SIDELOBE REDUCTION TECHNIQUE FOR RADAR PULSE COMPRESSION CODES

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Abstract—Side lobe reduction using different widowing techniques for Radar Pulse Compression Codes like P1, P2, P3 and P4 along with ISL, PSL and SNR loss has studied. In this paper new technique is used to reduce autocorrelation peak side lobes level of pulse compression codes The Synthesized results of proposed technique is compared with Woo filter form-1, form-2.

General terms: Pulse compression; Woo filter; Range resolution

Keywords— Polyphase codes**.** Woo filter; Range resolution, Peak Side lobe level (PSL); Integrated Side lobe level (ISL); Signal to Noise Ratio (SNR)

I. INTRODUCTION

The pulse compression in radar has major applications in recent years. The most common radar signal or waveform is a series of short duration, somewhat rectangular- shaped pulses modulating a sine wave carrier. Short pulses are better for range resolution, long range detection carrier frequency and SNR. A long pulse is needed for some long-range radar to achieve energy to detect small targets. But long pulse has poor resolution in range dimension. Hence pulse compression is such technique to increase the spectral width of a long pulse to obtain the resolution of the short pulse. This paper proposes a new technique to reduce the PSL significantly.

II. PULSE COMPRESSION

Pulse compression (PC) is an important module in many of the modern radar systems [3, 4]. It is used to overcome major problem of radar system that requires a long pulse to achieve large radiated energy and a short pulse for range resolution. Range resolution is an ability of that receiver to detect nearby targets. The receiver matched filter output is the autocorrelation of the signal. If matched filter is not able to give a satisfactory PSL, a mismatch filter can be used as to reduce the side lobe further at a cost of introducing SNR mismatch loss. The major advantage of PC is its resulting gain in SNR and relative tolerance to jammers. PC can also lift small target signals out of the clutter. Woo and Griffiths proposed Woo filter to reduce the peak side lobe.

III. POLYPHASE CODES

The codes that use any harmonically related phases on certain fundamental phase increments are called polyphase codes. These codes with better Doppler tolerance and low range side lobes are frank and P1 codes are derived from step frequency [1, 2]. Bolter matrix derived P2 code and linear frequency derived P3 and P4 codes. In this paper, P4 code is used for simulation purpose and phase sequence of P4 code is given by

$$\varphi i = \left(\frac{\pi}{N}\right)(i-1)(i-N-1) \qquad (1)$$

Where i=1, 2….N and N represents the length of the code. The autocorrelation results can still be improved by using amplitude weighting techniques before performing autocorrelation.

IV. WOO FILTER

Woo filter is a modified linear combination of matched filter for linear FM derived phase codes. The two correlation filters Ω1 and Ω2 are combined together to produce a single discrete filter called Woo filter. Let S (t) is a polyphase code sequence directly derived from a conventional linear FM signal[5]. The function S (t) may be expressed as

$$S(t) = \sum_{p=0}^{N} \exp\left(j\frac{\pi}{N}p^2\right) U\left[\frac{t-\left(p+\frac{1}{2}\right)t_b}{t_b}\right] \qquad (2)$$

Where $U(t) = 1$ for $|t| < \frac{1}{2}$ and zero elsewhere, t_b is the time duration of one element of the codes sequences.

V. WOO -FILTER FORM-1

Here, three types of woo filters are considered. In form-I, one bit shifted version of the input code is combined with two bit shifted version and later the combined output signal is subjected to correlation. In form I, Two bit shifted P4 signal is considered as the received signal expecting one bit delay in transmitting and receiving process.

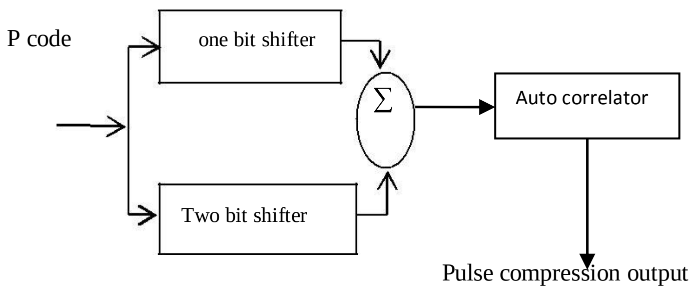

Fig. 1: WOO-FILTER FORM-I

VI. WOO-FILTER FORM-II

In the form-II the signal is combined with one -bit shifted version of itself and the resulting signal is passed through correlation process. This structure is known as form-II. In this form II, one bit shifted P4 signal is considered as the received signal expecting one bit delay in transmitting and receiving process.

