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Generating Transmitting Codes for MIMO Radar Using Polyphase Codes to Reduce Side-lobe Levels

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Abstract- High side-lobe levels reduction is an exhausting task in Multiple- Input Multiple-Output (MIMO) radar. Transmit sequence design plays a significant role in radar to overwhelm correlation side-lobe levels. In general, side-lobe levels performance of the incoming signals is observed by their cross-correlation function with other transmitted signals. New polyphase codes are projected that shows good auto-correlation and cross-correlation function responses to reduce peak side-lobe levels (PSL) and cross-correlation levels (CCL). Performances of the various poly phase codes are compared and the P4 code is chosen for the design of new poly phase code. The proposed composite poly phase codes (CPC) are produced by adding the left and right shifted versions of P4 code asP4 code is much Doppler accepting to another polyphase codes. Using ambiguity function, the influence of CPC on the delay-Doppler plane is observed. Finally, simulation results validate superiority of the proposed CPC equated to the counterpart techniques.

Keywords- Cross-correlation function; Polyphase codes; Radar waveforms; Side-lobe levels.

I. INTRODUCTION

In radar system, wider pulses are preferred for long range detection however range resolution becomes poor due to overlying of nearby targets. For better range resolution, small transmit pulses are required. Range resolution is the competency of the system to discriminate two targets in range profile [1-3]. The benefits of both short and long duration pulses are achieved by a technique known as pulse compression. In radar, the correlations among transmitted and returned signals from target are exploited. The correlate or includes of main-lobe and side-lobe levels. The side-lobe levels suppression is careful as important parameters to squared efficiency of the designed signal [4, 5].

The side-lobe levels can be suppressed by two different techniques. In the first technique, search for the transmitting waveform has to be conducted which gives least side-lobe levels in the correlation function response. In the second technique, the transmitting waveform has to be passed through the various window functions. The drawback of this method is to increase relative main-lobe breadth that disturbs range resolution [5].

In multiple-input multiple-output (MIMO) radar, to perceive numerous targets, several transmit and receive antennas are exploited at radar system. This process is different from phased-array an antenna in which single waveform is communicated. Every convey antenna can communicate dissimilar arrangement provides additional degrees of freedom. The waveform performances for the conveyed waveforms are affected due to high values of cross-correlation levels (CCL). To invalidate cross-interference, orthogonal sets for the transmission signals are preferred for CCL reduction. Fig. 1 shows the antenna pattern for monostatic radar.

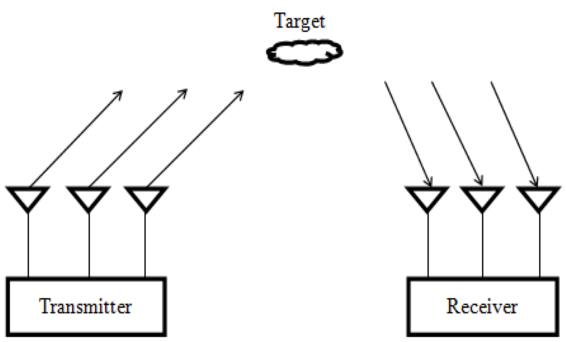


Fig 1. MIMO radar.

1. Related Works:

In the literature, numerous communicating signals exist such as non-linear frequency modulation, linear frequency modulation (LFM), and polyphase codes. Different methods are designed using all these existing codes. Starting from LFM, the auto-correlation function (ACF)of LFM signal gives the peak side-lobe level (PSL) value of -13.26dB which is much higher for adjacent target masking [5-7]. The Barker codes do not exist beyond code length of 13 offering -22.30dB PSL reduction which is insignificant for real-world applications [8].

In [8, 9], Chebyshev chaotic benefits for MIMO radar are investigated which offers higher spectral contents. In [7-10], side-lobe suppression methods are designed to mitigate range side-lobes. In [10], orthogonal polynomials are recycled to enhance bandwidth for range resolution improvement. A cyclic algorithm designed using chaotic Bernoulli system given in [11-15], useful in MIMO radar for rapid singular value putrefaction.

