Polyphase Codes Sidelobes Suppression

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***Abstract*—**In this paper, the performance of different windowing techniques and Doppler shift on polyphase codes viz., P3 and P4 codes without and with woo filter along with SNR loss and ISL has studied. A new modified woo filter form-III is proposed which gives better sidelobes suppression for some windows.

Keywords*—Peak Sidelobe level (PSL); Integrated Sidelobe Level (ISL); Signal to Noise Ratio (SNR); Polyphase Codes; Woo filter*

I. INTRODUCTION

Long pulse waveforms have low range resolution and short pulse waveforms have low Doppler resolution. Range resolution is the ability of the receiver to detect two closely spaced targets and Doppler resolution is the ability of receiver to detect two targets that are in same range cell but moving with different radial velocities. Pulse compression is the technique, which allows radar designers to obtain high energy of long pulse (good Doppler resolution) and high resolution of the short pulse (good range resolution) [1]. Pulse Compression can be achieved by modulating transmitted pulse either with frequency or phase. The received signal is then passed through matched filter whose output consists of a main lobe with peak amplitude and side lobes. In general, to detect strong and weak targets simultaneously, it is desirable that the sidelobes levels of the autocorrelated output should be minimum. However, the sidelobes are reduced at the cost of SNR loss. This paper proposes woo filter form-III, which gives better sidelobes suppression for some windows.

II. WOO FILTER

Woo filter is a technique used to reduce sidelobes levels which are decided by the length of the code as proposed by Woo and Griffiths [4]. Here, three types of woo filters are considered. In form-I, first, the input code is shifted to one bit and two bits. Second, both are added and passed through the autocorrelator as shown in Fig. 1. In woo Filter form-II, the one bit shifted signal is added with the input signal and passed through the autocorrelator. In this paper, author proposes woo filter form-III. In proposed Woo filter form-III, the weighted P code shifted by one bit, two bits, three bits are added along with the input reference signal and then passed through autcorrelator, which is shown in Fig. 2. This woo filter gives better sidelobes suppression for some windows which are explained in results analysis.

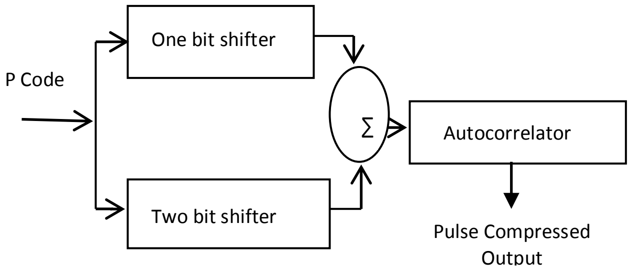

Fig. 1. WOO-FILTER FORM-I

III. POLYPHASE CODES

Phase modulation is mostly used for pulse compression because it clearly discriminates between two overlapped signals. Either binary phase coding or polyphase coding can be used. Polyphase codes are one whose phases are related harmonically [2]. In this paper, the weighting effect of various windows and woo filter on P3 and P4 codes is studied. P3 code phases are generated using

$$\emptyset_i = \left(\frac{\pi}{N}\right)(i-1)^2 \qquad (1)$$

where i=1,2,….N and N represents the length of the code. P3 code is more Doppler tolerant than frank, P1 and P2 codes [4]. P4 code phases are generated using

$$\emptyset_i = \left(\frac{\pi}{N}\right)(i-1)(i-N-1) \qquad (2)$$

where i=1,2,….N and N represents the length of the code. P4 code is more tolerant to pre-compression bandwidth limitation but same Doppler tolerance as P3 code [4]. The autocorrelation results can still be improved by using amplitude weighting techniques before performing autocorrelation [2]. The windows used are hamming, hanning, blackman, Kaiser, Blackman-Harris, Tukey, Flattop, Bohman and Parzen windows. These windows are used to reduce the sidelobes. The performance of P3 and P4 polyphase codes with different windows is tabulated below. All the autocorrelation outputs are studied under zero Doppler shift.