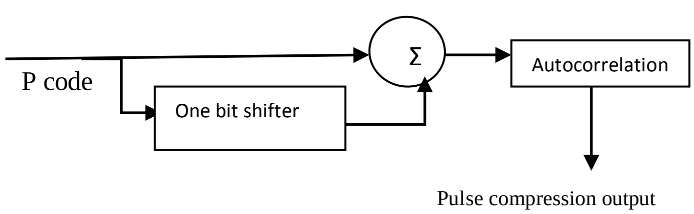

Fig. 2: WOO-FILTER FORM-II

VII. PROSPECTIVE RESULTS OF WOO-FILTER FORM-III

In this technique, combination of one-bit shifted version of the input signal, two-bit version of the input signal, three-bit version of the input signal along with the original input signal are added and then passed through Autocorrelator. Here, the input signal is the weighted polyphase code. The weighting techniques used here are Hamming, Hanning, Blackman, Kaiser, Rectangular, Turkey, flattop, Bartlett-Hanning, Parzen, Bohman, Blackman-Harris and Bartlett windows. This produces a high PSL and ISL for some windows which are discussed detailed in the following sections. The proposed filter is implemented as shown in below figure.

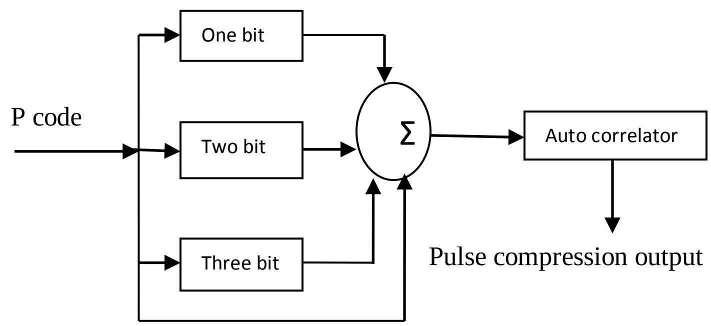

Fig. 3: WOO-FILTER FORM-III

VIII. PERFORMANCE MEASURES

A. Peak Side lobe Level (PSL)

Peak Side lobe level can be defined as the ratio of maximum of side lobe amplitude to the main lobe amplitude and is measured in decibels (DB).

$$PSL = 20\, log_{10}\left\{\left(\frac{\max_{i\neq 0}(r(i))}{r(0)}\right)\right\} \quad (3)$$

Where r(i) denotes side lobe levels of autocorrelation function (i≠0).

B. Integrated Side lobe Level (ISL)

Integrated Side lobe level is defined as the ratio of energy of all the side lobes to the energy of main lobe.

$$\text{ISL} = 10\,\log_{10}\sum_{i=-N}^{N}\left\{\frac{r(i)}{r(0)}\right\} \quad (4)$$

Where N denotes the length of the signal.

C. Signal to Noise Ratio (SNR)

The introduction of weighting window reduces the side lobes but increases SNR loss. SNR loss can be calculated using

$$\mathrm{SNR_{loss}} = \frac{\{\sum_{n=1}^{N} w(n)\}^2}{N\sum_{n=1}^{N} w(n)^2} \quad (5)$$

Where N denotes the length of the signal and w (n) represents the coefficients of the window function.

IX. SIMULATION RESULTS ANALYSIS

Different windowing function are used to reduce the PSL of pulse compression code. Results are compared in tables 1 to 3.

TABLE 1: PERFORMANCE OF WINDOWS AND WOO-FILTER ON P4 CODE (LENGTH=200)

Name of the window	Without woo filter		SNR Loss
	PSL (dB)	ISL (dB)	
Without window	-29.3	-14.6	-
Rectangular	-29.3	-14.6	0
Hamming	-59.9	-4.0	1.36
Hanning	-99.2	-15.3	1.78
Blackman	-98.8	-9.9	2.39
Kaiser	-67.4	-4.1	1.35
Blackman-Harris	-119.1	-16.4	3.03
Tukey	-99.2	-15.3	1.78
Flattop	-81.9	-13.1	4.45
Bohman	-71.7	-9.3	2.54
Bartlett	-40.9	-16.2	1.27

TABLE 2: PERFORMANCE OF WINDOWS AND WOO-FILTER ON P4 CODE (LENGTH=200)

Name of the window	Without woo-filter		With woo filter		SNR Loss
	PSL (dB)	ISL (dB)	PSL (dB)	ISL (dB)	
Without window	-29.3	-14.6	-67.2	-19.1	-
Rectangular	-29.3	-14.6	-67.2	-19.1	0
Hamming	-59.9	-4.0	-94.1	-16.1	1.36
Hanning	-99.2	-15.3	-119.9	-15.4	1.77
Blackman	-98.8	-9.9	-112.9	-12.3	2.38
Kaiser	-67.4	-4.1	-88.6	-16.3	1.34
Blackman-Harris	-119.1	-16.4	-130.9	-18.6	3.02
Tukey	-99.2	-15.3	-119.9	-15.4	1.77
Flattop	-82.4	-11.9	-93.5	-16.9	4.44
Bohman	-71.7	-9.3	-77.8*	-16.6	2.53
Bartlett	-40.9	-16.2	-47.9*	-10.2	1.26
barthann	-54.0	-15.5	-60.5*	-10.3	1.64

*PSL with woo-filter form-III.

