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Doppler Tolerant Convolutional Windows for Radar Pulse Compression

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Abstract

Pulse compression technique is used to enhance radar performance in terms of more efficient use of high power transmitters and increasing the system resolving capability. The polyphase pulse compression codes (P3 and P4) which are derived from linear frequency modulated waveforms have low sidelobes and are Doppler tolerant. To reduce the sidelobes further different types of windows have been used as the weighing function at the receiver. In this paper convolutional windows are used as weighing function for radar pulse compression which are more insensitive to Doppler shift as compared to conventional windows. From simulation study it is observed that the radar pulse compression technique using convolutional window as weighing function provides higher peak to sidelobe ratio (PSR) at higher Doppler shifts.

Keywords: Pulse compression, Polyphase code, Doppler shift, Convolutional windows, PSR.

Introduction

Pulse compression technique is essentially used by the pulse radars in order to obtain high pulse energy and large bandwidth. High accuracy without sacrificing the range resolution is obtained in peak power limited radars. In the receiver the reflected target echo signals are passed through a filter matched to the transmitted expanded impulse response which compresses the echo signal into a short pulse. But the matched filter output contains not only a compressed impulse but also undesired range sidelobes. These range sidelobes may mask the main peaks of small targets situated near large targets. Hence low level of range sidelobes are desired in a multiple target radar environment.

Phase coded waveforms usually used in radar for digital pulse compression. Digital waveforms are usually biphase modulated sinusoids, with two possible phases being 0 and 180 degree. But for a given sequence length the matched filter output of biphase codes contain large sidelobes. The lowest sidelobe biphase codes are Barker codes. These codes are known as perfect codes because the highest sidelobe has only one code element amplitude high. However the barker codes are available for limited lengths 2,3,4,5,7,11, and 13. The largest peak to sidelobe ratio (PSR) for a 13 bit barker code is 22.3 dB which is not suitable for many radar applications. As the number of Barker codes available are very less, these codes seriously suffer from security problem.

Instead of using biphase codes, the polyphase codes are also chosen for pulse compression to achieve better PSR and to avoid the security problem. Lewis and Kretschmer [1] have proposed suitable methods to generate P1 and P2 polyphase codes which are derived from the step approximation to a linear frequency modulated waveform. These polyphase codes are more tolerant to the limitedness of the receiver section bandwidth prior to pulse compression as compared to Frank code. In subsequent publication [2] they have suggested another two codes named as P3 and P4 codes which are derived from a linear frequency modulated waveform. These codes are more Doppler tolerant than P1 and P2 codes. It is described in [3] that peak sidelobes of P3 and P4 codes are larger than other polyphase codes, but performance of these codes degrade less with increase in Doppler frequency. A sliding window technique for reducing range-time-sidelobes of polyphase codes significantly is presented in [4]. By using this technique highest sidelobe reduces to only one code element magnitude irrespective of effective pulse compression ratio. The autocorrelation function (ACF) of polyphase codes contains undesired range sidelobes which may create problem in multi-target detection. Sidelobe reduction of polyphase codes using different types of amplitude weighing function in the receiver filter have been discussed in [5]. Although weighing windows when used both on transmitter and receiver provides better results, weighing on receiver is preferred because weighing on transmit leads to a power loss since the available transmit power cannot be fully utilized. Luszczyk and Mucha [6] have applied Kaiser-Bessel weighing function to reduce range sidelobes of P4 pulse compression waveforms. In the presence of high Doppler shift the performance of these weighing techniques are poor. In this paper convolutional windows are employed as amplitude weighing function to obtain better PSR at higher Doppler shifts.

Polyphase Codes

The codes that use only harmonically related phase based on certain fundamental phase increments are called polyphase codes. Polyphase codes exhibit better Doppler tolerance for broad range-Doppler coverage than biphase codes and they exhibit relatively good sidelobe characteristics. Polyphase compression codes have been derived from step approximation to linear frequency modulation waveforms (Frank,P1,P2) and linear frequency waveforms (P3,P4). Amplitude weighing is not used in case of Frank, P1 and P2 codes because of their unsatisfactory performance. In this work amplitude weighing is used with P4 codes.

P3 and P4 codes

To generate P3 code a linear frequency modulated waveform is converted to baseband using a local oscillator on one end of the frequency sweep and sampling the in phase I and quadrature phase Q video at Nyquist rate.