IV. PERFORMANCE MEASURES

A. Peak Sidelobe Level (PSL)

Peak Side lobe level can be defined as the ratio of maximum of sidelobe amplitude to the mainlobe amplitude and is measured in decibels (dB) [4].

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

Where r(i) denotes sidelobe levels of autocorrelation function ($i \neq 0$)

B. Integrated Sidelobe Level (ISL)

Integrated Sidelobe level is defined as the ratio of energy of all the sidelobes to the energy of mainlobe [5].

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

Where N denotes the length of the signal

C. Signal to Noise Ratio (SNR)

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

$$SNR_{loss} = \frac{\left(\sum_{n=1}^{N} w(n)\right)^2}{N \sum_{n=1}^{N} w(n)^2} \tag{5}$$

V. PROPOSED WOO FILTER

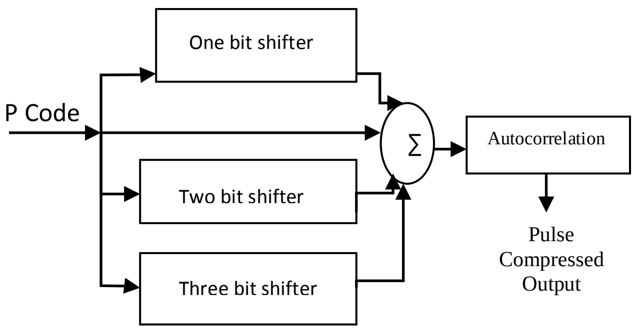

Fig. 2. WOO FILTER FORM-III

The proposed Woo filter form-III can be implemented by adding input referenced signal, one bit, two bit, three-bit shifted signals and autocorrelated. The input referenced signal is weighted P code. With this woo filter form-III, some windows gives better sidelobes reduction and the others do not.

VI. RESULTS ANALYSIS

TABLE I. PERFORMANCE OF WINDOWS AND WOO FILTER ON P3 CODE (LENGTH=100)

Name of the Window	Without Woo Filter		SNR Loss (dB)
	PSL(dB)	*ISL (dB)*	
Without Window	-26.32	-11.40	-
Rectangular	-26.32	-11.46	0
Hamming	-54.03	-5.50	1.37
Hanning	-86.17	-12.09	1.71
Blackman	-101.7	-13.08	2.41
Kaiser (β=5)	-62.09	-6.62	1.37
Blackman-Harris	-113.5	-13.90	3.06
Tukey	-86.17	-12.09	0.91
Flattop	-86.63	-11.85	5.80
Bohman	-76.76	-13.98	2.56

TABLE II. PERFORMANCE OF WINDOWS AND WOO FILTER ON P4 CODE (LENGTH=100)

Name of the Window	Without Woo Filter		With Woo Filter		SNR Loss (dB)
	PSL (dB)	*ISL (dB)*	*PSL (dB)*	*ISL (dB)*	
No Window	-26.3	-11.9	-57.82	-15.5	-
Rectangular	-26.3	-12	-57.82	-15.5	0
Hamming	-54.0	-5.7	82.12	-18.28	1.37
Hanning	-86.1	-12	-	-	1.71
Blackman	-104.5	-13.1	-113.6	-18.35	2.41
Kaiser (β=5)	-62.1	-6.80	-76.6	-18.1	1.37
Blackman-Harris	-113.6	-13.9	-129.1	-18.4	3.06
Tukey	-86.1	-13.7	-102.6	-11.08	0.91
Flattop	-86.6	-11.9	-113.8	-18.6	5.80
Parzen	-69.0	-13.8	-73.2*	-17.41	2.82
Bohman	-76.7	-14.1	-78.9*	-17.78	2.56
Bartlett-Hanning	-58.1	-10.4	-57.79	-8.67	1.67
Bartlett	-45.1	-9.4	-47.1*	-17.71	1.29

