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Generation of Low Probability of Intercept Signals

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Abstract- Vulnerability in the interception of radar transmission by anti-radiation missiles or the like, can be avoided by using Low Probability of Intercept (LPI) techniques like Barker codes, Frank codes, polyphase codes, Costas code, etc. In this project, we simulate different kinds of complex waveforms that are obtained by superimposing LPI signal onto the radar signal. Analysis of the power spectral density of the complex waveforms reveals that Costas codes efficiently combats interception of radar signals.

Keywords—. **Low Probability of Intercept, Barker codes, Frank codes, polyphase codes, Costas code**.

I. INTRODUCTION

In the past, military radars were characterized by short duration pulses having relatively high peak power, with Radar Warning Receivers (RWR) and Electronic Support (ES) receivers being designed to detect those radars. Now, radar designers have considered new waveforms which are more difficult to intercept protecting them against Anti-Radiation Missiles (ARM) and reducing the detection range of RWRs and ES equipment. They are now specifying Low Probability of Intercept (LPI) as an important technical and tactical requirement.

The LPI technique is based on the property of an emitter that due to its low power, wide bandwidth, frequency variability and other attributes makes radar difficult to intercept or identify by conventional passive intercept receiver devices. LPI radar works to detect targets at a longer range than an intercept receiver. This concept is well- summarized in a statement 'It tries to see and not be seen.' This is the response to the increasing capability of modern intercept receivers to detect and locate radar emitters, possibly leading rapidly to an electronic attack or the physical destruction of the radar by guided munitions or Anti-Radiation Missiles.

The proliferation of radar, altimeters, tactical airborne targeting, surveillance and navigation devices employing LPI capabilities has demonstrated that power spectral analysis is useless when intercepting these signals; therefore, a more sophisticated signal processing must extract the necessary parameters of the waveform to create a proper electronic response.

Characteristics of LPI Radar Signals:

A LPI radar design must focus on the ability to defeat all the external threats that can lead to a precise identification of the system. Therefore, the following systems must be carefully designed to achieve the desired capability:

- Security of the matched filter
- Minimized signal PSD
- Randomized radar parameters
- Wideband operation
- LPI antenna design
- Power management

LPI radar requires wideband signal modulations that reduce the signal's detectability. Wideband modulations spread the signal's energy in frequency, so that the frequency spectrum of the transmitted signal is wider than what is required to carry signal's information.

There are three ways in which modulation is used to spread the signal in frequency:

- Periodically changing the frequency
- Sweeping the signal frequency at a high rate, or chirping
- Modulating the signal with a high rate digital signal, or direct sequence-spectrum spreading.

Included in these categories are many wideband modulation techniques available to provide secure LPI waveforms:

- Frequency Modulation
- Linear FM (Chirp)
- Non-Linear FM
- Frequency Modulation Continuous wave
- Costas Array, frequency hopping
- Phase modulation (bi-phase coding, polyphase coding)
- Combined phase shift keying, frequency shift keying (PSK, FSK)
- Pseudo-noise modulation

Polarization modulation

LPI Receivers:

Due to the nature of the new LPI threat, modern intercept receivers are becoming increasingly ineffective. Detection and interception of these LPI signals require sophisticated digital receivers that use time frequency signal processing and correlation techniques to collect signal data, to do the analysis and generate an electronic attack (jamming).

II. DIFFERENT KINDS OF LPI RADAR SIGNALS

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Binary Phase Shift Keying:

In BPSK modulation, the phase of the frequency carrier is shifted 180 degrees in accordance with the digital bit stream. A ‘1’ does not produce a phase-transition, and a ‘-1’ causes a phase transition. In the transmitter design part a continuous wave (CW) signal x (t) is considered. After sampling at the Nyquist rate, the modulated signal is created by adding an n-bit Barker code. This code has been used widely because of its low-side at zero Doppler shifts.

