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A Novel Pulse Compression Technique For Side-Lobe Reduction Using Woo Filter Concepts

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***Abstract*—The theme of this paper is to present a novel technique for the reduction of the side-lobes in the pulse compression (PC) for the radar systems. The peak sidelobe level (PSL), integrated sidelobe level (ISL) and relative main-lobe width are computed using P4 polyphase codes, and compared the proposed technique results with other PC techniques such as Woo filter as well as modified Woo filter. This proposed PC technique is implemented by shifting the input P4 polyphase codes and multiplied it with reference signal in the frequency domain, after that the side-lobe behavior is analyzed by converting it into the time domain. Results show that the method introduced in this paper produces certain improvement in PSL and ISL.**

***Index Terms*—Integrated side-lobe levels, Matched filter, Peak side-lobe level, Pulse compression, Relative main-lobe width**.

I. INTRODUCTION

In the radars systems, the PC is used to increase the range resolution, which is very significant capability of the system to separate two nearby targets in term of distance [1]. In general, the short and long duration pulses are necessary for good range and velocity resolution in the radar, respectively because the long duration pulse which is transmitted is responsible for detection [1], and the bandwidth which is increased after modulation is responsible for the range resolution. For a particular waveform, the matched filter (MF) and auto-correlation function (ACF) are used to observe PC response [2]. However, for good PC, the main peak should be narrow and it contains low side-lobes level. The main-lobe of the filter respond to the main target but due to the presence of small PSL in the MF output corresponds to some nearby targets, which decreases pulse compression ratio [1]. To reduce the peak sidelobe levels several PC techniques have been developed rely on linear frequency modulation (LFM), nonlinear frequency modulation (NLFM), classic barker codes and polyphase codes.

In [2], the authors have proposed a technique in which ACF for modified two and tri-stage NLFM signal are analyzed and -19dB sidelobe suppression is achieved without disturbing the relative main-lobe width. Baghel and Panda [3], have proposed a hybrid model for the phase coded waveforms in which MF output is modulated by the output of radial function for different Barker codes. In addition to this, the hardware requirement is also significantly less to implement this hybrid model without any training iterations as in the neural network. In [4], the authors have developed a model in which a mismatched filter, comprised of a matched filter is cascaded with a parameterized multiplicative finite-duration impulse response filtemar. For a given main-lobe to sidelobe ratio, the proposed filter is longer than the length-optimal filters but uses fewer multipliers and adders.

Vizitiu [5] has produced a technique to overcome the problems of LFM signal that is stretching of the main-lobe width which disturb the range resolution by using nonlinear laws. A hyper chaotic coding scheme and corresponding optimal selection method are proposed by authors [6], to obtain the phase code signal, which exhibits great performance for sidelobe reduction. Simulation shows that it has a better sidelobe suppression effect than other ways. When the Gaussian-noise variance is less than 0.01, the sidelobe level can decrease to the order of -55dB, but the signal-to-noise ratio loss is less than 0.05dB. In [7, 8] has proposed a simple technique for polyphase codes to synthesize amplitude weighting correlators at the cost of minimal range resolution loss. The weighting in time and frequency domain is applied in order to suppress the side-lobes.

Rihaczek [9] has proposed a sidelobe suppression technique in which only few distinct tap weight line are used to reduce the side-lobes that reduces the complexity of digital processor. The Barker codes and multistage Barker codes are

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used for higher pulse compression factors. In [10, 11], the mismatched received finite impulse response filters based on the minimization of Lp-norms of the side-lobes. The goal of the minimization process is to reduce the range sidelobe levels of the convolution of the transmit pulse and the receive filter.

In this paper, the sidelobe reduction technique for P4 code based on Woo filter concepts has been produced. This technique uses the combination of shifted bits of P4 codes which is converted in to the frequency domain and a reference signal that multiplied with input signal. The author's contribution is summarized as follows:

- PC output for two proposed filters has been observed. First filter is classified in two forms, in the form-1 uncompressed input P4 codes are shifted by one bit and two bits lefts, which are combined together to make a single input signal.
- In form-2 same input signal is applied as of reference signal which is the combination of right and left shifted bits and twice of the P4 code.
- In filter-2 raised weighting in the time domain is incorporated for the coming input signal. After this performance measuring parameters are calculated and compared with other techniques.

Consequently, the PC output is observed by converting the signal in to the time domain. The remaining paper is organized as follows. In section II, the polyphase P4 codes and parameters on which the performance of system is determined are described. The section III illustrates the proposed PC technique for the side-lobes reduction. The section IV presents the numerically simulated results of the proposed PC technique and validates the result of the proposed technique with the reported literature. Finally, the section V concludes the work presented in this paper.

