFM the 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. NLFM provides the better sidelobe levels compared to the LFM, and the performance characteristics of the NLFM waveforms for sawtooth frequency coding are studied. NLFM waveforms are sensitive to Doppler frequency shift and are not Doppler tolerant. The major limitations are system complexity, limited development of NLFM generating devices and stringent phase control requirements.

With short pulse, short range target detection is done efficiently but for long range, detection resolution decreases. Hence, the research work proceeded to other waveforms with high duration but the drawback is range resolution. To improve the range resolution, pulse compression technique is used and this can be achieved by frequency coding and phase coding. In this dissertation phase coding is employed for pulse compression of the signals and it is of two types named binary phase codes and poly phase codes.

For Barker code of length 7, a sidelobe level of -16.9 dB is obtained, Barker code of length 11, a sidelobe level of -20.82 dB and Barker code of length 13, a sidelobe level of -22.27 dB is obtained. Here the Barker code is limited to 13 and sensitive to doppler shift. So to reduce the sidelobe level further Frank code has been introduced.

Frank code is derived from Barker code and it is a square length sequence. The Frank code is derived from a step approximation to a linear frequency modulation waveform using M frequency steps and M samples per frequency. The Frank code has a length or processing gain of $N_c=M^2$***. For a Frank code of length 16, a sidelobe level of -21.07 dB is obtained but this code is limited up to the maximum length of 139.***

P4 code belongs to polyphase code. It has no restriction on code elements, and are normally derived from the phase history of frequency modulated pulse generated, which is used for any length of the sequence and it has provided the sidelobe level of -31.4089 dB. It provides a better sidelobe level and Doppler resolution.

Keywords: Matched Filter, Ambiguity Function, Autocorrelation, Peak Sidelobe Level, Polyphase codes and weighting functions.

I. INTRODUCTION

RADAR is an abbreviation for Radio Detection and Ranging [10]. It is an object-detection system which uses electromagnetic waves specifically radio waves to determine the range, altitude, direction or speed of both moving and fixed objects such as aircraft , ships, spacecraft , guided missiles, motor vehicles, weather formations, and terrain. The radar dish or antenna transmits pulses of radio waves or microwaves which bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna which is usually located at the same site as the transmitter. The modern uses of radar are highly diverse, including air traffic control, radar astronomy, and aircraft anti-collision systems, anti-missile [4].

1.1 Radar Block Diagram and Operation

Pulsed radar, the block diagram is shown in Fig. 1.1, describes the flow of signals through each of its modules. The detailed explanation has given for each and every block.

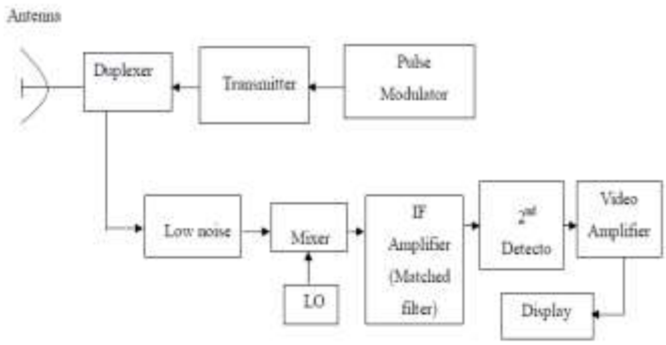


Fig. 1.1 Block diagram of pulsed Radar

The transmitter may be an oscillator, such as a magnetron, that is "pulsed"(turned on and off) by the modulator to generate a repetitive train of pulses. The magnetron has probably been the most widely used of the various microwave generators for radar. A typical radar for the detection of aircraft at ranges of 100 or 200 nmi might employ a peak power of the order of a megawatt, an average power of several kilowatts, a pulse width of several microseconds, and a pulse repetition frequency of several hundred pulses per second [4].

The waveform generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space. A single antenna is generally used for both transmitting and receiving. The receiver must be protected from damage caused by the high power of the transmitter. This is the function of the duplexer. The duplexer also serves to channel the returned echo signals to the receiver and not to the transmitter. The duplexer might consist of two gas-discharge devices, one known as a TR (transmit-receive) and the other an ATR (anti-transmit-receive). The TR protects the receiver during transmission and the ATR directs the echo signal to the receiver during the reception. Solid-state ferrite circulators and receive protectors with gas-plasma TR devices and/or diode limiters are also employed as duplexers [4].

