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SIDELOBES LEVEL IMPROVEMENT BY USING A NEW SCHEME USED IN MICROWAVE PULSE COMPRESSION RADARS

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Abstract—P4 polyphase code is well known in microwave pulse compression technique. There are different reduction techniques to reduce the sidelobes of P4 code. This paper presents a new sidelobe reduction technique which its results are excellent. To valid our work, other sidelobe reduction techniques such as Woo filter and modified forms of Woo filter are investigated and compared with the technique presented in this paper. Results show that the method introduced in this paper produces better peak side lobe ratio (PSL) and integrated side lobe ratio (ISL) than other solutions.

1. INTRODUCTION

Pulse compression techniques are used in many radar systems for increasing the range of resolution [1]. This is a method combining the high energy of a long pulse with the high resolution of a short pulse. In order to get large time-bandwidth product, the transmitted pulse is modulated by using frequency modulation or phase coding [2, 3].

The matched filter for waveforms pulse compression can be performed by applying the digital correlator. The output of the matched filter will be an extremely narrow pulse with a large peak value, thus the transmitted pulse is compressed in time domain [4]. Unfortunately, the autocorrelation function of a real expanded impulse consists not only of a main peak which is used for target detection but also of range sidelobes which can cover main peaks caused by small targets [4, 5].

Polyphase is one of phase coding methods to overcome this problem. P4 polyphase pulse compression waveform discussed by

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the authors [6, 7], provide a class of phase coded waveform that can be sampled upon reception and processed digitally. These waveform is derivable from the chirp and step-chirp analog waveforms, so it is similar in certain respects with their analog counterparts. Differences in sidelobe levels, implementation techniques, and Doppler characteristics are some important issues between them. The compressed pulse of the polyphase coded waveforms has sidelobes which decrease the pulse compression ratio (PCR). For PCR equal to 100, the sidelobe peaks range from 26 to 30 dB below the main peak signal response, depending on the particular code [8].

The polyphase coded waveforms are capable of large pulse compression ratios which may be efficiently implemented using the phase shifts provided by a fast Fourier transform (FFT). Thus the FFT can be used directly as the pulse compressor. These waveforms can also be efficiently compressed with another pulse compression technique where the FFT is used to convert to the frequency domain where the matched filtering and weighting are performed. This processing is followed by an inverse FFT to restore the signal to the time domain [8].

There are reduction techniques developed to reduce the sidelobe levels. Lewis proposed sliding window two-sample subtractor to reduce the sidelobes for the polyphase codes [9]. Weighting in frequency and time domain can generally be applied to reduce the sidelobes [8, 10]. In [11, 12] three sidelobe cancellers are developed to reduce peak and integrated sidelobe level. In this paper, a new technique to reduce the sidelobes significantly is presented.

This paper is organized as follows. Section 2 describes P4 of polyphase codes. Section 3 defines the quantities used as performance evaluations and comparison between the considered sidelobes reduction techniques. Section 4 describes the new pulse compression filter for sidelobes reduction. On this basis, results and discussion are given in Section 5. Finally, Section 6 is the conclusion of the paper.

2. P4 CODES

P4 code is considered to be cyclically shifted [7, 13]. Accordingly, P4 code is not restricted to perfect square length but can also be constructed for any length N. P4 code is shown in [7] to be more Doppler tolerant and good tolerance for pre-compression bandwidth limitations compared to other poly phase code such as Frank, P1 and P2 code. The elements of P4 code are given by $u(i) = \exp[j\varphi(i)]$ and their phases are defined as

$$\text{P4:} \quad \varphi(i) = \frac{\pi}{N}(i-1)(i-1-N) \tag{1}$$

3. PERFORMANCE MEASURES

Let N denote the length of each polyphase code $u = \{u(0), u(1), \ldots, u(N-1)\}$. In the sequel, we provide the definitions of the measures used to assist with the performance comparisons of the effect of sidelobes reduction techniques on P4 code.