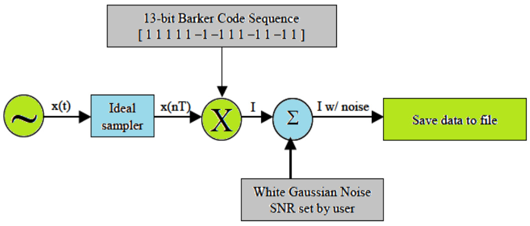

Fig 1: Block Diagram of a BPSK Implementation

Polyphase Codes (Frank code, P-codes):

Polyphase sequences are finite length, discrete time complex sequences with constant magnitude but with a variable phase $\emptyset_k$.

Frank Codes:

The Frank code is a polyphase code (more than two phase states). The Frank phase modulation code is derived from a step approximation to a linear frequency modulation waveform using N frequency steps and N samples per frequency.

A Frank-coded waveform consists of a constant amplitude signal whose carrier frequency is modulated by the phases of the Frank code. The representation of a frank- coded signal, where *i* is the number of the samples in a given frequency and *j* is the number of frequency, the phase of the *i*th sample of the *j*th frequency is given by the following equation:

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

Where *i* = 1, 2. . . N, and *j* = 1, 2. . . N. the Frank code has a length of $N_c = N^2$ sub codes.

$$A = \begin{bmatrix} 0 & 0 & 0 & \ldots & 0 \\ 0 & 1 & 1 & \ldots & (N-1) \\ 0 & 2 & 4 & \ldots & 2(N-1) \\ & & & & \\ 0 & (N-1) & 2(N-1) & \ldots & (N-1)^2 \end{bmatrix}$$

The phases of the Frank code may be generated for transmission by multiplying the elements of the matrix by the phase 2π/N and by transmitting the phases of row 1 followed by row 2.

P1 Polyphase Code:

By changing the synchronous oscillator frequency, different phase codes can be generated with equal amplitudes but with different phases. By placing the synchronous oscillator at the center frequency of the step chirp IF waveform and by sampling the base band waveform at the Nyquist rate, the polyphase code called P1 may be obtained. The P1 code and the Frank code consist of same number N^2 elements.

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

Where i = 1, 2. . . N and j = 1, 2. . . N.

P2 Polyphase Code:

The P2 code also consists of N^2 elements as P1 code, that way P2 code signal with N=4 produce a matrix of 16 different phases. The P2 code has the same phase increments within each group as the P1 code, except that the starting phase is different. The P2 code is valid for N even, and each group of the code is symmetric about 0 phases

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

Where i = 1, 2. . . N and j = 1, 2. . . N.

P3 Polyphase Code:

This code is derived by converting a linear-frequency modulation waveform to baseband using a local oscillator on one end of the frequency sweep and sampling the in phase I and quadrature Q signal at the Nyquist rate.

$$\phi_i = \frac{\pi(i-1)^2}{N}$$

Where i = 1, 2. . . N and j = 1, 2. . . N

P4 Polyphase Code:

The P4 code is conceptually derived from the same waveform as the P3 code. The P4 also consists of N elements.

$$\phi_i = \frac{\pi(i-1)^2}{N} - \pi(i-1)$$

Where i = 1, 2. . . N and j = 1, 2. . . N

Costas Codes

In a frequency hopping system, the signal consists of one or more frequencies being chosen for a set $f_1, f_2\ldots f_m$ of available frequencies, for transmission at each of a set $t_1, t_2\ldots t_n$ of consecutive time intervals

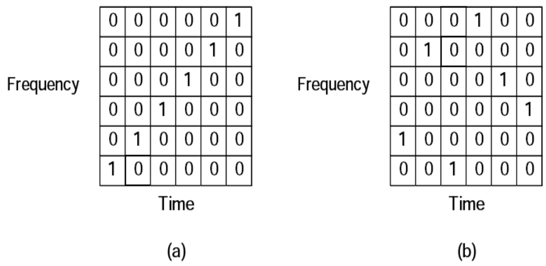

Fig 2: Frequency Assignment for a Burst of N Sub Pulses (a) Linear FM and (b) Costas Signal of Length 6

This hopping order strongly affects the ambiguity function of these signals. Costas frequency-hopping signals allow a

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simple procedure that result in a rough approximation of their ambiguity function. From the results of the difference matrix in above figure except for the zero-shift cases, when the number of coincidence is not possible.