II. Polyphase Codes and Performance Parameters

In the literature, there are more polyphase codes viz. Frank, P1, P2 and P3 [12, 13]. Frank and P1 are well known for low range-side lobes to derive these codes step frequency is used. Advantage of P4 codes are that these can be derived for any length sequence and these codes are cyclic shifted which gives better sidelobe reduction than other polyphase codes. Moreover P4 polyphase codes are more Doppler tolerant than P1 and P2 code [12, 13]. So, in this paper P4 code has been considered to analyze the response in the proposed techniques.

Phases of the P4 codes [14] are calculated using

$$\phi(i) = \frac{\pi}{N}(i-1-N)(i-1) \tag{1}$$

where N is the total length of polyphase code. P4 code elements are calculated by

$$x(i) = \exp\left[j\phi(i) \right] \tag{2}$$

Measuring the performance parameters are computed by using the following formulae: PSL for a code of length N measures the ratio of maximum sidelobe magnitude to the main lobe amplitude. Its value should be low as much as possible and it can be calculated as:

$$PSL(dB) = 20\log_{10} \frac{\max_{1\le l\le N} \left|M(l)\right|}{\left|M(0)\right|} \tag{3}$$

where $M(l)$ is amplitude of the lth sample number of compressed pulse. The ratio of energy in the side lobes to the main lobe of the compressed pulse is called as ISL. For better PC its value should be low and it can be calculated by:

$$ISL(dB) = 10\log_{10}\left(\left(2\sum_{l=1}^{N-1}\left|M(l)\right|^2\right)/\left(\left|M(0)\right|^2\right)\right) \tag{4}$$

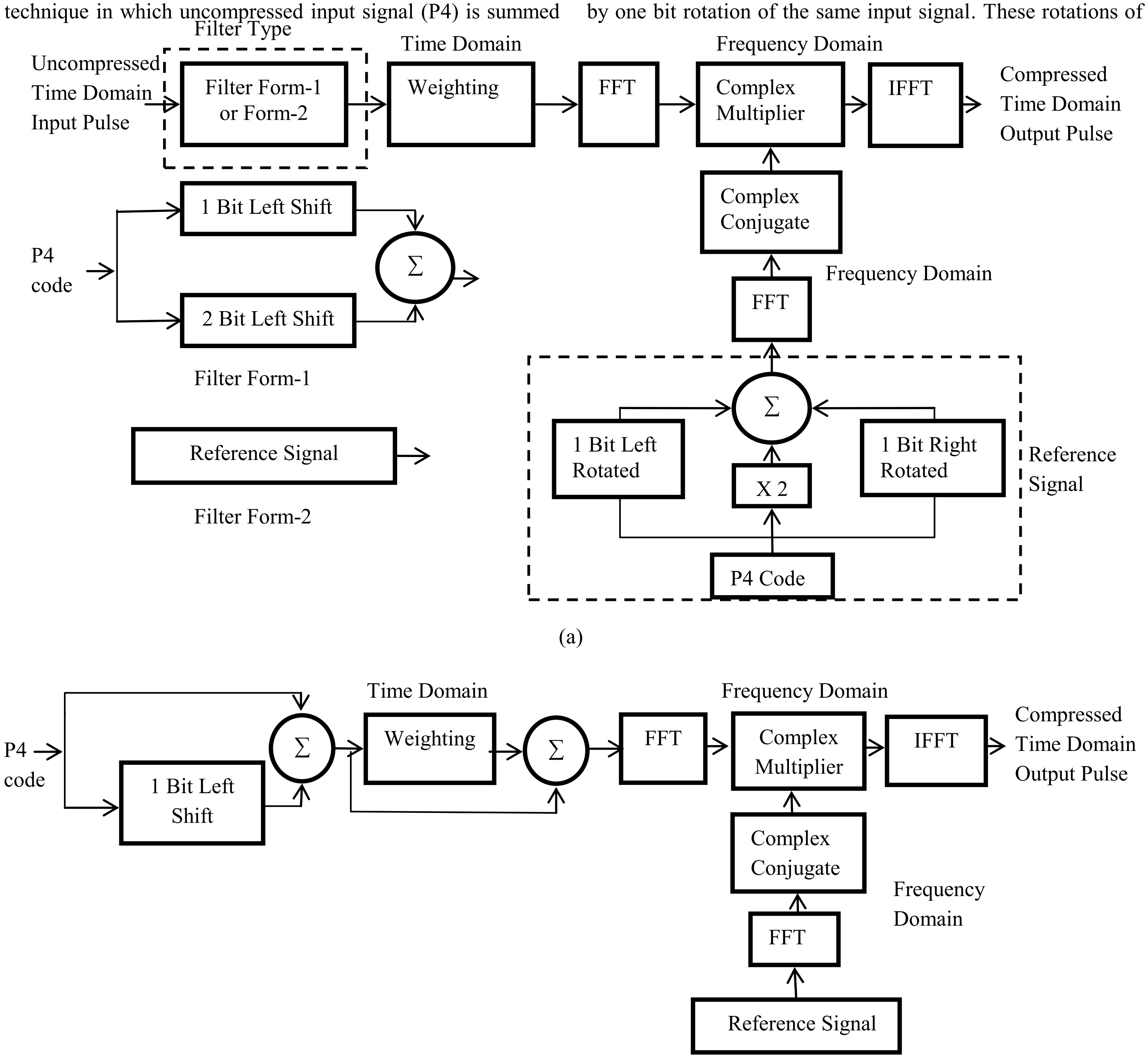
III. Proposed Pulse Compression Technique