***** - PSL with woo filter form-III

TABLE III. PERFORMANCE OF WINDOWS AND WOO FILTER ON P4 CODE (LENGTH=64)

Name of the Window	Without Woo Filter		With Woo Filter		SNR Loss (dB)
	PSL (dB)	*ISL (dB)*	*PSL (dB)*	*ISL (dB)*	
Without Window	-24.3	-10.9	-51.73	-14.68	-
Rectangular	-24.3	-10.9	-51.73	-14.68	0
Hanning	-79.8	-10.4	-	-	1.71
Hamming	50.4	-4.3	-74.24	-15.72	1.37
Blackman	-94.7	-11.2	-102	-9.57	2.41
Kaiser (β=5)	-59.1	-5.4	-69.15	-15.15	3.06
Blackman-Harris	-110	-11.6	-118.1	-15.13	3.06
Tukey	-79.8	-10.3	-90.05	-8.36	0.91

Flattop	-85.1	-9.92	-105.1	-15.92	5.80
Parzen	-82.6	-10.81	-77.29*	-15.56	2.82
Bohman	-86.9	-11.68	-75.63*	-15.82	2.56
Bartlett-Hanning	-55.1	-9.08	-56.97*	-15.87	1.67
Bartlett	-41.9	-8.5	-45.03*	-16.04	1.31

* - PSL with woo filter form-III

A. *Performance of Polyphase Codes with Doppler Shift*

Doppler shift is defined as the difference between the frequency received and the frequency transmitted [1]. Doppler Shift increases the side lobe hence introducing SNR loss.

1) P3 Code with Doppler shift of 0.05: The Doppler shift of 0.05 increases the sidelobe from -26.32 dB to -22.31 dB with SNR loss of 1.18.

TABLE IV. PERFORMANCE OF P3 CODE UNDER DOPPLER SHIFT OF 0.05

Length of the Code	PSL without Doppler shift (dB)	PSL with Doppler shift (dB)	SNR Loss
100	-26.32	-22.31	1.18
64	-24.35	-19.19	1.26
36	-21.94	-14.65	1.49

2) P4 Code with Doppler shift of 0.05: The Doppler shift of 0.05 increases the sidelobe to -22.31 dB and introduces SNR loss of 1.18 which is similar to P3 Code but P4 code has more tolerance to pre-compression bandwidth limitation. The performance results of different weighting techniques on different polyphase codes are analyzed in detail.

TABLE V. PERFORMANCE OF P4 CODE UNDER DOPPLER SHIFT OF 0.05

Length of the Code	PSL without Doppler shift (dB)	PSL with Doppler shift (dB)	SNR Loss
100	-26. 32	-22.31	1.18
64	-24.35	-19.19	1.26
36	-21.94	-14.65	1.49

3) Autocorrelation Results of P3 Code and P4 Code (Length=100): From table (2), parzen, Bohman and Bartlett windows with woo filter form-III gives better sidelobes of -73.23 dB, -78.9 dB and -47.07 dB respectively when compared to the other forms of woo filter for P4 Code of length 100.

From table (3), Bartlett, Bartlett-hanning, bohman and Parzen windows with woo filter form-III gives reduced sidelobes of -45.03 dB, -56.97 dB, -75.63 dB and -77.29 dB respectively when compared to the other forms of woo filter for P4 code of length 64.

As shown in figure (3) and table (1), the best Sidelobe of -113.5 dB and ISL of -13.90 dB are obtained for Blackman-Harris Window which is compared to PSL of -26.32 dB and ISL of -11.40 dB without any window. But Blackman-Harris Window introduces SNR Loss of 3.06 dB.