The receiver is usually of the super-heterodyne type. The first stage might be a low-noise RF amplifier, such as a parametric amplifier or a low-noise transistor. However, it is not always desirable to employ a low-noise first stage in radar. The receiver input can simply be the mixer stage, especially in military radars that must operate in a noisy environment. Although a receiver with a low-noise front-end will be more sensitive, the mixer input can have greater dynamic range, less susceptibility to overload, and less vulnerability to electronic interference [4].

The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency (IF). A " typical" IF amplifier for an air-surveillance radar might have a centre frequency of 30 or 60 MHz and a bandwidth of the order of one megahertz. The IF amplifier should be designed as a notched filter; i.e., its frequency-response function H (f) should maximize the peak-signal-to-mean-noise-power ratio at the output. This occurs when the magnitude of the frequency-response function $|H(f)|$ is equal to the magnitude of the echo signal spectrum $|S(f)|$, and the phase spectrum of the matched filter is the negative of the phase spectrum of the echo signal. In a radar whose signal waveform approximates a rectangular pulse, the conventional IF filter bandpass characteristic approximates a matched filter when the product of the IF bandwidth B and the pulse width τ is of the order of unity, that is, $B\tau \approx 1$ [4].

After maximizing the signal-to-noise ratio in the IF amplifier, the pulse modulation is extracted by the second detector and amplified by the video amplifier to a level where it can be properly displayed, usually on a cathode-ray tube (CRT) [4].

The basic principle of radar is simple to understand. A transmitter generates an electro-magnetic signal (such as a short pulse of a sine wave) that is radiated into space by an antenna. A portion of the transmitted signal is intercepted by a reflecting object (target) and is re-radiated in all directions. It is the energy re-radiated in a back direction that is of prime interest to the radar. The receiving antenna collects the returned energy and delivers it to a receiver, where it is processed to detect the presence of the target and to extract its location and relative velocity. The distance to the target is determined by measuring the time taken for the radar signal to travel to the target and back. The range is,

$$R = cT_R/2 \qquad \textbf{(1.1)}$$

Where T_R is the time taken by the pulse to travel to target and return, c is the speed of propagation of electromagnetic energy (speed of light). Radar provides the good range resolution as well as long detection of the target [4].

II. METHOD OF APPROACH

1. Matched Filter

A network whose frequency-response function maximizes the output peak-signal-to-mean noise (power) ratio is called a matched filter. Which in turn maximizes the detect ability of a target.

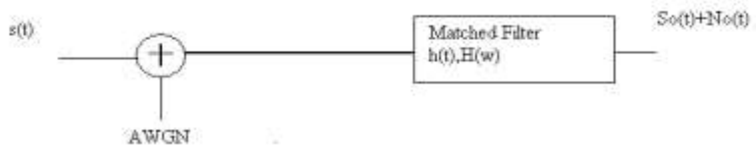


Fig1: Matched Filter Definitions

2. Ambiguity Function

The ambiguity function (AF) represents the time response of a filter matched to a given finite energy signal is received with a delay τ and a Doppler shift υ relative to the values(zeros) expected by the filter.

$$|\chi(\tau,\upsilon)| = \left|\int_{-\infty}^{+\infty} u(t)\, u*(t+\tau)\exp(j2\pi\upsilon t)dt\right|$$

3. Pulse Compression

Increasing the duration of the transmitted waveform results in an increase of the average transmitted power and shortening the pulse width results in greater range resolution. Pulse compression is a method that combines the best of both techniques by transmitting a long coded pulse and processing the received echo to get a shorter pulse. The transmitted pulse is modulated by using frequency modulation or phase coding in order to get the large time-bandwidth product. There are two types of frequency modulation.

i. Linear Frequency Modulation.
ii. Non-Linear Frequency Modulation.

i. Linear Frequency Modulation

The basic idea is to sweep the frequency band *B* linearly during the pulse duration T. the complex of a linear-FM pulse is given by

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

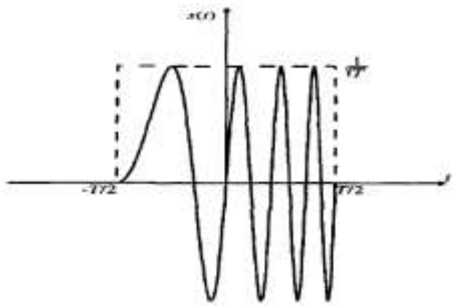


Fig: Linear-FM Signal

ii. Non-linear frequency modulation

In linear FM the transmitter spends equal time at each frequency, hence the nearly uniform spectrum. 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).