For example if a_i={2,6,3,8,7,5,1} is a Costas sequence, then its coding matrix and difference matrix are shown in fig3.

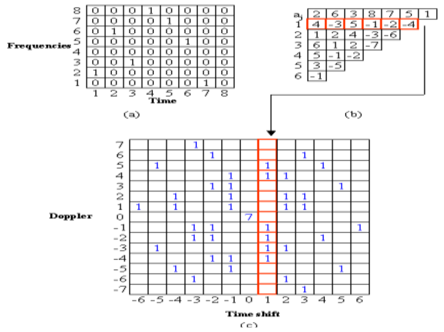

Fig 3: (a) The Coding Matrix (b) Difference Matrix (c) Ambiguity Side-lobes Matrix of a Costas Signal

III. SIMULATION RESULTS

Barker Code:

Some random selection of the 0, π phases are better than others (where better means a lower maximum side lobe level). Completely random selection of the phases, therefore, is not a good idea if compressed waveforms with low time-side lobes are desired and they usually are. One criterion for selecting the sub pulse phases is that all the time side lobes of the compressed pulse should be equal. The 0, π binary phase codes that result in equal time side lobes are called Barker codes. The barker code of length N=13 is shown in auto correlation fig 1.

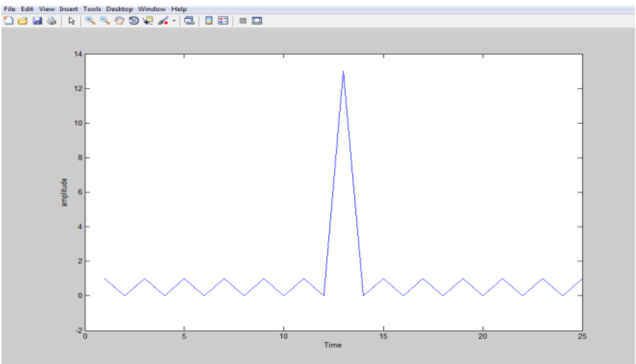

Fig 1: Autocorrelation Function of 13-bit Barker Code

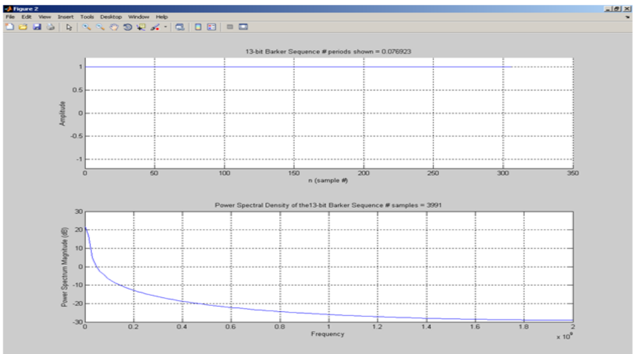

Fig 2:13-bit Barker Sequence and Power Spectral Density.

Frank Code:

Frank polyphase code is defined by an N by N matrix as shown in the above matrix. The numbers in the matrix are each multiplied by a phase equal to 2π/N radians .The polyphase code starts at the upper left-hand corner of the matrix, and a sequence of length N^2 = M, the total number of subsamples.