TABLE 3: PERFORMANCE OF WINDOWS AND WOO-FILTER ON P4 CODE (LENGTH=144)

Name of the window	Without woo filter		With woo-filter		SNR Loss
	PSL (dB)	ISL (dB)	PSL (dB)	ISL (dB)	
Without window	-27.9	-13.9	-55.7	-12.0	-
Rectangular	-27.9	-13.9	-55.7	-12.0	0
Hamming	-57.2	-4.0	-78.4	-19.2	1.36
Hanning	-94.3	-15.3	-96.0	-18.6	1.78
Blackman	-95.6	-9.8	-104.4	-15.7	2.38
Kaiser	-64.9	-4.1	-78.6	-19.4	1.34
Blackman-Harris	-77.5	-16.5	-114.3	-13.6	3.02
Tukey	-94.3	-15.3	-96.0	-18.6	1.78
Flattop	-86.6	-13.1	-103.7	-20.8	4.44
Bohman	-76.7	-9.2	-82.4*	-15.1	2.53
Bartlett	-44.2	-16.2	-46.3*	-15.8	1.26
barthann	-57.3	-15.4	-58.7*	-17.9	1.64

*PSL with woo-filter form-III

TABLE 4: COMPARISION OF PSL OF P4 CODE (LENGTH=200) WITHOUT WOO-FILTER, WITH WOO-FILTER (FORM-I, FORM-II) AND FOR PROPOSED TECHNIQUE ALONG WITH SNR LOSS

Name of the window	PSL Without woo-filter	PSL With woo-filter			SNR Loss
		Form-I	Form-II	Form-III	
Without window	-29.3	-39.3	-67.2	-60.3	-
Rectangular	-29.3	-39.3	-67.2	-60.3	0
Hamming	-59.9	-65.9	-94.1	-84.1	1.78
Hanning	-99.2	-98.0	-119.9	-104.5	1.36
Blackman	-98.8	-116.7	-112.4	-112.9	2.39
Kaiser	-67.4	-72.1	-88.6	-84.1	1.35
Blackman-Harris	-119.1	-121.1	-130.9	-122.8	3.03
Tukey	-99.2	-98.0	-119.9	-104.5	1.36
Flattop	-81.9	-107.1	-93.5	-104.2	4.45
Bohman	-71.7	-83.8	-87.3	-77.8	2.54
Bartlett	-40.92	-46.6	-38.5	-47.9	1.27

Table 1 shows performance of P4 code of length 200 with different windows and WOO- Filter. As shown in table (1), the best Side lobe of -119.1 dB and ISL of -16.49 dB are obtained for Blackman-Harris Window which is compared to

PSL of -29.3 dB and ISL of -14.6 dB without any window. But Blackman-Harris Window introduces SNR Loss of 3.03 dB

Table 2 shows performance of P4 code of length 200 with different windows and WOO- Filter. From table (2), it can be shown that Bohman, Bartlett and Barthann windows with woo filter form-III gives lower Side lobes of -77.8dB, -47.9 dB and -60.5 dB respectively when compared to the other forms of woo filter for P4 Code of length 200, As shown in table (2), minimum Side lobe of -119.1 dB and ISL of -16.4 dB is obtained by applying Blackman-Harris window with SNR loss of 3.02 dB. This Side lobe is far less than -29.3 dB and ISL of -14.6 dB which is obtained without window. If woo filter is used, then the minimum Side lobe of -130.9 dB(Form-II) and ISL of -18.6dB is obtained for Blackman-harris window with SNR loss of 3.02 dB compared to PSL of -67.2 dB and ISL of -19.1dB obtained without window.

From table 3, Bohman, Bartlett and Barthann windows with woo filter form-III gives less Side lobes of -82.4 dB, -46.3 dB, and -58.7 dB respectively when compared to the other forms of woo filter for P4 code of length 144.

Fig. 4 shows the performance of P4 code of length 200 with different windowing techniques without Woo filter. Fig.(5) shows the performance of P3 code of length 200 with different windowing techniques and Woo filter form-1. Fig 6. Shows the Autocorrelation results of P4 Code (length=200) with different windows with woo-filter form-I. Fig 7. Shows the Autocorrelation results of P4 Code (length=200) with different windows with woo-filter form-II.

