A New Sidelobe Reduction Technique For Range Resolution Radar

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Abstract:
In radar and communication applications not only low time sidelobes but also uniform sidelobes are important. Polyphase codes have low sidelobes and are more Doppler tolerant, but correlated sidelobes are not uniform. New filters are modeled in this paper for polyphase codes to reduce the sidelobes and also to generate uniform sidelobes. Uniform sidelobe pattern is useful for detection of weak targets. In this paper, a new model is proposed for P4 signal as well as for E-P4 signal to reduce sidelobes.

Keywords: Polyphase code, Doppler, Sidelobes, Peak sidelobe, Integrated sidelobe

1.Introduction

Radar needs a large peak signal power to average power ratio at the time of the target's return signal [1]. Waveform design plays an important role for range, velocity and angle measurement for different radar and sonar applications. Pulse compression technique is employed in radar for good detection and range resolution. A uniform sidelobe level represents an optimum performance. The only code that achieves this property is Barker code. Barker codes [2] are the perfect codes because the highest sidelobe is only one code element and sidelobes are uniform throughout the entire sidelobe region. But the maximum code length available for Barker is limited and it is more sensitive to Doppler. This restricts their applications. Doppler tolerance and high pulse compression ratio can be achieved from polyphase codes. It is possible to construct a polyphase-coded waveform with modern digital systems.

2. Polyphase Codes

Phase coded waveforms in polyphase codes employ more than two phases. The phase of the sub pulses alternate among multiple values rather than just 0^0 and 180^0 of binary phase codes.

Well-known polyphase codes are the step frequency derived Frank[3] and P1[4] codes and linear frequency derived P3 and P4 codes [5]. Polyphase codes are used in search radar because of its low range and Doppler sidelobes.
The phase of the i^{th} sample of the P4 code is given by [6]

$$\mathbf{P}4[\mathbf{i}] = \exp\left\{2\pi\left(\frac{(\mathbf{i}-1)^2}{\mathbf{N}} - (\mathbf{i}-1)\right)\right\} \tag{1}$$

All these polyphase codes can be implemented and compressed digitally. Because of the discrete nature of the phase coded signal it is easier to manipulate the sidelobe pattern and to implement the sidelobe reduction techniques [7]. Digital pulse compression techniques can be easily implemented. P4 code has their own advantages compared to other codes and are given by

- Low peak sidelobes, approximately 1/4R to main lobe peak
- Do not produce large time sidelobes with large Doppler shifters
- More Doppler tolerant than other phase codes.

E_P4 code [8] is another polyphase code has low peak sidelobes and more Doppler tolerant than P4 code and is given by

$$\text{E\_P4}[i] = \exp\left\{-\pi\left(\frac{(i-1)^2}{N} - 2\right)\right\} - \exp\left\{-\pi\left(\frac{i^2}{N} - 2\right)\right\} \tag{2}$$

where N is the pulse compression ratio.

3. Merit Measures

Performance measures of a pulse compression system can be quantified with the calculation of peak sidelobe ratio, integrated sidelobe ratio.

3.1 Autocorrelation: Autocorrelation function measures the relation between two identical signals.
For general complex-valued sequence $\{a_n\}$ of length N, the autocorrelation function (ACF), for $k \geq 0$, is given by [9]

$$r[k] = \sum_{n=0}^{N-k-1} a_n a_{n+k}^{*} \tag{3}$$

3.2 Peak sidelobe ratio: One of the most commonly used performance measures is the peak sidelobe ratio (PSR) .The peak sidelobe is the largest sidelobe in the correlation of a code and its filter. The peak sidelobe ratio is usually expressed as a ratio of the peak sidelobe amplitude to the main lobe peak amplitude and is expressed in decibels [9].

$$PSR = 20 \log_{10}\left[\max\left\{\frac{r(i)}{r(0)}\right\} \; i \neq 0\right] \tag{4}$$

3.3 Integrated sidelobe ratio: Another important measure is integrated sidelobe ratio (ISR). This refers to the total energy in all the sidelobes and is expressed as a ratio of the total sidelobe energy to main peak energy [9].

$$ISR = 10 \log_{10} \sum_{i=-L}^{L} \left\{\frac{r(i)}{r(0)}\right\}^2 \; i \neq 0 \tag{5}$$

4. Block diagram

The block diagram of the proposed sidelobe reduction technique is shown in fig.1. The reference signal is same as the transmitted signal and the received signal is the Doppler shifted version of the transmitted signal. The auto correlated output of the reference signal is combined with the cross correlated output of the reference signal and shifted version of the received signal. With the proposed technique both peak sidelobe ratio (PSR) and integrated sidelobe ratio (ISR) can be reduced and uniform sidelobes can be obtained.