Using polyphase codes, Woo filters are proposed for side-lobe levels suppression in [16-20]. Filters are designed by combining the shifted versions of polyphase codes and best combination has to be produced at the transmission side. Unimodular sequences are developed using cyclic procedure obtainable in [21, 22] having worthy correlation belongings.

Binary sequences are established with radar codes such as Gold, Random, and Kasami. It is found that the Kasami sets provide improvement in PSL. By Fourier transform, non-convex optimization problems of higher iterations are removed [23-24].

2. Motivation:
The main indices that are to be considered for the enhancement of MIMO radar performance are:

- Complexity of the designed radar waveforms must be least to get high system speed as existing waveforms and optimized algorithms affects system speed.
- PSL and CCL values in the correlation function response must be least to avoid blind target detection.
- Radar waveform response must be equivalently feast with least side-lobe levels on the ambiguity function delay-Doppler plane.

3. Contributions:
Using P4 polyphase codes, new codes for MIMO radar are designed for the reduction of high side-lobe levels. The main contribution is as:

- Search for the best polyphase codes have been conducted for the reduction of side-lobe levels. Proposed polyphase codes are designed by combining the shifted version of polyphase P4 codes.
- Many combinations of right and left shifted versions of polyphase codes are observed and the combination which gives maximum reduction in side-lobe levels is chosen for transmission purposes.
- Using correlation function response, PSL and CCL values of the proposed codes are observed with varying code length. Further, the delay-Doppler planes of ambiguity function are studied in details.

This paper is arranged as: The method to design proposed polyphase codes is given in section 2. Section 3 describes simulation results for different combinations and the designed code performances are compared with the counterpart methods for validation purposes. Section 4 concludes the work presented in this paper.

II. PROBLEM FORMULATION

The polyphase codes advantage is to provide multiple phases which are not confined to 0 and π. The phases in polyphase codes lie between 0 and π which depends upon the sequence length. In the proposed method, P4 codes are used due to its high Doppler tolerances and recurring properties [15].

The P4 code phases are given by

$$\boldsymbol{\phi_n = \frac{\pi}{N}(n-1)(n-1-N)} \quad \textbf{(1)}$$

In MIMO radar, each sequence has length N and L numbers of transmitting antennas are considered. The transmitted signal is given as

$$\boldsymbol{X = [x_1 \ \ x_2 \ \ x_3 \ \dots \ x_L]_{N\times L}} \quad \textbf{(2)}$$

A single antenna transmit signal as

$$\boldsymbol{x_l(n) = [x_l(1) \ \ x_l(2) \ \ x_l(3) \ \dots \ x_l(N)]^T} \quad \textbf{(3)}$$

Where $l \in [1{:}L]$specifies sequence entities. Using auto-correlation and cross-correlation function, the transmitting sequence performance can be analyzed. For sequence $x_l(n)$, the ACF values are calculated as

$$\boldsymbol{r_k = \sum_{l=1}^{N-k} x_l^* x_{l+k,} \quad k = 0, 1, \dots, N-1} \quad \textbf{(4)}$$

The highest value of side-lobe levels in (6) represents the PSL value which is calculated as

$$\boldsymbol{PSL = \max\{|r_k|\}_{k=1}^{N-1}} \quad \textbf{(5)}$$

Further, the cross correlation function of two neighboring sequences$x_{l_1}(k)$ and $x_{l_2}(k)$gives the CCL values given in (6).

$$\boldsymbol{r_{l_1 l_2}(n) = \sum_{k=n+1}^{N} x_{l_1}(k)\, x_{l_2}^*(k-n) \ = r_{l_2 l_1}^*(-n)} \quad \textbf{(6)}$$

Where $l_1, l_2 \in [1{:}L]$and $n \in [0{:}N-1]$. If $l_1 = l_2$, then (6) gives ACF response of the transmitted signal. For the case $l_1 \neq l_2$, then $r_{l_1} r_{l_2}(n)$ value should be approaches to zero for orthogonal cases. The covariance matrix provides the PSL and CCL values for all the antenna combinations. In (7), diagonal and non-diagonal elements represent the normalized PSL and CCL values, respectively. For orthogonal signal, non-diagonal elements must be zero for ideal case.