From the result analysis it can be shown that Woo filter is effective to suppressed Side lobes.

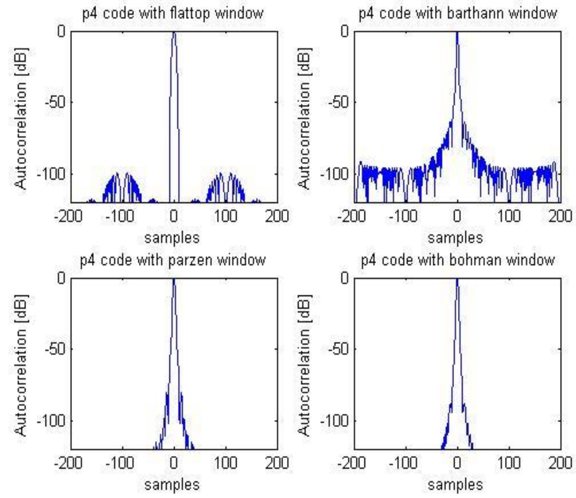

Fig. 4: Autocorrelation results of P4 Code (length=200) with different weighting techniques

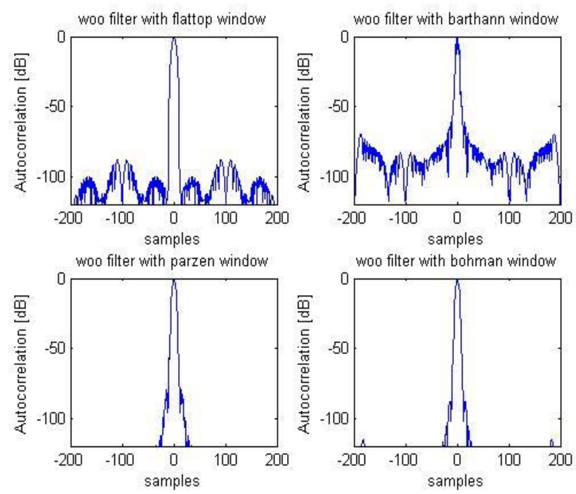

Fig. 5: Autocorrelation results of P3 Code (length=200) with different windows with woo-filter form-I.

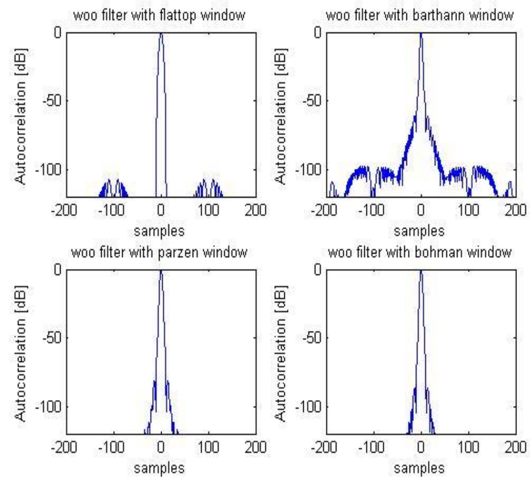

Fig 6. Autocorrelation results of P4 Code (length=200) with different windows with woo-filter form-I.

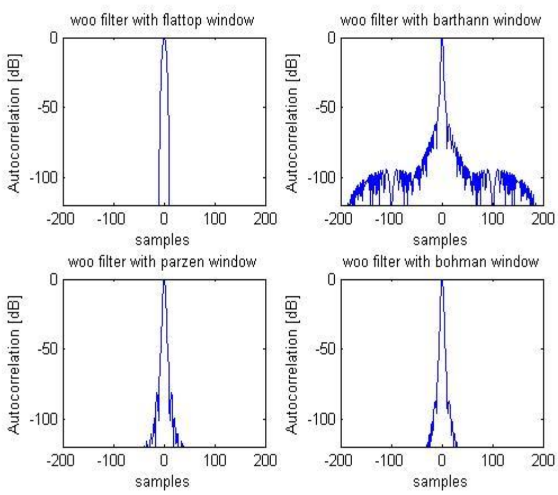

Fig. 7: Autocorrelation results of P4 Code (length=200) with different windows with woo-filter form-II.

X. CONCLUSION

After results analysis, it is found that minimum Side lobe of -119.1 dB is obtained by applying Blackman-Harris Window on P4 code. For P4 Code of length 200, the best Side lobe of -130.9dB and ISL of -18.6 dB is obtained for Blackman-Harris Window with woo filter with SNR loss of 3.03 dB. .With the proposed woo filter from-III, Barthann, Bohman and Bartlett windows gives better Side lobes suppression than the other windows for P4 code (length=200). For P4 code of length 144, the proposed woo filter gives better Side lobes for Bartlett, Blackman-harris, Bohman and Barthann windows.

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