3.1. Integrated Sidelobe Level

The integrated sidelobe level ratio (ISL) of a code u of length N indicate the ratio of energy in the sidelobes to that in the mainlobe of the compressed pulse. It is defined as:

$$\mathrm{ISL}\,(\mathrm{dB}) = 10\log_{10}\frac{2\sum_{l=1}^{N-1}|C(l)|^2}{|C(0)|^2} \tag{2}$$

where $C(l)$ is amplitude of lth Sample Number of compressed pulse.

3.2. Peak Sidelobe Level

Similarly, the peak sidelobe level (PSL) of a code of length N measures the ratio of the maximum sidelobe magnitude $|C(l)|$ to the inphase value $C(0)$ of the autocorrelation function. It is defined as:

$$\mathrm{PSL}\,(\mathrm{dB}) = 20\log_{10}\frac{\max_{1\leq l\leq N}|C(l)|}{|C(0)|} \tag{3}$$

3.3. Relative Mainlobe Width

Usually sidelobe reduction techniques increase the mainlobe width. This increase causes the range resolution loss. Range resolution is an ability of the receiver to detect nearby targets. Relative mainlobe width for sidelobe reduction techniques on a code is defined as:

$$\text{Relative mainlobe width} = \frac{\dfrac{\text{Mainlobe width of technique in its PSL (dB) level}}{\text{PSL (dB) of technique}}}{\dfrac{\text{Mainlobe width of origin code in its PSL (dB) level}}{\text{PSL (dB) of origin code}}} \tag{4}$$

4. NEW PULSE COMPRESSION TECHNIQUE

Woo filter is a modified linear combination of matched filter for linear FM derived phase codes [11, 14]. The two correlation filters $\Omega 1$ and $\Omega 2$ are combined together to produce a single discrete filter called Woo filter. $\Omega 1$ is the autocorrelation function of the original code and $\Omega 2$

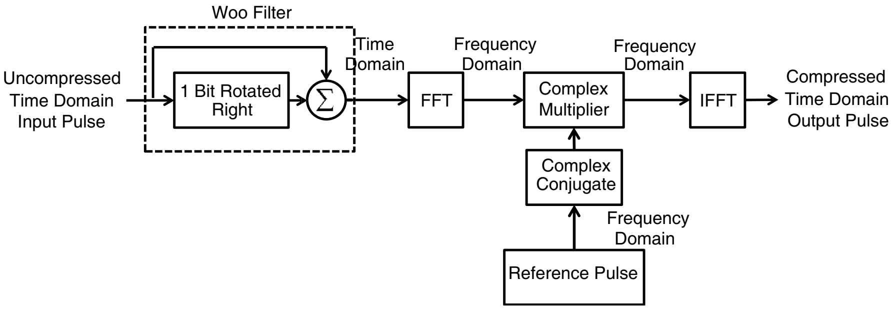

Figure 1. A block diagram of Woo filter in addition to matched filter based on FFT and IFFT.