4. Phase Coding

In this form of pulse compression, a long pulse of duration T is divided into N sub-pulses each of width τ. An increase in bandwidth is achieved by changing the phase of each sub-pulse. The phase of each sub-pulse is chosen to be either 0 or π radians or they can be harmonically related. The output of the matched filter will be a spike of width τ with an amplitude N times greater than that of long pulse. Phase coding can be either

i. Binary Phase Coding (Bi-phase Coding)
ii. Polyphase Coding.

The complex envelop of the phase coded pulse is given by

$$u(t) = \frac{1}{\sqrt{T}} \sum_{m=1}^{N} u_m \, \mathrm{rect}\left[\frac{t-(m-1)t_b}{t_b}\right]$$

Where u_m = exp(j$\emptyset_m$) and the set of N phases [$\emptyset_1$, $\emptyset_2$,$\emptyset_3$,…..,$\emptyset_N$] is the phase code associated with u(t).

i. Bi-Phase Coding

The binary choice of 0 or π phase for each sub-pulse may be made at random. The binary phase-coded sequence of 0, π values that result in equal side-lobes after passes through the matched filter is called a Barker code. This is a Barker code of length 13.

ii. Polyphase Codes

Allowing any phase value (non-binary) can lead to lower side-lobes. The polyphase sequence with minimal peak-to-side lobe ratio excluding the outermost side-lobes is called generalized Barker sequence or polyphase Barker. Frank proposed a polyphase code with good non-periodic correlation properties and named the code as Frank code

5. Construction of Frank Code And P4 Code

i. Construction of Frank Code

The Frank code is derived from a step approximation to a linear frequency modulation waveform using N frequency steps and N samples per frequency. Hence the length of Frank code is N^2. The Frank coded waveform consists of a constant amplitude signal whose carrier frequency is modulated by the phases of the Frank code.

The phases of the Frank code is obtained by multiplying the elements of the matrix A by phase (2π/N) and by transmitting the phases of row1 followed by row 2 and so on.

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

The phase of the i^{th} code element in the j^{th} row of code group is computed as

$$\emptyset_{i,j} = \left(\frac{2\pi}{N}\right)(i-1)(j-1)$$

Where *i* and *j* range from 1 to N.

Frank code has a peak side lobe level (PSL) ratio of -29.79dB which is approximately 10dB better than the best pseudorandom codes.

i. Construction of P4 Code

The P4 Code is conceptually derived from the same waveform as the P3 Code. However, in this case, the local oscillator frequency is set equal to f_o + kT/2 in the I,Q detectors. With the frequency, the phases of successive samples taken t_c apart are

$$\emptyset_i^{p4} = 2\pi \int_0^{(i-1)tc} \left[(f_0 + kt) - \left(f_0 + \frac{kT}{2}\right)\right] dt$$

$$= 2\pi \int_0^{(i-1)tc} k\left(t - \frac{T}{2}\right) dt$$

Or

$$\emptyset_i^{p4} = \pi k(i-1)^2 tc^2 - \pi kT(i-1)^2 tc^2$$

$$= [\pi(i-1)^2/\delta] - \pi(i-1)$$

Thus the phase sequence of the P4 signal is given by

$$\emptyset_i = \frac{\pi}{N}\text{(i-1) (i-N-1)}$$

Where varies from 1 to N and N is the compression ratio. For example, the P4 code with N = 16, by taking phase value modulo 2 is given by the sequence,

$$= \left[0 \ \frac{17\pi}{16} \ \frac{4\pi}{16} \ \frac{25\pi}{16} \ \pi \ \frac{9\pi}{16} \ \frac{4\pi}{16} \ \frac{\pi}{16} \ 0 \ \frac{\pi}{16} \ \frac{4\pi}{16} \ \frac{9\pi}{16} \ \pi \ \frac{25\pi}{16} \ \frac{4\pi}{16} \ \frac{17\pi}{16}\right]$$

The PSL value is obtained as -26.32dB under zero Doppler, and -22.31dB under Doppler of 0.05 which are similar to P3 code.