The phase sequence of P3 signal is given by

$$\Phi_i = \frac{\pi}{N}(i-1)^2 \tag{1}$$

where $i = 1, 2, ...N$ and N=Sequence length

The autocorrelation function value of P3 code with length 100 is shown in Figure.1(a)

P4 code is generated by coherent double sideband detection of a linear modulating waveform and sampling at Nyquist rate. The phase sequence of P4 is given by

$$\Phi_i = \frac{\pi}{N}(i-1)^2 - \pi(i-1) \tag{2}$$

The autocorrelation function value of P4 code with length 100 is shown in Figure 2(a). It is clear from Figures. 1(a) and 2(a) that the matched filter output are almost identical. It is observed from the phase angle plots (Figures. 1(d) and 2(d)) that the largest phase increment from code element to code element are on the two ends of the P4 code but in case of P3 code the largest phase increment from code element to code element occurs at the middle. So P4 code is more precompression bandwidth limitation tolerant than the P3 code.

Due to Doppler shift, when the radar waveform reflects from a moving target changes the radar waveform. Objects with larger velocities experience detection range degradation due to Doppler shift. The reflected pulse is mathematically represented as multiplying the transmitted code as $e^{j2\pi i f_d / B}$ and passed through a receiver filter whose impulse response is matched to transmitted expanded pulse. Here f_d is the Doppler shift and B is the waveform bandwidth. So the Doppler shifted reflected pulse is no longer matched to the receiver filter hence signal to noise ratio (SNR) loss occurs. The Doppler shifted output of P3 code for $\frac{f_d}{B} = 0.05$ and 0.1 are shown in Figures 1(b) and 1(c) and that of P4 code is represented in Figures 2(b) and 2(c). It is observed that under Doppler shift PSR values of both codes are equal.

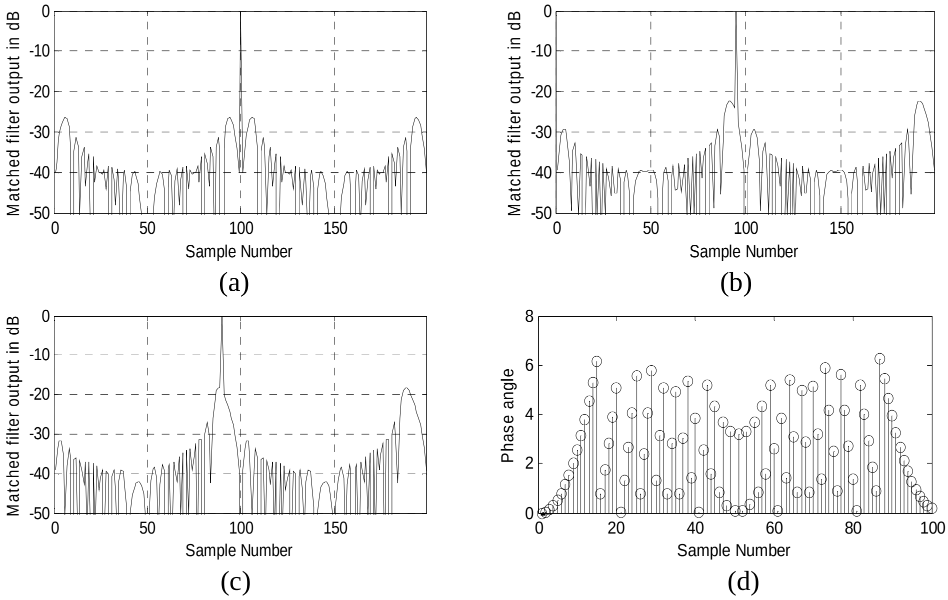


Figure 1: Matched filter output of P3 code (a)Without Doppler shift (b)0.05 Doppler shift (c)0.1 Doppler shift (d)Phase angle.