$$\boldsymbol{C_n = \begin{bmatrix} r_{11}(n) & r_{12}(n) & \cdots & r_{1L}(n) \\ r_{21}(n) & r_{22}(n) & \cdots & r_{2L}(n) \\ \vdots & \vdots & \ddots & \vdots \\ r_{L1}(n) & \cdots & \cdots & r_{LL}(n) \end{bmatrix}} \quad \textbf{(7)}$$

III. PROPOSED METHODOLOGY

The proposed code is designed using P4 codes. The ACF responses of ordinary P4 codes are observed which gives high side-lobe levels leading to ambiguous target detection. New polyphase codes are proposed by shifting the ordinary P4 codes to left and right. These shifts depend upon the sequence length and we have to choose that combination of shifts which produces maximum side-lobe levels reduction in the correlation function response. During new polyphase code designs, several shifts are incorporated to the incoming P4 code like one shift, two shifts, three shifts and (N-1)*th* shifts.

The proposed code is designed using the addition of one bit left shift of P4 code to the original P4 code which is named as composite polyphase code (CPC). In MIMO radar, multiple orthogonal sequences are preferred for transmission. The main objective is to achieve orthogonality among transmitting sequences.

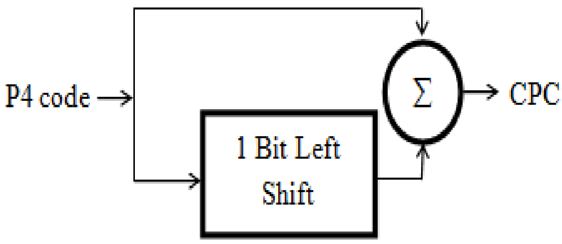


Fig 2. Proposed CPC generation method.

Once the best polyphase code is generated then orthogonality among transmitting sequences has to be maintained for MIMO radar applications. In this paper, orthogonality among transmitting signals is achieved by changing the phases of proposed CPC through multiplying $Y(N,L)$.

$$\boldsymbol{Y(N,L)} = \mathbf{e}^{(j2\pi * rand(N,L))} \qquad \textbf{(8)}$$

Where *r and* (*N*, *L*) generates random sequences. In literature, many optimization techniques are available for orthogonal signal generations. In our proposed methods, orthogonal signals are produced without using any optimization methods.

IV. SIMULATION RESULTS

In this section, performance of the designed CPC is compared with counterpart codes. The well-known P4 code's ACF response is plotted in Fig. 3for N=500. It is observed that the PSL value of -33.39dB occurs which is much higher for blind target detection. The ACF response of Golomb code is similar to P4 code hence its plot is not given here. Further, the ACF response of CPC is plotted in Fig. 4for N=500 which gives the PSL value of -79.46dB. Comparing PSL values, it is found that CPC offers higher PSL suppression which is greater than two times offered by P4 and Golomb codes.

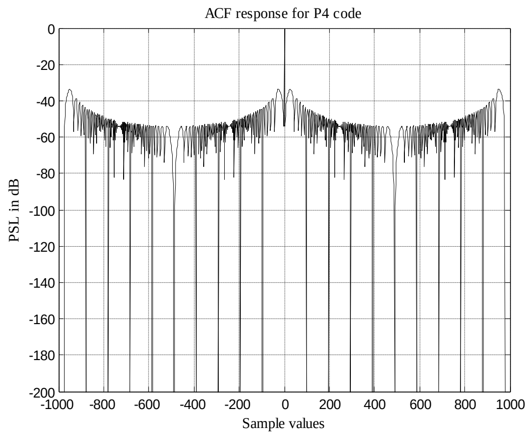


Fig 3. ACF response of P4 code for N=500.