Present work

This dissertation work present about the simple pulse with various input waveforms, pulse burst waveforms, LFM (linear frequency modulation), LFM with weighting techniques and NLFM (non-linear frequency modulation). Mainly, the research work is carried on Barker codes, Frank and P4 codes, which belongs to phase coded techniques and are used to improve the range resolution and Doppler resolution by reducing the peak sidelobe level.

III. POLYPHASE CODES

1. Introduction

The codes that use any harmonically related phases based on a certain fundamental phase increments are called Polyphase codes. There are many types of polyphase codes like Frank code, P_1, P_2, P_3, and P4. Here I mainly concentrated on Frank codes and P_4 code because of their advantages compared to remaining techniques. Frank proposed a polyphase code with good non-periodic correlation properties and named the code as Frank code. Kretscher and Lewis proposed different variants of Frank polyphase codes called p-codes which are more tolerant than Frank codes to receiver band limiting prior to pulse compression.

Polyphase compression codes have been derived from step approximation to linear frequency modulation waveforms (Frank, P1, P2) and linear frequency modulation waveforms (P3, P4). These codes are derived by dividing the waveform into sub codes of equal duration and using phase value for each sub code that best matches the overall phase trajectory of the underlying waveform. In this section, the polyphase codes namely Frank, P4 codes and their properties are described.

Binary phase codes were originally developed in which the phase elements φi are restricted to 0 or π. The main drawback of binary codes such as Barke code and m-sequences is their sensitivity to Doppler shift.

Polyphase codes have no restriction on code elements and are normally derived from the phase history of the frequency-modulated pulse. The Frank code and the P1 and P2 codes, the modified version of Frank code, is derived from the frequency stepped pulses. These three codes are only applicable for perfect square length ($M = L^2$).

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

$$P_1\text{: } \emptyset_{i,j} = (\pi/L)[L-(2j-1)][(j-1)L+(i-1)].$$

$$P_2\text{: } \emptyset_{i,j} = (2\pi/L)\left[\frac{L+1}{2} - j\right]\left[\frac{L+1}{2} - i\right].$$

Another two well-known polyphase codes are P3 and P4 codes derived from the linear frequency modulated pulse. Unlike Frank, P1, and P2 codes, the length of P3 and P4 codes can be arbitrary. P3 and P4 codes can be expressed as

$$P_3: \emptyset_i = \frac{\pi(i-1)^2}{M}.$$

$$P_4: \emptyset_i = \frac{\pi(i-1)(i-1-M)}{M}.$$

It is known that Frank, P1, and P2 codes are more Doppler-tolerant than binary phase codes and P3 and P4 codes are even better

2. Frank Code

The Frank code is derived from a step approximation to a linear frequency modulation waveform using N frequency steps and N samples per frequency. Hence the length of Frank code is N^2. The Frank coded waveform consists of a constant amplitude signal whose carrier frequency is modulated by the phases of the Frank code.

The phases of the Frank code is obtained by multiplying the elements of the matrix A by phase (2π/N) and by transmitting the phases of row1 followed by row 2 and so on.

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

The phase of the *i*th code element in the *j*th row of code group is computed as

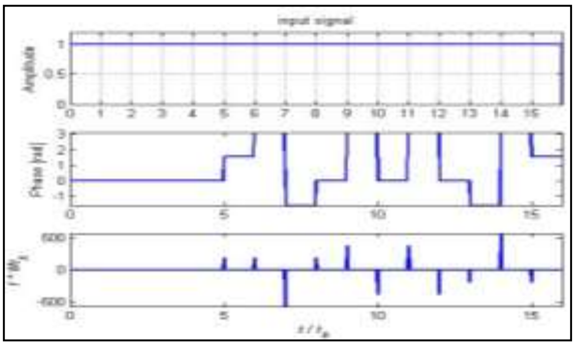
$$\emptyset_{i,j} = \left(\frac{2\pi}{N}\right)(i-1)(j-1).$$