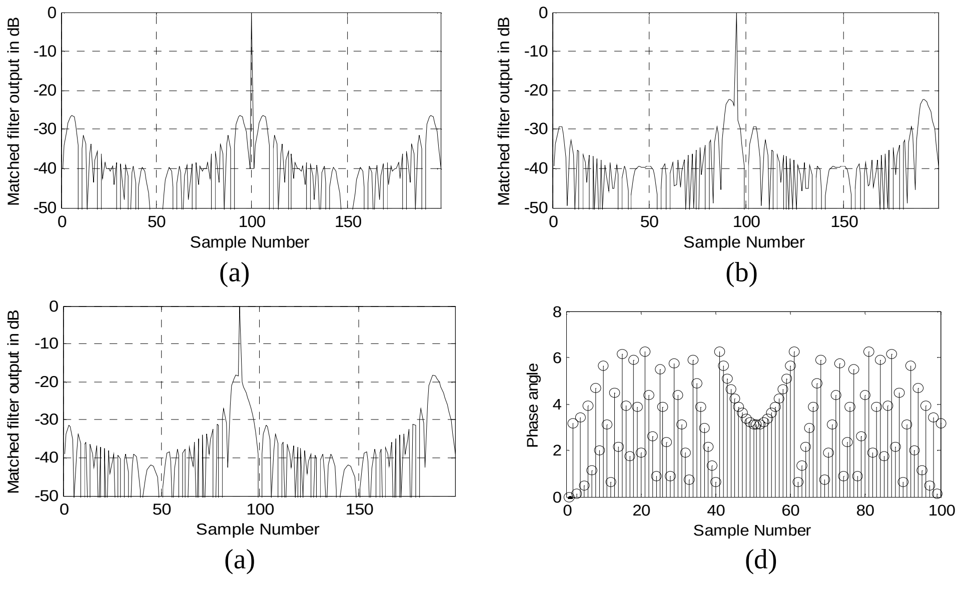
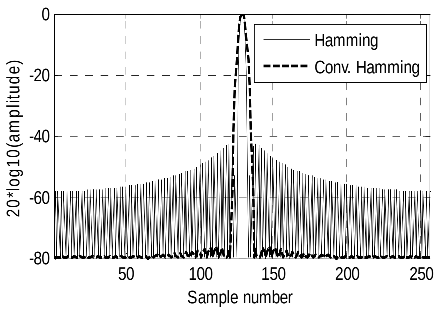


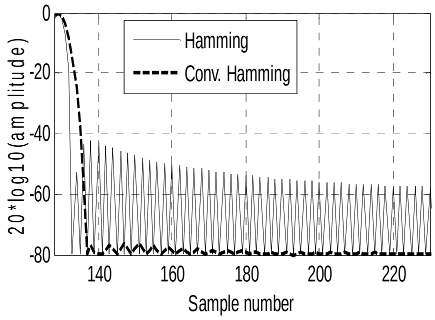
Figure 2: Matched filter output of P4 code (a)Without Doppler shift (b)0.05 Doppler shift (c)0.1 Doppler shift (d)Phase angle.

Convolutional Windows

Convolutional windows are derived by convolving the window with itself. Reljin *et. al* [7] have discussed a class of windows that are generated by the time convolution of classical windows to obtain both flat top high sidelobe attenuation. These windows are suitable for harmonic amplitude evaluation in nonsynchronous sampling case. The convolutional windows from second to eighth order for rectangular window is derived in [8]. These windows applied for high accuracy harmonic analysis and parameter estimation of periodic signals. Phase difference algorithm based on Nuttal self-convolutional window is used to eliminate the measurement errors of dielectric loss factor [9]. Dielectric loss factor is caused by non-syncronised sampling and non-integral periodic truncation conditions. A self convolution hanning window used to complex signal harmonics parameter estimation is presented in [10]. The convolutional window based phase correction algorithm suppresses the impact of fundamental frequency fluctuation and white noise on harmonic estimation.



(a)



(b)

Figure 3: Frequency response curve (a)Hamming And Convolutional Hamming window (b)Zoomed version.

The discrete time Hamming window of length *M* is represented as

$$w_H(m) = 0.54 - 0.46\cos\left(\frac{2\pi m}{M}\right) \quad (3)$$

where $m = 0,1,......,M-1$.The Hamming self convolutional window is formed by convolving $w_H(m)$ with itself. The length of the convolutional window is $2M-1$. So a zero is padded to get the second order convolutional window with length $2M$.

A Hamming self convolution frequency response is shown in Figure.4. Here *M*=128 is chosen for conventional hamming window. To get a convolutional window we first chose a window of length 64. Then this window is convolved with itself to give a 127 point window. A zero is padded to get a 128 point window for comparison purpose.

Simulation Results

Here P4 code of length 100 is used for simulation study. Various windows available in the MATLAB library is used for amplitude weighing. From Figures 1 and 2 it is observed that due to Doppler shift the near in and far out sidelobes are mostly affected. The weighing function which can suppress these sidelobes are more Doppler tolerant.