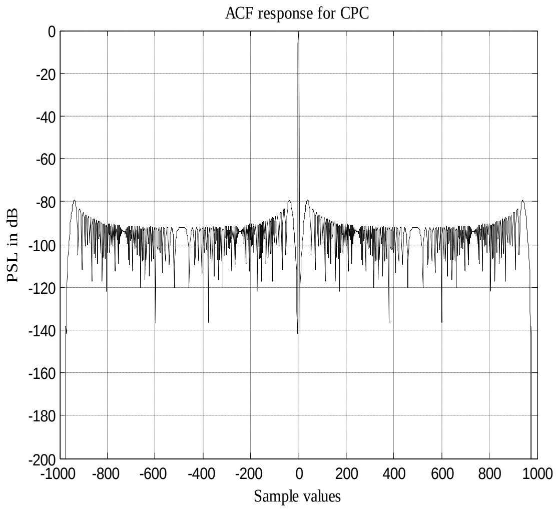


Fig 4. ACF response of proposed CPC for N=500.

Like Frank codes, proposed CPC have not constraint of perfect square length. It means CPC sequences can be designed for any arbitrary length N. In MIMO radar, proposed CPC performance is compared with Golomb and P4 code considering L=3 and N=128. The PSL values given by three transmitting antennas are observed usingr_{11},r_{22}, and r_{33} response. Fig. 5 and Fig. 6(a) give the ACF responses and it is clear that CPC gives least side-lobe levels than Golomb and P4 code. Whereas CCL values are observed using r_{12},r_{13}, and r_{23} responses given in Fig. 6(b) and Fig. 7.

Table 1. PSL values comparison for L=3 and N=128.

Correlation response	PSL (dB) Values		
	Golomb	P4	CPC
r_{11}	-14.42	-15.14	-15.24
r_{22}	-12.76	-16.48	-17.72
r_{33}	-12.96	-14.24	-15.49

In this paper, plots of r_{21}, r_{31}, and r_{32} are not given because responses are similar to r_{12}, r_{13}, and r_{23}, respectively. Table 1 and Table 2 gives the PSL and CCL values of Golomb, P4, and proposed CPC for *N*=128 and *L*=3. All these values are calculated using correlation plots given in Fig. 5 to Fig. 7. The *N* and *L* values can be changed as per requirement, here *N*=128 is considered due to clear visibility of results. If the sequences length is increases then more reduction in side-lobe levels can be achieved.

Table 2. CCL values comparison for *L*=3 and *N*=128.

Correlation response	CCL (dB) Values		
	Golomb	P4	CPC
r_{12}	-12.04	-13.56	-15.39
r_{13}	-12.77	-13.64	-14.89
r_{23}	-12.40	-12.76	-13.76

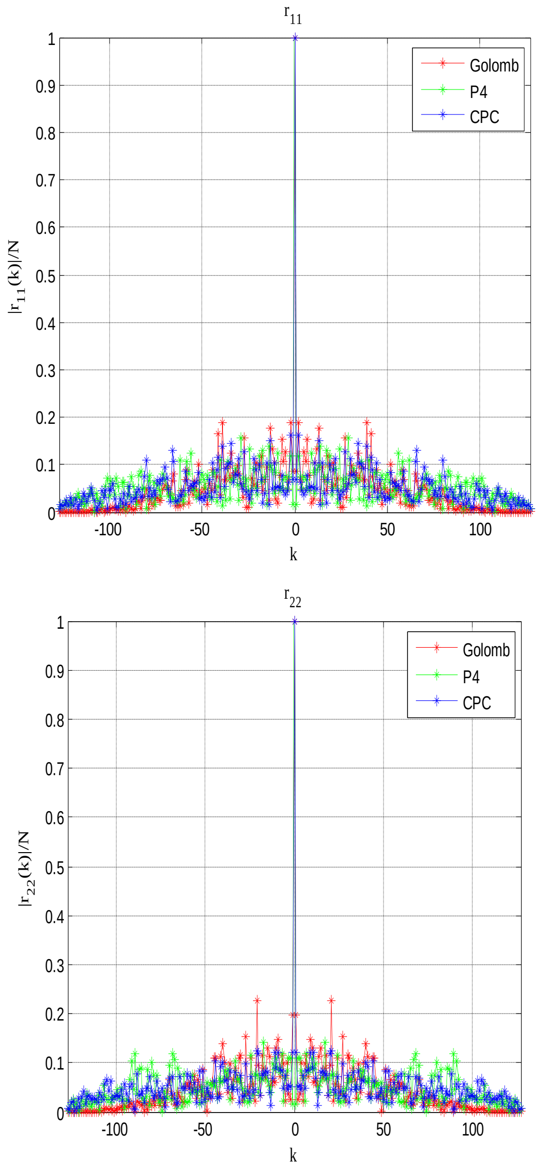


Fig 5. Correlation response for *N*=128 and *L*=3 (a) r_{11} (b) r_{22}.