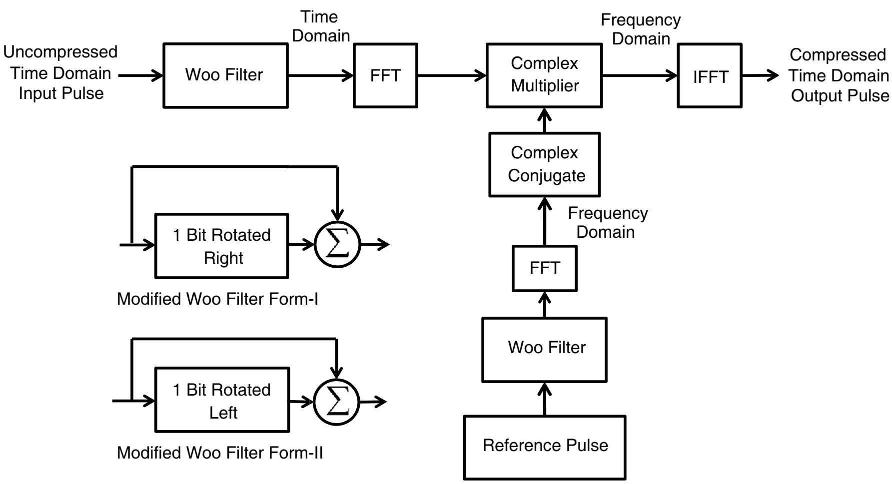

Figure 2. A block diagram of modified Woo filter in addition to matched filter based on FFT and IFFT.

is generated by correlating the original code with the conjugate signal of itself but shifted by one bit. Uniform sidelobe patterns have been achieved throughout the entire range bins except at the beginning and ends of the sidelobe sequences. Figure 1 indicates the implemented Woo Filter in addition to matched filter based on FFT and IFFT. The authors [12], proposed the modified version of Woo filter that formulated by adopting post compression processing. Two modified forms of Woo filter in addition to matched filter are shown in Figure 2.

In this paper, a new Pulse Compression technique is proposed for P4 coded signal in two forms. The structure of proposed technique in addition to matched filter are shown in Figure 3. In the form-I, The incoming P4 signal and one-bit rotated to right version of the incoming signal are combined to which amplitude weighting is applied. This is considered as the input signal of matched filter. One-bit rotated to left and one-bit rotated to right version and redoubled of P4 signal are summed. Also, this is considered as the reference signal in matched filter. The form-II is approximately the same as the form-I, except that one-bit rotated to right in input block in form-I replaced by one-bit rotated to left. In both forms, PSL and ISL have shown significant improvement in reduction over Woo filter and modified woo filters.

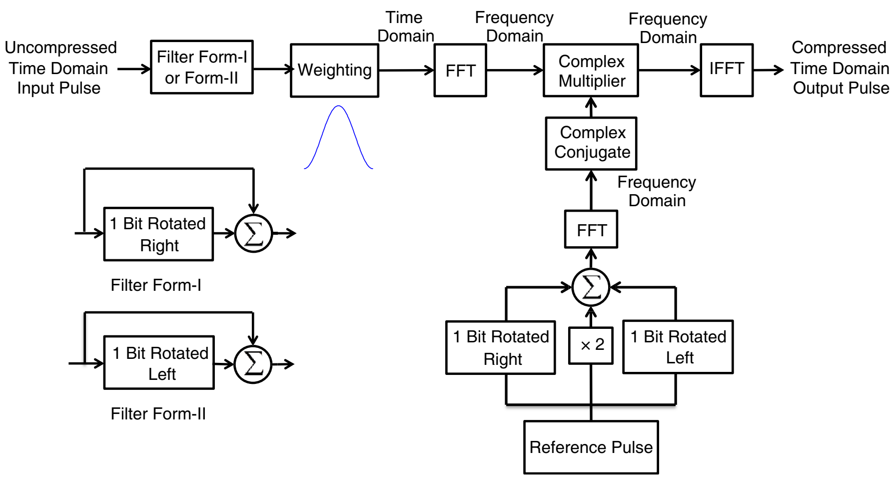

Figure 3. A block diagram of proposed technique for pulse compression based on FFT and IFFT.

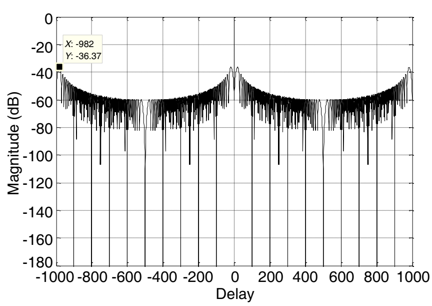

Figure 4. Compressed pulse of 1000-element P4 code.