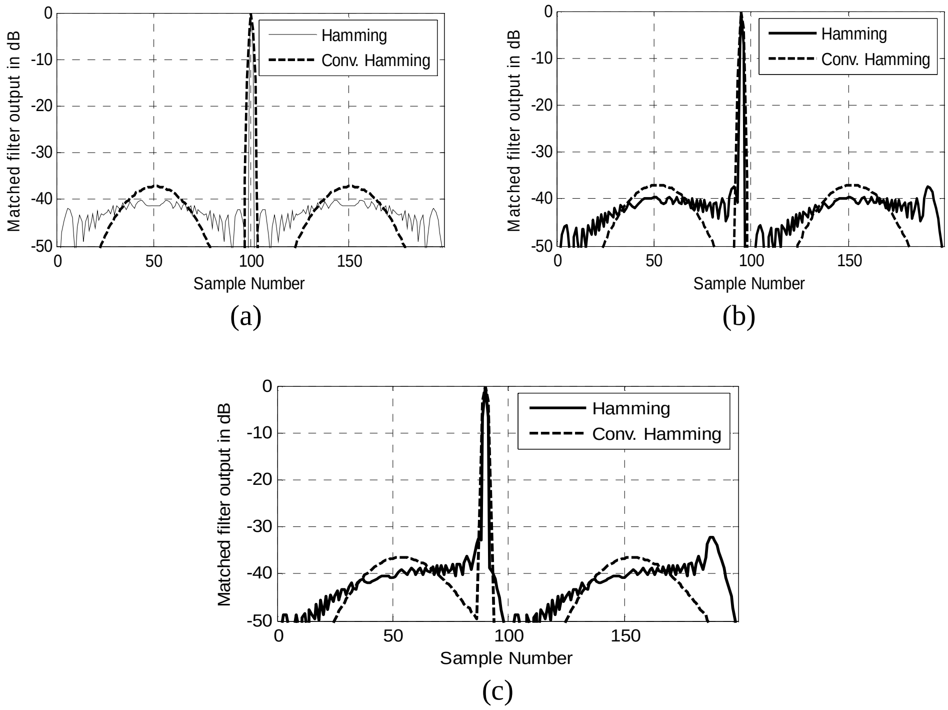


Figure 4: Effect on sidelobes due to Doppler shift(a)without doppler shift and (b) 0.05 Doppler shift (c) 0.1 Doppler shift.

Table 1: Comparison of PSR for different Doppler shift.

Doppler Shift $\left(\frac{f_d}{B}\right)$	PSR using Hamming window in dB	PSR using convolutional Hamming window in dB
0.01	40	37.17
0.05	37.3	37
0.1	32	36.5
0.15	27	35.7
0.2	22.18	33
Doppler Shift $\left(\frac{f_d}{B}\right)$	PSR using Hanning window in dB	PSR using convolutional Hanning window in dB
0.01	40	36.3
0.05	39.6	36.1
0.1	37.1	35.7
0.15	30	35

0.2	25	33.6
Doppler Shift $\left(\frac{f_d}{B}\right)$	PSR using Blackman window in dB	PSR using convolutional Blackman window in dB
0.01	38.3	35
0.05	38.23	34.9
0.1	37.7	34.5
0.15	35.8	33.8
0.2	29.8	32.6
Doppler Shift $\left(\frac{f_d}{B}\right)$	PSR using Kaiser window in dB $(\beta = 5.44)$	PSR using convolutional Kaiser window in dB
0.01	40.1	36.8
0.05	37.9	36.7
0.1	33.8	36.2
0.15	28.2	35.4
0.2	23	34
Doppler Shift $\left(\frac{f_d}{B}\right)$	PSR using Chebysev window in dB $(\sigma = 50)$	PSR using convolutional Chebysev window in dB
0.01	39	37
0.05	37.9	36.8
0.1	33.3	36.3
0.15	27.8	35.5
0.2	22.7	33.8

In Figure.3 it is depicted that the convolutional Hamming window has lowered the near in and far out side lobes compared to Hamming window. But the side lobes in the middle has increased. At the higher Doppler shift values the convolutional windows giving better result as compared to conventional windows. The PSR values under different Doppler shifts using different windows are presented in Table 1. From the Table it is observed that for lower values of Doppler shift i.e $\left(\frac{f_d}{B}\right) = 0.01$ the PSR values for classical windows are better than that of convolutional windows. But as the Doppler shift increases the PSR values for classical windows drops rapidly as compared to convolutional windows.

Conclusions

In this paper convolutional windows are applied for radar pulse compression and compared with the performance of conventional windows. From Figure 4 it is evident that the near in and farther out sidelobes are suppressed by using convolutional windows which are mostly affected by Doppler shift. From the simulation results it is evident that variation of PSR values in case of convolutional windows is less as compared to that of conventional windows and also the PSR value of convolutional windows is greater at higher Doppler shifts. In case of convolutional windows the mainlobe width is slightly increased, so this technique has less range resolution.

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