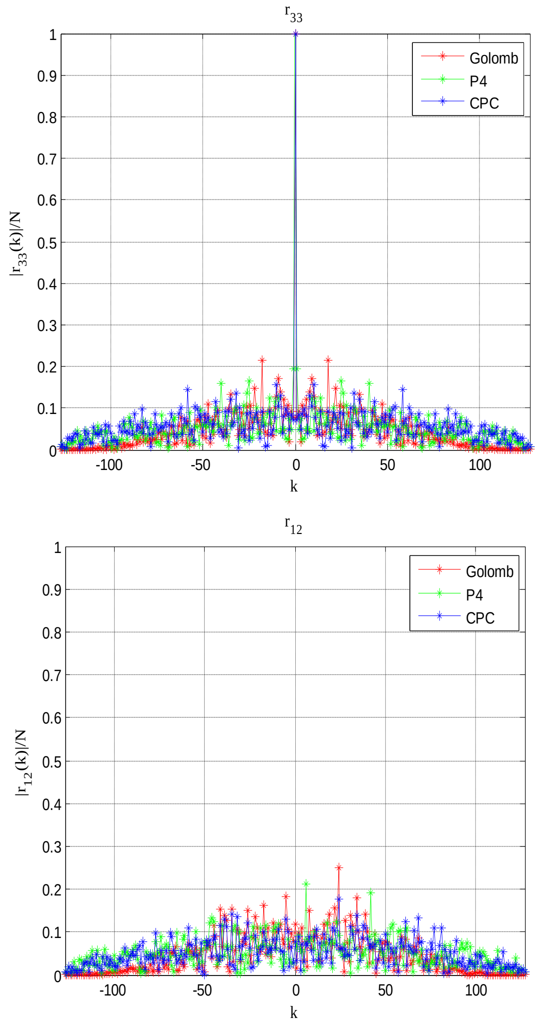
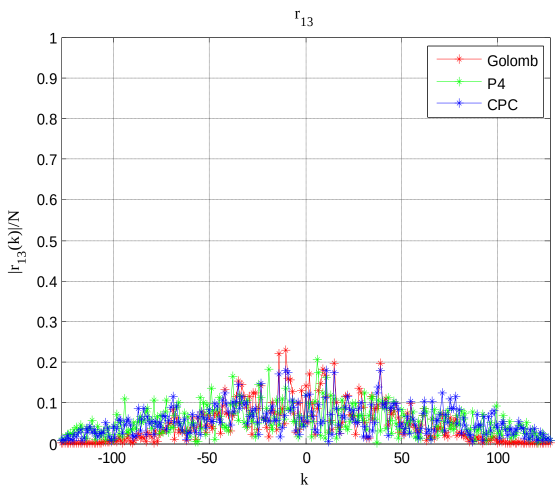


Fig 6. Correlation response for *N*=128 and *L*=3 (a) r_{33} (b) r_{12}.

The performance of the designed CPC is observed for different combinations of antennas and sequence lengths. In this paper, all simulations are shown for *N*=128 and *L*=3.



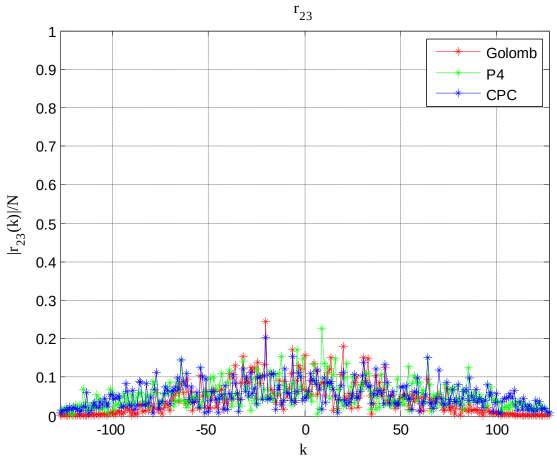


Fig 7. Correlation response for N=128 and L=3 (a)r_{13}(b)r_{23}.