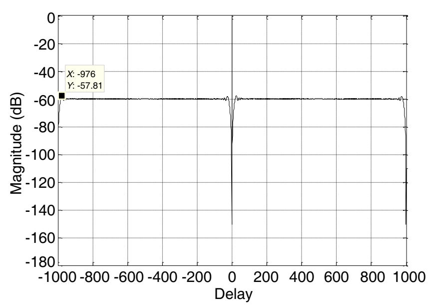

Figure 5. Pulse compression output generated by Woo filter for P4 code of length 1000.

5. RESULTS AND DISCUSSION

In this section we compare the performance measures of the new technique with different sidelobe reduction techniques, using P4 code of the length 1000.

Figure 4 shows compressed pulse of P4 code of the length 1000. The pulse compression output generated by Woo filter for P4 code is shown in Figure 5. The modified Woo filter of form-I and form-II responses are shown in Figures 6 and 7. The modified forms of Woo filter reduces the PSL further than Woo filter. Figures 8 and 9 show the proposed technique of form-I and form-II outputs without weighting. Applying weighting function reduces the sidelobe of compressed pulse.

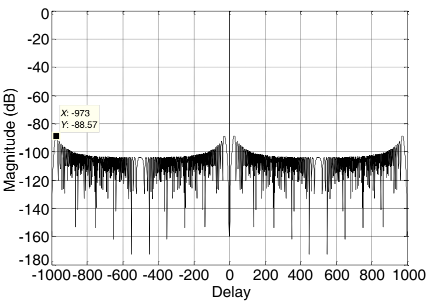

Figure 6. Pulse compression output generated by modified Woo filter of form-I for P4 code of length 1000.

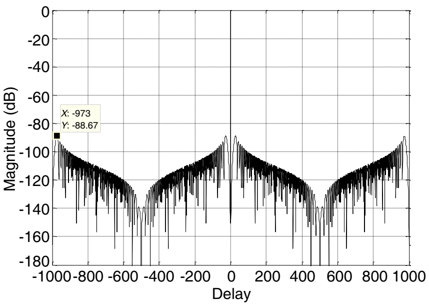

Figure 7. Pulse compression output generated by modified Woo filter of form-II for P4 code of length 1000.

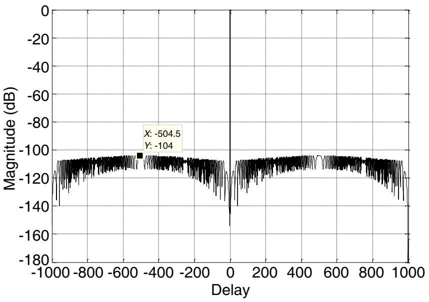

Figure 8. Pulse compression output generated by proposed technique of form-I for P4 code of length 1000 (without weighting).

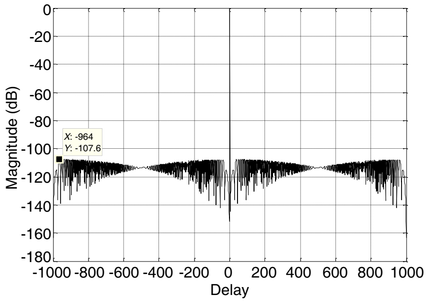

Figure 9. Pulse compression output generated by proposed technique of form-II for P4 code of length 1000 (without weighting).

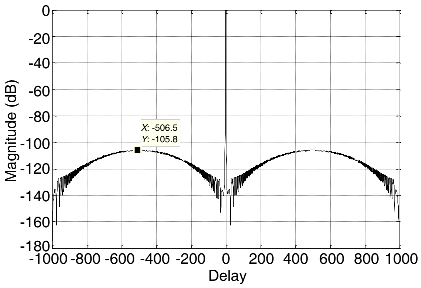

Figure 10. Pulse compression output generated by proposed technique of form-I for P4 code of length 1000 (with Hamming weighting).