Where *i* and *j* ranges from 1 to N. For example, the Frank code with N = 4, by taking phase value modulo 2 is given by the sequence,

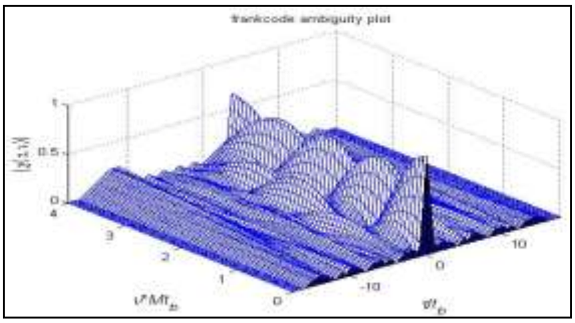
$$\phi_{4\times 4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \frac{\pi}{2} & \pi & \frac{3\pi}{2} \\ 0 & \pi & 0 & \pi \\ 0 & \frac{3\pi}{2} & \pi & \frac{\pi}{2} \end{bmatrix}$$

The autocorrelation function under zero Doppler and the phase values of Frank code with length 16 are given in Figure 5.1.

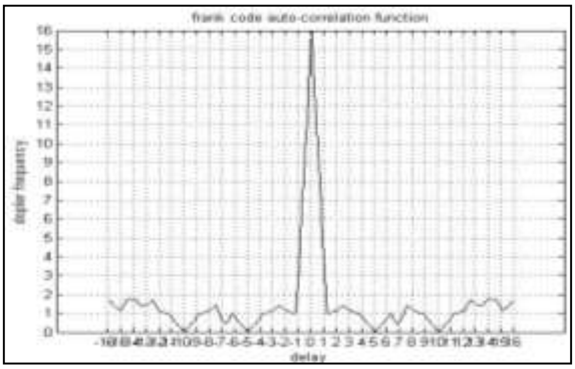
Input and Ambiguity Function diagrams for Frank Code



(a)



(b)



(c)

Figure 5.1: (a) Frank Code with [1 1 1 1 1 j -1 -j 1 -1 1 -1 1 -j -1 j] input, (b) Ambiguity Function in 3-Dimention, (c) Ambiguity function with zero Doppler cut.

Fig. 5.1 (a), (b), (c) represents Amplitude and frequency characteristics, Ambiguity function, Ambiguity function with zero Doppler cut of Frank code for N is equal to 16. From the ambiguity function, the range side lobes are suppressed compared to Barker code. The side lobe peaks around the origin are especially low. In general, the thumbtack nature of the AF is clearly evident. The average side lobe level of the ambiguity function is -27.037 dB which is improved.

From the above figure, it is evident that the Frank code has the largest phase increments from sample o sample in the center of the code. Hence, when the code is passed through a band pass amplifier in a radar receiver, the code is attenuated more in the center of the waveform. This attenuation tends to increase the side lobe of the Frank code ACF. Hence it is very intolerant to precompression band limiting. But comparing with binary phase codes, the Frank code has an average peak side lobe level (PSL) ratio of -27.03dB. An exception to this is the 4-element frank code which is identical to the 4-element barker code. As the length of the sequence increases the value of the peak side lobe level decreases. With the length of the sequence 25, obtained a result of peak side lobe level -38.5770dB, if we increase the length of the sequence complexity to build the circuitry also increases.

Table 5.1 comparison of input parameters and the PSL & APSL

Length of the Sequence	**Code elements**	**PSL in dB**	**Average side lobe level in dB**
4	[1 1 1 -1]	-12.04	-18.061
16	[1 1 1 1 1 j -1 -j 1 -1 1 -1 1 -j -1 j]	-21.8067	-27.0394
25	[0 0 0 0 0 0 2π/5 4π/5 6π/5 8π/5 0 4π/5 8π/5 12π/5 16π/5 0 8π/5 16π/5 24π/5 32π/5]	-38.5770	-44.5976

3. P_4 Code

1. Introduction

Pulse compression is used in peak power limited radars to transmit long waveforms with sufficient energy to detect the targets while simultaneously achieving resolution.