The Woo filter is the combination of MF for polyphase codes [14, 15]. The two correlation filters are combined together to produce a single discrete filter called Woo filter. In the proposed technique for PC [14], input signal is the combination of original polyphase code and one bit left or right shift is applied to the fast Fourier transform (FFT) and reference signal is same as in our proposed technique. The main difference between our proposed technique and in [14] is the sifts in the input polyphase code. Here one shift and second shifts has been considered for the analysis of Woo filter and raised weighting are applied.

Our proposed filter-1 is described in two forms. In form-1, the input signal is the combination of one bit and two bits left shifts as shown in Fig. 1(a) which is given to FFT to get its frequency domain signal (without weighting). This frequency domain signal is multiplied with conjugate version of the reference signal in frequency domain. After that this frequency domain signal is converted in to time domain to observe the sidelobe level behavior. In form-2, input signal is same as of reference signal and remaining structure is same. In proposed filter-2, input signal to the FFT is the combination of coming P4 code and one bit left shift which is further passed through weighting filter (Blackman) and summed by itself as shown in Fig. 1(b). It is considered as raised weighting rather than simple weighting.

IV. Simulations and Results

In this paper P4 code of length 1000 is taken, performance of this new technique is compared with other PC techniques related to the Woo filter in order to suppress the side lobes. The authors in [14] have developed a modified Woo filter technique in which uncompressed input signal (P4) is summed by one bit rotation of the same input signal. These rotations of



(b)

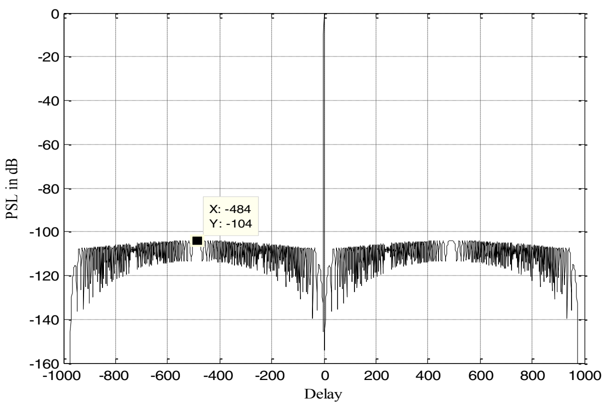
Fig. 1. Proposed filter block diagram (a) filter–1 and (b) filter-2

the bits may be right side and left side, named, as modified Woo filter-1and filter-2 respectively. Fig. 2 (a) shows the PC results for modified Woo filter-1 [14] having -104dB PSL. Fig. 2(b) shows the output for filter-2 having -107.6dB PSL. Fig. 3(a) and 3(b) represent the output of the method followed in this paper with filter form-1 and form-2 without weighting. It is observed that for filter form-1 the PSL level exists at -104.1dB, ISL is -75.34dB and relative main lobe width is 2.51.