As shown in figure (4) and Table (2), minimum sidelobe of -113.6 dB and ISL of -13.89 dB is obtained by applying Blackman-Harris window with SNR loss of 3.06 dB. This sidelobe is far less than -26.32 dB and ISL of -11.99 dB which is obtained without window. If woo filter is used, then the minimum sidelobe of -129.1 dB and ISL of -18.15 dB is obtained for Blackman-Harris window with SNR loss of 5.80 dB compared to PSL of -57.82 dB and ISL of -15.5 dB obtained without window.

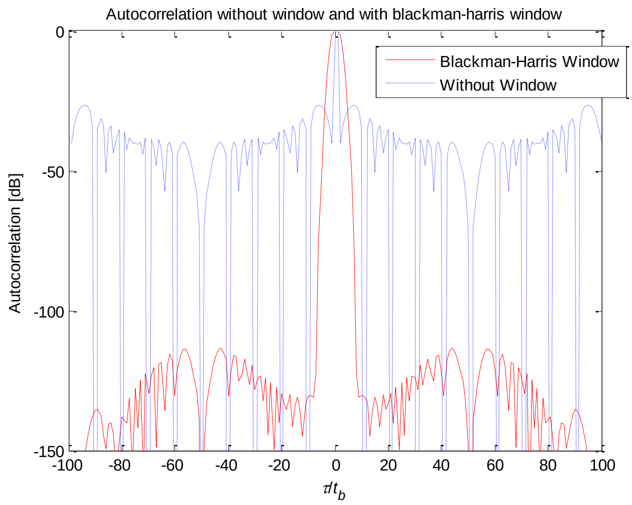

Fig.3: Autocorrelation of P3 code (length=100) without and with Blackman-Harris window

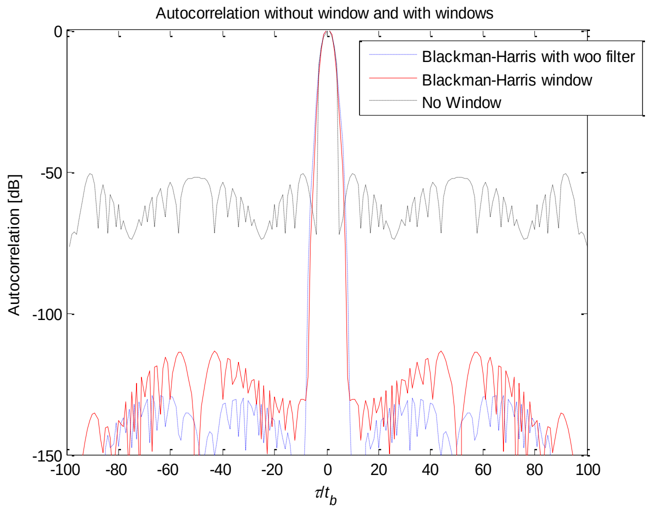

Fig.4: Autocorrelation of P4 code (length=100) without and with Windows

VII. CONCLUSION

After results analysis, it is found that minimum sidelobe of -113.5 dB is obtained by applying Blackman-Harris Window on P3 code. For P4 Code of length 100, the best sidelobe of -129.1dB and ISL of -18.15 dB is obtained for Blackman-Harris Window with woo filter with SNR loss of 5.80 dB. For P4 Code of length 64, the sidelobe of -118.1 dB and ISL of -15.13 dB is obtained by applying Flattop window with woo filter (Form-II) with an SNR loss of 3.06 dB. When Doppler shift of 0.05 is introduced on P3 Code, sidelobe of -22.31 dB is obtained for P4 Code o f length 100 with SNR loss of 1.18. The same sidelobe is obtained for P4 Code when Doppler shift of 0.05 is introduced. With the proposed woo filter from-III, parzen, Bohman and bartlett windows gives better sidelobes suppression than the other windows for P4 code (length=100). For P4 code of length 64, the proposed woo filter gives better sidelobes for Bartlett, Barlett-hanning, Bohman and parzen windows.

VIII. REFERENCES

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