Apart from frank code, the new codes are referred as the P1, P2, P3 and P4 codes. In this P1 and P2 are same as Frank Codes, these two are the square sequence codes and will provide better Doppler tolerance. P3 and P4 codes are arbitrary, we can choose any length for better Peak side lobe level. In this chapter, detailed explanation has given for P4 code.

P3 code is not precompression bandwidth limitation tolerance than the Frank [22] or P1 and P2 codes. The P4 code is re arranged P3 code with the same Doppler tolerance and with better precompression bandwidth limitation tolerance.

P3 code is conceptually derived by converting a linear frequency modulation waveform to baseband using a local oscillator on one end of the frequency sweep and sampling the inphase *I* and quadrature Q video at the Nyquist rate [28].

P4 code is conceptually derived from the same waveform as the P3 code. In this case, the local oscillator frequency is set equal to $f_o + kT/2$ in the inphase *I* and quadrature Q detectors. With this phases of successive samples taken t_c apart are

$$\emptyset_i^{P4} = 2\pi \int_0^{(i-1)t_c} [(f_0 + kt) - (f_0 + kT/2)]\, dt$$

$$= 2\pi \int_0^{(i-1)t_c} k(t - {}^{T}/_{2})dt$$

Or

$$\emptyset_i^{P4} = \pi k(i-1)^2 {t_c}^2 - \pi kT(i-1)t_c$$

$$= [\pi\,(i-1)^2/N] - \pi(i-1)$$

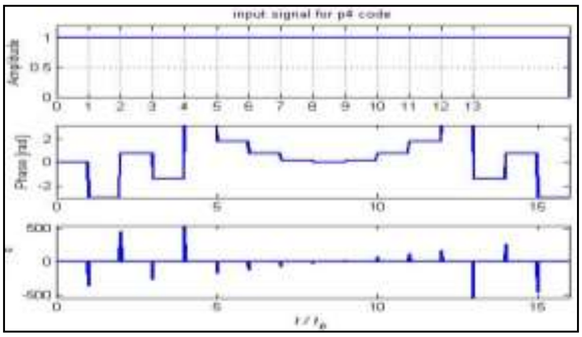
With N=16, the P4 code modulo 2π is

[0 17π/16 4π/16 25π/16 π 9π/16 4π/16 π/16 0 π/16 4π/16 9π/16 π 25π/16 4π/16 17π/16]

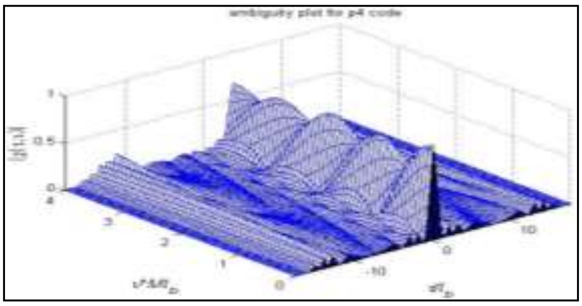
For N=25, the P4 code modulo 2π is

[0 26π/25 4π/25 9π/25 19π/25 0 11π/25 24π/25 14π/25 6π/25 0 21π/25 19π/25 19π/25 21π/25 0 6π/25 14π/25 10π/25 5π/25 0 16π/25 9π/25 4π/25 26π/25]

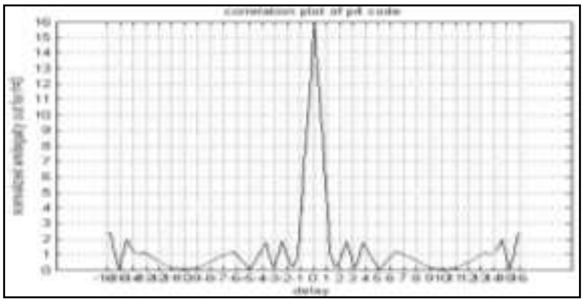
Input and Ambiguity Function diagrams for P4 Polyphase Code



(a)



(b)



(c)

Figure 6.1 (a)P4 Code with [0 17π/16 4π/16 25π/16 π 9π/16 4π/16 π/16 0 π/16 4π/16 9π/16 π 25π/16 4π/16 17π/16] input, (b) Ambiguity Function in 3-Dimention, (c) Ambiguity function with zero Doppler