1. Observations on Delay-Doppler Plane:

The proposed CPC performance is observed on the delay-Doppler plane of Ambiguity function which is represented by $Q(\tau_d, f_d)$. The ambiguity function is a two variable function used to find target characteristics like range, angle and velocity resolutions. It is given by

$$\boldsymbol{Q(\tau_d, f_d) = \int_{t=-\infty}^{\infty} x(t)x^*(t-\tau_d)\, e^{-j2\pi f_d(t-\tau_d)}dt} \qquad (9)$$

Where τ_d, f_d, and $x(t)$ are the time-delay, frequency-delay and transmitting signal. The P4 and proposed CPC's contour plots are shown in Fig. 8 and Fig. 9, respectively. Simulation results shows that the P4 code has Doppler frequency are much spread from 30 KHz to 100 KHz. Whereas in CPC, Doppler frequency range exist from 90 KHz to 100 KHz. It is concluded that the nearby targets might be hidden in the higher range of Doppler frequency. Therefore, the proposed code has less probability to hide the undesired target which in result offers accurate detection at the radar receiver. All the simulations related to ambiguity function are done with sampling frequency of200 KHz and pulse repetition frequency of 10 KHz.

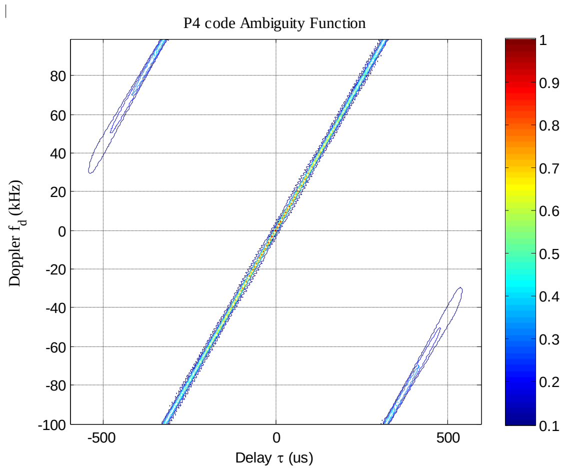


Fig 8. P4 code contour plot for N=128.

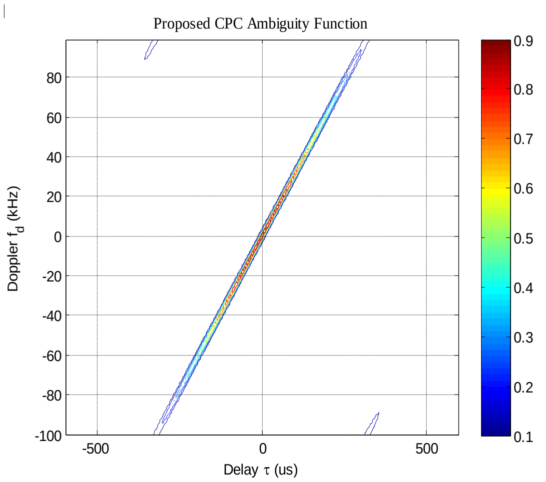


Fig 9. Proposed CPC contour plot for N=128.

IV. CONCLUSIONS

In this paper, CPC are designed with the help of existing P4 codes. In MIMO radar, orthogonality is an essential parameter which is much needed to reduce cross-interference. Therefore, orthogonal signals are generated for multiple antennas which are mutually orthogonal to each other. Using ACF responses, side-lobe levels are observed for the designed code.

Different combinations of shifts on the P4 code are incorporated to design best polyphase code. It is concluded that the addition of original P4 code with respect to one bit left shifted P4 code offers least side-lobe levels in the cross-correlation function response. Further, proposed CPC sequences can be designed for any arbitrary length N. The delay-Doppler plane of ambiguity function for CPC has well defined response than ordinary P4 code which is good to avoid target masking in MIMO radar. In future, performances of the designed sequences can be observed to determine the range and velocity resolutions.

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