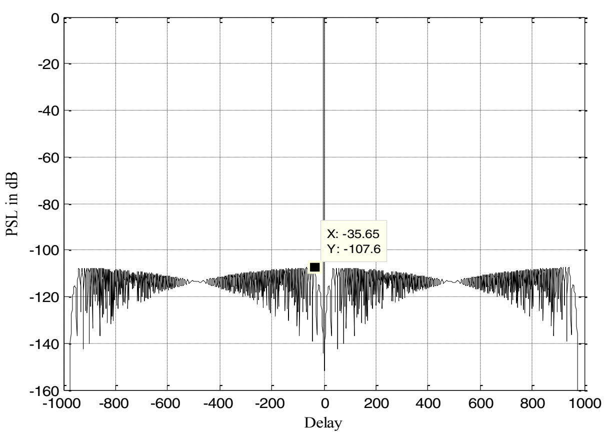
By comparing it to the modified Woo filter-1 [14] without weighting it has 0.1dB more reduction in side lobes and ISL is also improved, whereas -46.29dB reduction in PSL is achieved than Woo filter [14], as shown in Table I. On comparing proposed filter form-1 with the modified Woo filter-2 in [15], -15.43dB PSL and -2.74dB ISL reduction are achieved using the method introduced in this paper.

Investigation has been done regarding the rotation of bits, it is observed if second and third shifts are combined to make input signal then there is no improvement in PSL. It is also concluded that left rotation of bits are more suitable for PC because these has more reduction in the side lobes than other combination of shifts. Here also in all the proposed methods left rotation is done for input signal. Performance measuring parameters for P4, Woo filter, modified Woo filter [14] and the proposed methods are calculated and represented in Table 1. Its performance parameters are calculated and it is observed that there is a little improvement in ISL than recently developed Woo filter.

In proposed filter-2 as shown in Fig. 1(b), PC output is shown in Fig. 4(a), have -54dB sidelobe reduction than Woo filter. By comparing the results of this proposed method with the modified Woo filter [15], the improvement in the gain is approximately -23dB and -9.4dB in ISL. It is observed that raised window is giving more reduction in side lobes than directly applying weighting to the signal as shown in filter-2. All these simulations have been done in MATLAB with 4096 FFT points. No doubt weighting can be used for further reduction in the side-lobes but on the loss of relative main-lobe width that affect the range resolution. From the results it is observed that by applying different window techniques relative main-lobe width has been increased slightly.

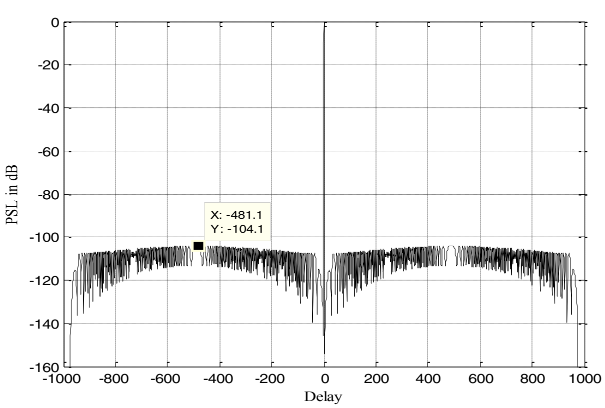


(a)

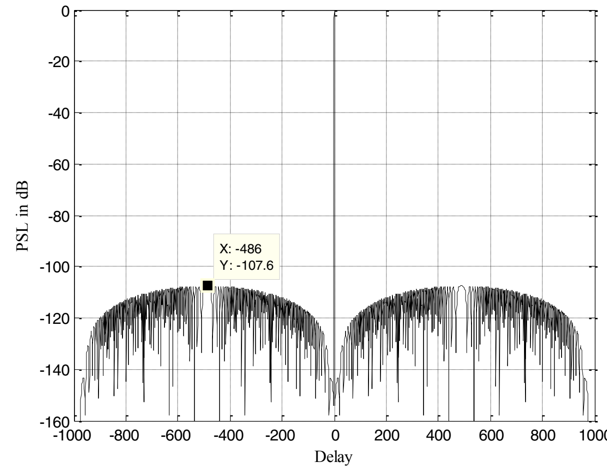


(b)

Fig. 2. PC output for modified Woo (a) filter-1and (b) filter-2.