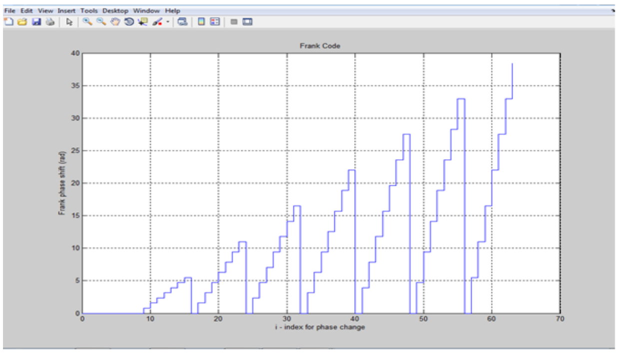

Fig 3: Frank Code (Phases of row 1 followed by row 2)

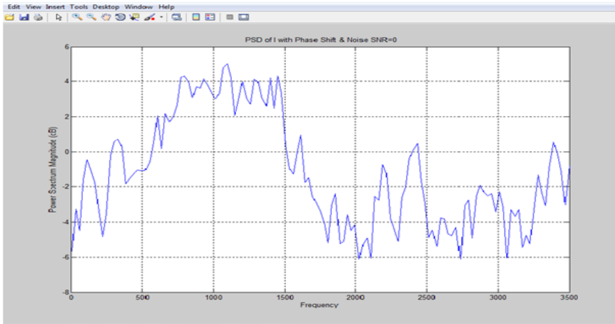

Fig 4: Power Spectral Density of In phase with Phase Shift and Noise (SNR=0)

They produce lower side lobe levels than the binary phase codes and are tolerant to Doppler frequency shifts if the Doppler frequencies are not too large.

P1 Code:

The P1 code also consists of N^2 elements as Frank code, that way P1 code signal with N=4 produces a matrix of 16 different phases, if N=8 produces a matrix of 64 phases

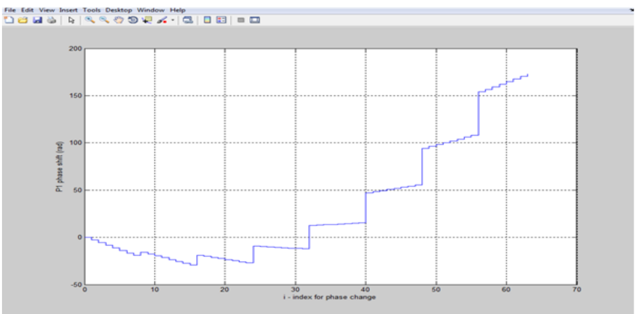

Fig 5:P1 Code

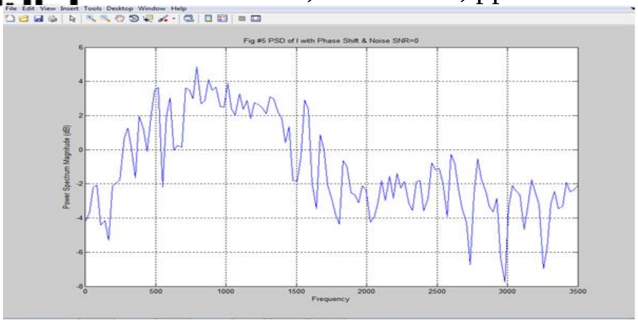

Fig 6: Power Spectral Density of In Phase Signal With Phase Shift And Noise (SNR=0)

Processing this signal we can detect the carrier frequency, bandwidth and code period with very good resolution for the case of signal only and SNR = 0dB. But at SNR = - 6dB the efficiency of the signal goes down 50% approximately. This code has the lowest code increments from one code element to code element in the center of the waveform.