The above figure 6.1 (a), (b) and (c) shows the input signal, phase and frequency characteristics, Ambiguity Function and ambiguity function with zero Doppler cut. From the above, we can observe that the side lobe level of the autocorrelation function is less compared to the side lobe level of the remaining techniques like Frank, P1, P2, and P3. Peak side lobe level provided by the P4 code is -51.4089dB, here the length of the sequence is 16. For the sequence length 25, the peak side lobe level is -54.84dB. Here the drawback is if we increase the length of the sequence complexity provided by the circuit also increases.

Length of the Sequence	Code elements	PSL in dB	Average side lobe level in dB
16	[0 17π/16 4π/16 25π/16 π 9π/16 4π/16 π/16 0 π/16 4π/16 9π/16 π 25π/16 4π/16 17π/16]	-51.4089	-57.4257
25	[0 26π/25 4π/25 9π/25 19π/25 0 11π/25 24π/25 14π/25 6π/25 0 21π/25 19π/25 19π/25 21π/25 0 6π/25 14π/25 10π/25 5π/25 0 16π/25 9π/25 4π/25 26π/25]	-54.84	-60.8612

IV. CONCLUSION

In this paper, different forms of radar waveforms and their performance characteristics are observed. To observe the performance characteristics of range sidelobe behavior and ambiguities. Ambiguity diagram is used which is generated in the MATLAB. The MATLAB code [17] generated for a different type of radar waveforms.

In this paper, concentration was given more on reducing the range sidelobes. Starting with the simple pulse various types of radar waveforms like pulse burst, different types of LFM, different types of NLFM, Frank and P4 codes and their performance characteristics are observed. In each type of radar waveform, the range sidelobe is observed and compared with other type and introduced different types of radar waveforms to suppress the range sodelobes are introduced.

Generally, in many applications, LFM is used, but the range sidelobes of this waveform are more and to suppress these sidelobes amplitude weighting is done at the transmission side which reduces the range sidelobes but conversely energy is affected. In order to get back the energy criteria which is important to transmit the signal, NLFM of different types are used out of which some types reduce the range sidelobes but complexity rises in generating such signals. In order to reduce the complexity in generating signals frequency and phase coded radar waveforms are used.

In this paper phase coded radar waveforms such as Frank and P4 codes are used in reducing sidelobes. The range sidelobes of Barker codes are reduced when compared to that of LFM. To reduce the range sidelobe level further and to get the AD thumbtack like structure, Frank and P4 codes are used and performance characteristics of different types of Frank and P4 code are performed. The above discussion concludes that by using Frank and P4 signals one can produce a thumbtack shape ambiguity diagram which is called ideal ambiguity diagram. The sidelobe levels of Frank and P4 codes are reduced to that of Barker and LFM. The peak sidelobe level of Frank code for 16 elements is -27.037 dB and for P4 code PSL is -31.4089.