(a)

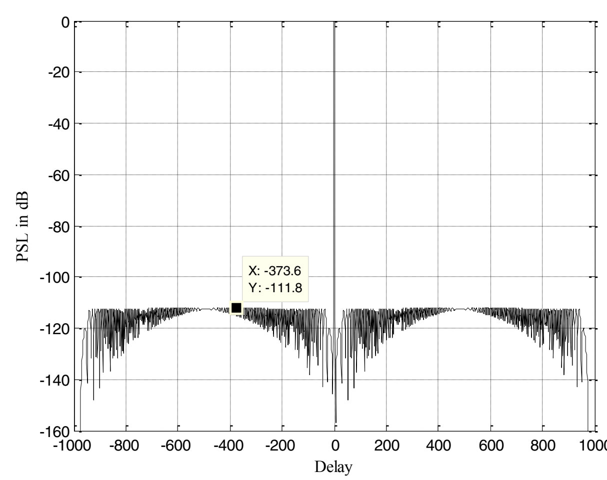


(b)

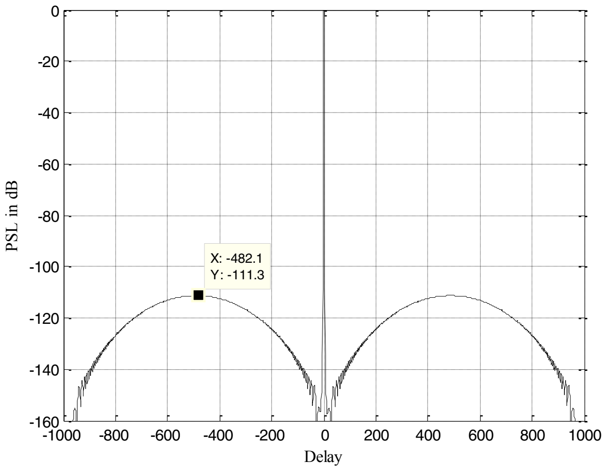
Fig. 3. PC output for proposed filter (a) form-1and (b) form-2.

TABLE 1
PSL, ISL AND RELATIVE MAIN-LOBE WIDTH COMPARISON FOR REPORTED SIDELOBE REDUCTION TECHNIQUES

PC Techniques	Peak Side-lobes Level(dB)	Integrated Side-lobes Level (dB)	Relative Main-lobe Width
P4 code	-36.37	-16.99	1
Woo filter	-57.81	-27.08	2.03
Modified Woo filter -1	-104	-75.18	2.51
Modified Woo filter -2	-107.6	-79.11	2.98
Modified Woo filter -1 with Hamming window	-110.8	-82.18	3.20
Modified Woo filter -2 with Hamming window	-112.1	-83.10	3.37
Proposed filter form-1	-104.1	-75.34	2.57
Proposed filter form-2	-107.6	-80.43	2.97
Proposed filter -2with Blackman window	-111.8	-81.44	4.77



(a)



(b)

Fig. 4. PC output for proposed (a) filter-2 and (b) filter form-1 with the Blackman window.

TABLE II
PSL AND ISL COMPARISON FOR PROPOSED METHOD WITH VARIOUS WINDOWS

Window Technique-s	Proposed filter form-1		Proposed filter form-2		Proposed filter-2	
	PSL(dB)	ISL(dB)	PSL(dB)	ISL(dB)	PSL(dB)	ISL(dB)
Hamming	-110.9	-83.02	-111.5	-83.95	-111.6	-81.21
Hanning	-112	-83.46	-112	-84.03	-111.8	-81.40
Blackman	-111.3	-83.41	-111.3	-83.99	-111.8	-81.44
Nuttall	-110.5	-83.44	-110.5	-83.86	-111.7	-81.46

By applying weighting to the input signal in time domain for the proposed filter-2 some more reduction is achieved in PSL and ISL, it also smoothen the spectrum except at the end and beginning of the sidelobe sequence. For the proposed filter-2, the Blackman window is applied as weighting and it is expressed as follows:

$$b(n)=\begin{Bmatrix} 0.4265-0.4965\cos\left(\dfrac{2\pi n}{N-1}\right)+ \\ 0.0768\cos\left(\dfrac{4\pi n}{N-1}\right) \end{Bmatrix} 0\le n\le N \quad (5)$$

Fig. 4(b) shows the PC output for proposed filter form-1 with Blackman weighting, by which -7dB gain is achieved. In the similar way, other weighting techniques are applied for the proposed models; results for PSL and ISL are tabulated in Table II.

V. CONCLUSION

This paper has demonstrated a new PC technique which gives significant improvement in PSL and ISL. Further, it is observed that if more numbers of shifts are incorporated for the input P4 code then results deviate from the optimal PSL. Left shifts in the input P4 code gives better results than right shifts. By applying raised amplitude weighting in time domain more PSL and ISL reduction is achieved with slight increase in the main-lobe width. So, the compressed signal which is produced in this paper can be applied in real application. In summary, the method has been demonstrated to be real sidelobe reduction technique having applicability inside the pulse compression radar systems.

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