P2 Code:

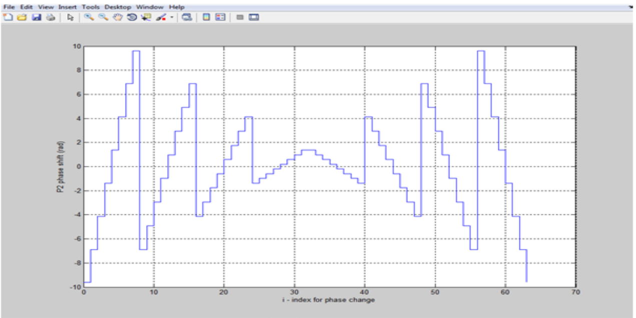

Fig 7: P2 Code

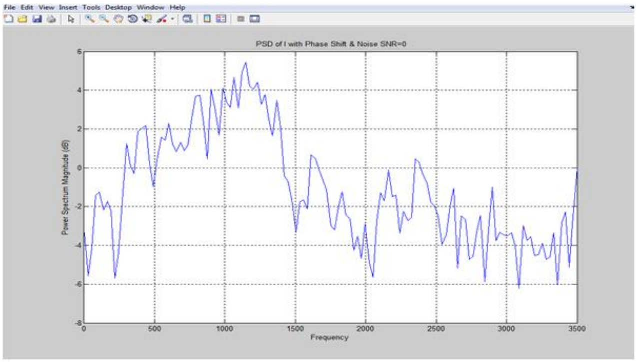

Fig 8: Power Spectral Density of In phase with Phase Shift and Noise (SNR=0)

The P2 code also consists of N^2 elements a P1 code, so P2code signal with N=4 produce a matrix of 16 different phases, if N=8 produces a matrix of 64 phases. The P2 code has the same phase increments within each group as the P1 code, except that the starting phase is different. The P2 code is valid for N even, and each group of the code is symmetric about 0 phases. We have to transmit the signal using radar. This code is valid for even numbers of phases, and each group of the code is symmetric about zero phases

P3 Code:

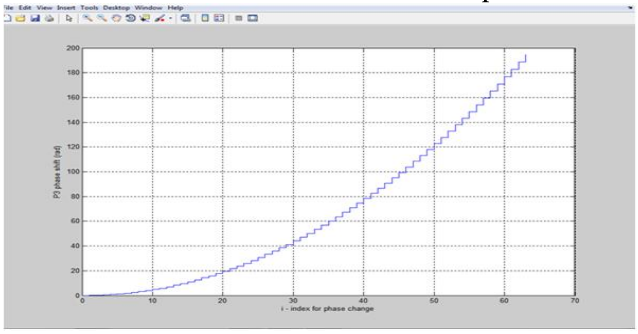

Fig 9: P3 Code

P3 only differs from Frank code by 180° phase shifts every N1/2 code elements (one frequency group) and by added phase increments that repeats every N1/2 samples (every frequency group). The largest phase increments from code element to code element are in the middle of the P3 code as presented

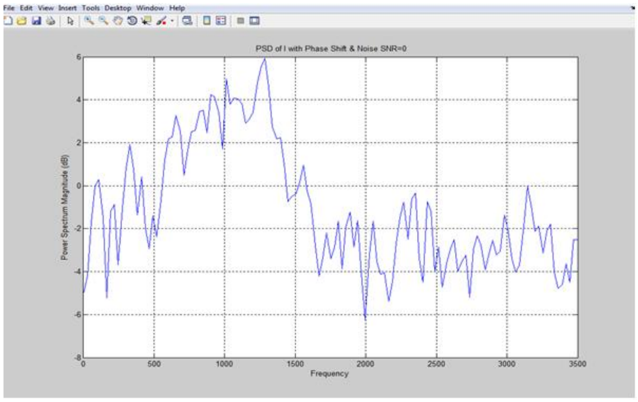

Fig 10: Power Spectral Density of In phase with Phase Shift and Noise (SNR=0)

P4 Code:

P4 code is very similar to P1 code except that the phase samples are those of a sampled chirped waveform rather than step-chirp waveform. It is noted that the largest phase increments from code element are on the two ends of the P4 code.