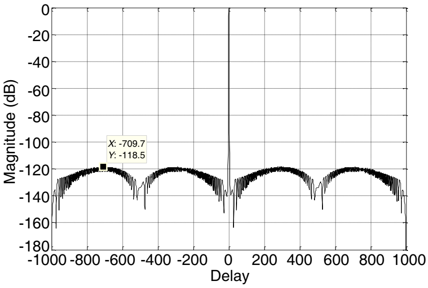

Figure 11. Pulse compression output generated by proposed technique of form-II for P4 code of length 1000 (with Hamming weighting).

Table 1. PSL, ISL and relative mainlobe width comparison for various sidelobe reduction techniques on P4 code.

Reduction technique sidelobe	Peak Sidelobes Level (dB)	Integrated Sidelobes Level (dB)	Relative Mainlobe Width
P4 code	−36.37	−16.993	1
Woo filter	−57.81	−27.08	2.01
Modified Woo filter form-I	−88.57	−68.3	2.068
Modified Woo filter form-II	−88.67	−69.56	2.12
Proposed filter form-I with rectangular window	−104	−75.18	2.51
Proposed filter form-II with rectangular window	−107.6	−79.11	2.4
Proposed filter form-I with Hamming window	−105.8	−77.5	4.89
Proposed filter form-II with Hamming window	−118.5	−89.95	5.58

Figures 10 and 11 represent the form-I and form-II outputs of the proposed technique with weighting using Hamming window. Applying weighting function reduces the sidelobe of compressed pulse. PSL, ISL and relative mainlobe width for Woo filter, modified Woo filters and form-I and form-II of the proposed technique for P4 code of the length $N = 1000$ are shown in Table 1.

For investigating in detail, at first, the proposed technique without weighting effect and then with weighting effect are compared with other reduction sidelobe techniques.

5.1. Without Weighting

From the results it is observed that, reduction around 16 dB of PSL and 7 dB of ISL is achieved using proposed technique compared with modified Woo filters and around 48 dB improvement of PSL and ISL over Woo filter. This improvements of PSL and ISL are respectively around 68 dB and 59 dB compared with ordinary P4 code. In form-II of proposed technique PSL and ISL Improved approximately 4 dB compared to form-I. But, this technique would only cost a small increase of relative mainlobe width.

5.2. After Weighting

Amplitude weighting is widely used for sidelobe reduction in pulse compression. In proposed technique, as represented in Figure 3, input signal of matched filter is weighted with window function. Hamming window is well known in radar pulse compression and it can be expressed as follows:

$$w(n) = 0.54 - 0.46 \cos\left(2\pi \frac{n}{N}\right) \quad 0 \leq n \leq N \tag{5}$$

Considering Figures 10, 11 and Table 2, it is observed that, using of weighting in proposed filter reduces PSL and ISL. This improvement in the form-II is more than the form-I. Weighting improved PSL and ISL nearly 10 dB in form-II of proposed technique, But it approximately doubled relative mainlobe width.

Other window can be use for weighting in proposed technique. Effect of Hann, Blackman and Nuttallwin windows in this technique for P4 code of the length $N = 1000$ are shown in Table 2.

Table 2. PSL and ISL comparison for various windows in proposed technique on P4 code.

Window	For Form-I		For Form-II	
	PSL (dB)	ISL (dB)	PSL (dB)	ISL (dB)
Hann	−106	−77.5	−120.3	−91
Blackman	−105.2	−77.8	−121.3	−92.55
Nuttallwin	−104.6	−77.75	−121.9	−93.7

6. CONCLUSIONS

In order to sidelobe reduction, this paper proposed a new technique in two forms. For investigation of its performance measure, it is compared with other technique such as Woo filter and modified Woo filters. Result show that the method introduced significant improves PSL and ISL, but increases the mainlobe width. Also, this paper indicated that using of amplitude weighting in the proposed technique, reduced PSL and ISL more but increased mainlobe width a little.

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