REFERENCES

1. Prudyus I.N., Sumyk M.M., Yankevych R.V. "Investigation of Phase Coded Signals Based on Generalized Frank Codes", 2010. National University "Lvivska Politechnika", Lviv, Ukraine.
2. Edwin A. De Roux Fuentes, Adly T.Fam. "Mismatched Filter for Polyphase Codes via Sidelobe Inversion", 2009 IEEE.
3. Nadav Levanon and Eli Mozeson, "Radar Signals", A John Wiley & Sons, Inc., Publication, Hoboken, New Jersey, 2004.
4. Merrill I. Skolnik, "Introduction to Radar Systems", Second Edition, Tata McGraw-Hill, 2008.
5. Fred E. Nathanson, "Radar Design Principles", second edition, McGraw-Hill, 1969.
6. Mark. A Richards, "Fundamentals of Radar Signal Processing", Tata McGraw-Hill Edition, 2005.
7. Peyton Z. Peebles, Jr., "Radar Principles", John Wiley & Sons, Inc, 1998.
8. M. Bernfeld, C. E. Cook, "Radar Signals: An Introduction to Theory and Application", Academic Press, 1967.
9. Nadav Levanon, "Modified Costas Signal", IEEE Transactions on Aerospace and Electronic Systems, Vol.40, No.3, Jul 2004, 946-953.
10. Bassem R. Mohafza, "Radar Systems Analysis and Design using MAT LAB", Chapman & Hall/CRC, 2000.
11. Nadav Levanon, "Nullifying ACF Grating lobes in Stepped frequency train of LFM pulses", IEEE Transactions on Aerospace and Electronic Systems, Vol. 39, No. 2, April 2003.
12. P. Ramesh Babu, "Digital Signal Processing", Fourth Edition, Scitech Publications (India) Pvt. Ltd, 2001.
13. Eli Mozeson, Nadav Levanon, "MATLAB Code for plotting Ambiguity Functions", IEEE Transactions on Aerospace and Electronic Systems, Vol. 38, No. 3, July 2002, 1064-1068.
14. Rihaczek, A. W., "Principles of High-Resolution Radar", McGraw-Hill, New York, 1969.
15. Skolnik, Merrill I., "Radar Hand Book" McGraw-Hill, New York, 1990.
16. Skolnik , Merrill I., "Introduction to Radar Systems", 3rd ed. Tata McGraw Hill, 2001.
17. Woodward, P. M., "Probability and Information Theory with Applications to Radar", Pergamon Press, Oxford, 1953.
18. Turyn, R., "On Barker Code of Even Length", Proc. of IEEE (corr.), vol. 51, no. 9, September 1963, p.1256. Friese, M., Zottmann, H., "Polyphase Barker Sequences up to Length 31", Electronics Letters, vol. 30, no. 23, Nov 1994, pp. 1930-1931.
19. Friese, M., Zottmann, H., "Polyphase Barker Sequences up to Length 31", Electronics Letters, vol. 30, no. 23, Nov 1994, pp. 1930-1931.
20. Friese, M., "Polyphase Barker Sequences up to Length 36", IEEE Trans. on Information Theory, vol. 42, no. 4, July 1996, pp.1248-1250.
21. Borwein, P., and Ferguson, R., "Polyphase Sequence with Low Autocorrelation", IEEE Trans. on Information Theory, vol. 51, no. 4, Apr 2005, pp. 1564-1567.
22. Frank, R. L., and Zadoff, S. A., "Phase Shift Pulse Codes with Good Periodic Correlation Properties", IEEE Trans. on Information Theory, vol. 8, Oct 1962, pp. 381-382.
23. Frank, R. L., "Polyphase Codes with Good Non-periodic Correlation Properties", IEEE Trans. on Information Theory, vol. 9, no. 1, Jan 1963, pp. 43-45.
24. Heimiller R. C., "Phase Shift Pulse Codes with Good Periodic Correlation Properties", IEEE Trans. on Information Theory, Oct 1961, pp. 254-257.
25. Chu, D. C., "Polyphase Codes with Good Periodic Correlation Properties", IEEE Trans. on Information Theory, vol. 18, no. 4, July 1972, pp. 531-533.
26. Frank, R. L., "Comments on Polyphase Codes with Good Correlation Properties", IEEE Trans. on Information Theory, vol. 19, no. 2, March 1973, p. 244.
27. Lewis, B. L., and Krestschmer, F. F., "A New Class of Polyphase Pulse Compression Codes and Techniques", IEEE Trans. on Aerospace and Electronic Systems, vol. AES-17, no. 3, May 1981a, pp. 364-372.
28. Lewis, B. L., and Krestschmer, F. F., "Corrections to A New Class of Polyphase Pulse Compression Codes and Techniques", IEEE Trans. on Aerospace and Electronic Systems, vol. AES-17, no. 5, September 1981b, p. 726.
29. Lewis, B. L., and Krestschmer, F. F., " Linear Frequency Modulation Derived Polyphase Pulse Compression Codes", IEEE Trans. on Aerospace and Electronic Systems, vol. AES-18, no. 5, September 1982, pp. 673-641.
30. Krestschmer, F. F., and Lewis, B. L., "Doppler Properties of Polyphase Coded Pulse Compression Waveforms", IEEE Trans. on Aerospace and Electronic Systems, vol.19, no. 4, July1983, pp. 521-531.