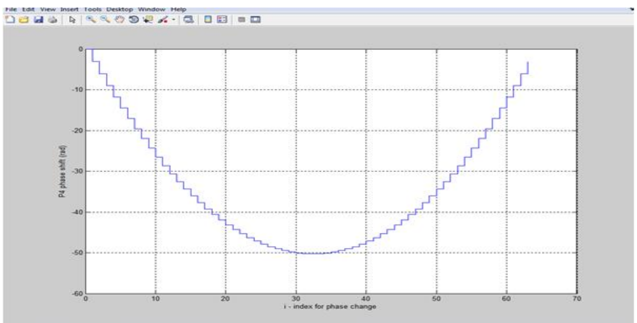

Fig 11: P4 Code

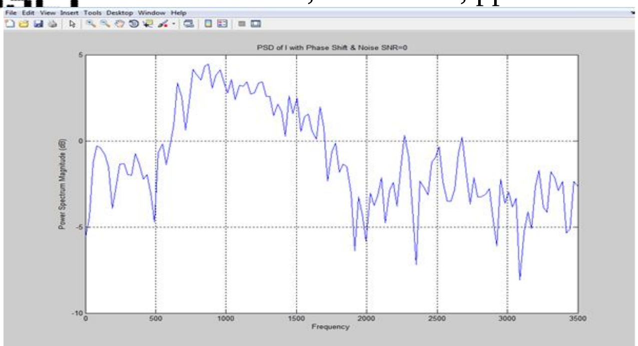

Fig 12: Power Spectral Density of In phase with Phase Shift and Noise (SNR=0)

Costas:

A Costas array is an *n*× *n* array of frequencies and times with exactly one frequency in each row and column, and with distinct vector differences between all pairs of frequencies. As a frequency-hopping pattern for radar or sonar, a Costas array has an optimum ambiguity function, since any translation of the array parallel to the coordinate axes produces at most one out of phase coincidence [10]

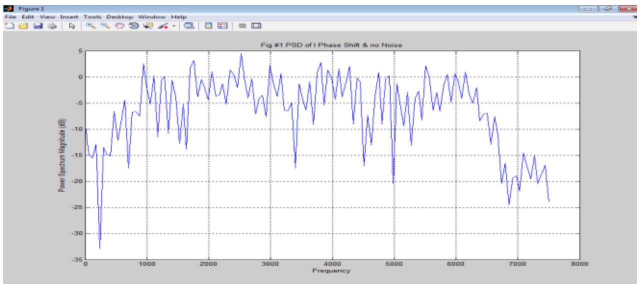

Fig 13: Power Spectral Density of In phase with Phase Shift and no Noise

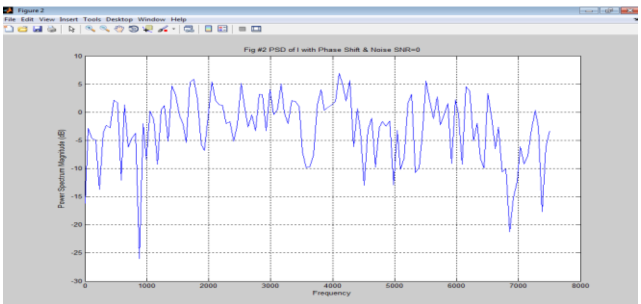

Fig 14: Power Spectral Density of In phase with Phase Shift and Noise (SNR=0)

Costas (frequency-hopping) codes achieve a particular pulse compression ratio with fewer sub pulses than phase-coded waveforms. Their side lobes appear to be almost the same as ordinary binary phase-coded waveforms. Many more different Costas codes of a given length are available than that can be obtained with binary phase codes. This might be of interest in military radars concerned with operating against some form of electronic countermeasures.

IV. CONCLUSION

In this project, radar signals are superimposed with a variety of LPI signals using codes such as Barker codes, Frank codes, polyphase codes, Costas codes and their power spectra are analyzed. The results show that Costas codes generate the most complex power spectrum which efficiently fights the problem of interception of radar signals. This provides high degree of security from deception jamming which is useful in several military and navy applications.

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