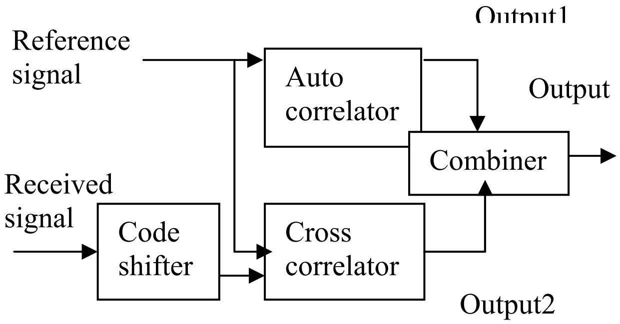

Fig.1 The block diagram of the proposed sidelobe Reduction technique

Various cases considered based on code shifter and combiner are:

Case 1: Linear shift in code shifter with Addition / subtraction
Case 2: One bit circular shift in code shifter with addition
Case 3: One bit circular shift in code shifter with subtraction
Case 4: Two bit circular shift in code shifter with addition
Case 5: Two bit circular shift in code shifter with subtraction
Case 6: Three bit circular shift in code shifter with addition/ subtraction in combiner

5. Results

Peak sidelobe ratio and integrated sidelobe ratio are computed for P4 and E_P4 signal of length 100 for all the above cases and shown in Table1,2 &3. From the results, it is observed that for P4 signal the sidelobes in the output are not symmetric for case1 where as uniform sidelobes are obtained for case2 with PSR of -37.50 dB and ISR of –17.28dB. In case of case 3 sidelobes are increased and mainlobe split is observed in case 4, 5 and 6. Out of six cases one bit circular shift with addition (case 2) provides satisfactory results for P4 code.
Similarly, output with E-P4 signal is observed for all the cases. From the results it is observed that sidelobes are reduced and also more uniform for case 3 with PSR and ISR of -67.36dB and -49.82 dB respectively. Sidelobes are increased for case 2 and case 4. Mainlobe split in case 5 & case 6 and unsymmetrical output in case1 is observed.

6. Conclusions

Out of all six cases, the best results are obtained for P4 signal with one bit circular shift & adder and for E-P4 signal one bit circular shift & subtractor and shown in fig.2 to fig.5

Table 1: PSR for different cases for P4 and E-P4 code length 100

	PSR(dB) P4 code	**PSR(dB) E-P4code**
Pulse compressed output	-26.32	-58.83
Case 1	–	–
Case 2	**-37.50**	-46.81
Case 3	-20.04	**-67.36**
Case 4	_	-52.48
Case 5	_	_
Case 6	_	_

Table 2: ISR for different cases for P4 and E-P4 code length 100

	ISR(dB) P4code	**ISR(dB) E-P4code**
Pulse compressed output	-12.02	-45.40
Case 1	–	–
Case 2	**-17.28**	-33.00
Case 3	-6.26	**-50.00**
Case 4	_	-37.78
Case 5	_	_
Case 6	_	_

Table 3: Outputs for different cases for P4 and E-P4 code length 100

	Observed output (P4 code)	**Observed output (E-P4code)**
Pulse compressed output	Non uniform sidelobes	Non uniform sidelobes
Case1	Un symmetric output	Un symmetric output
Case2	**Uniform sidelobes**	Non-Uniform sidelobes
Case3	Non-uniform sidelobes	**Uniform sidelobes**
Case4	Main lobe split	Non-Uniform sidelobes
Case5	Main lobe split	Main lobe split
Case6	Main lobe split	Main lobe split

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Figures:

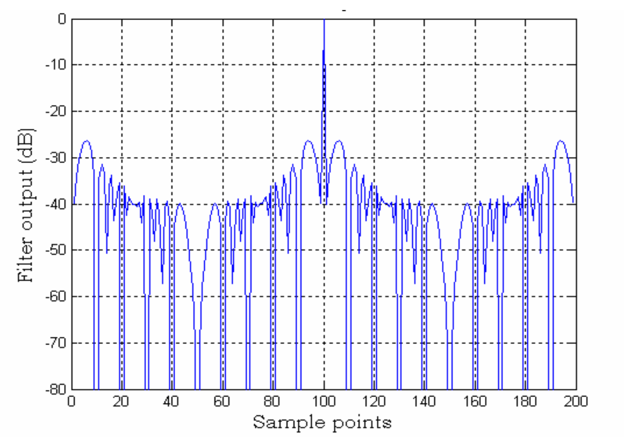

Figure2 Pulse compressed output of P4 signal of length 100

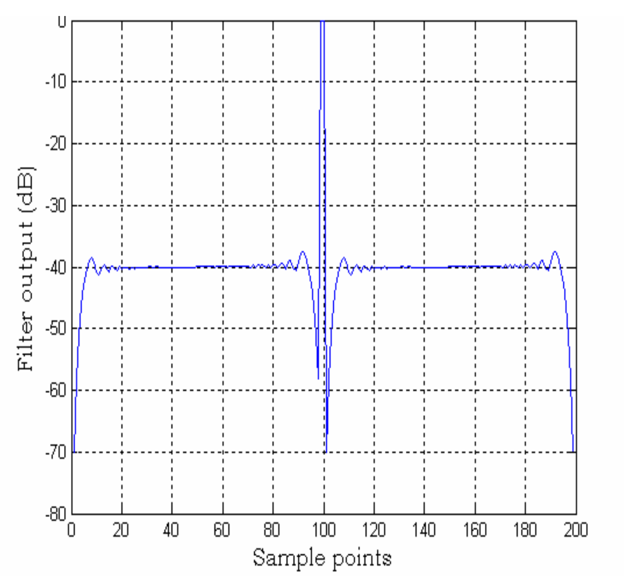

Figure3. Filter output with one bit circular shift and addition for P4 signal

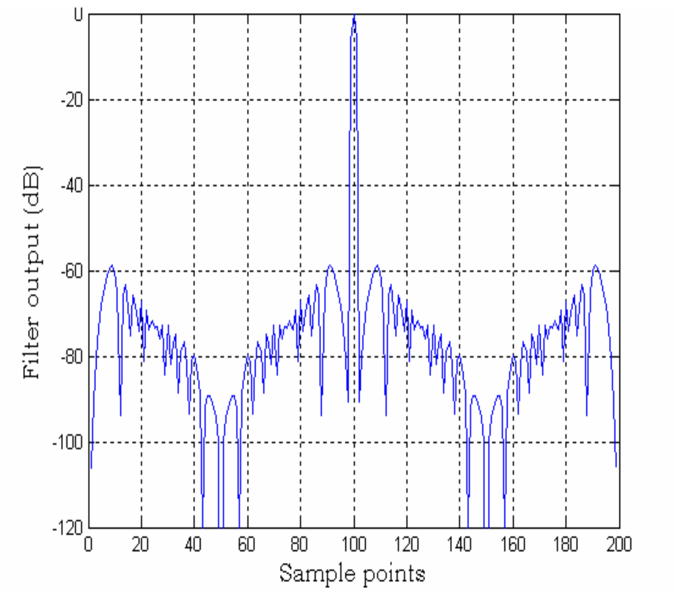

Figure4 Pulse compressed output of E-P4 signal

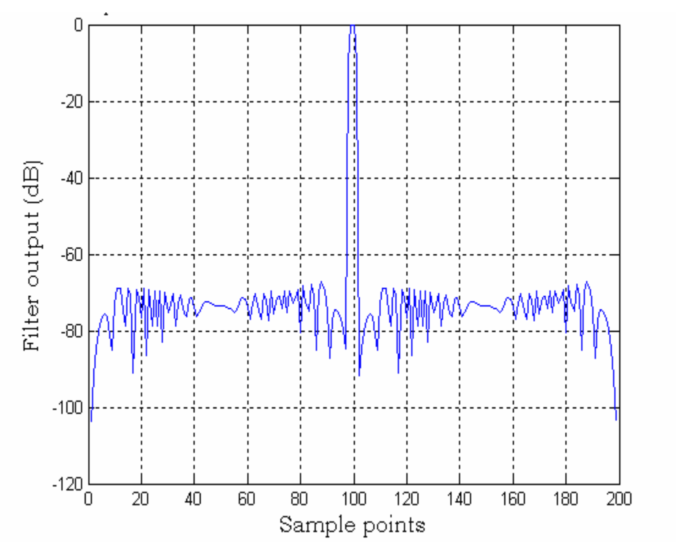

Figure5 Filter output with one bit circular shift and subtraction for E-P4 signal