Amplitude Shifting for Sidelobes Cancellation pulse compression

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Abstract

Pulse compression has been used to improve radar resolution. Many techniques are involved in pulse compression and they fall under frequency modulation and phase modulation. All of the techniques that have been implemented so far suffer from the sidelobe phenomena including Barker code, which uses a phase modulation technique. Mismatch filter is used to minimize sidelobes. Using mismatch filter increases hardware complexity, area, cost and power consumption and also degrades the performance. Not only that, sidelobe reduction takes place at the expense of Signal to noise ratio loss. Amplitude shifting technique is proposed to cancel the sidelobes of Barker code completely without any loss in signal to noise ratio and with much less hardware complexity, area and cost. Elimination of mismatch filter reduces the power consumption and improves the performance.

Introduction

To see the importance of pulse compression let us look at an application that utilizes it. The pulsed radar sends pulses of radio waves for a small interval of time T_0 then stops sending signal for a longer interval of time T_1 as shown in figure 1. The whole period is $T = T_0 + T_1$ which is related to the pulse repetition frequency f as follows f = 1/T. The transmitter will be working while sending the signal and the receiver gator shuts down the receiver [1]. After interval T_0 the transmitter is shut down allowing the receiver to listen to echoes scattered back from targets.

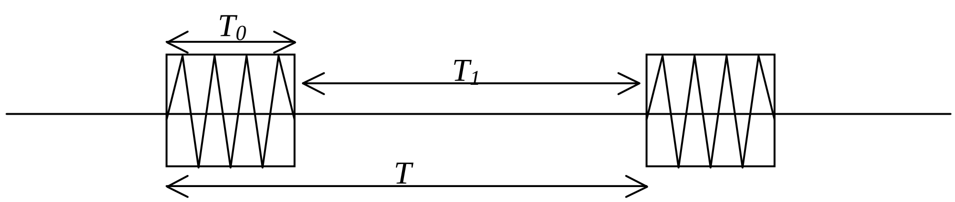

Figure 1. Radar pulse signal

This interval of time T_0 multiplied by the power of the transmitter will give the energy of that signal which is needed to travel long distance and hit a target and get back to the receiver to be detected. So in order for the received echo to be detected and for long-range detection application this energy should be as high as possible. This goal can be achieved by either increasing the transmitted power or increasing interval time T_0. High-power transmitters present problems because it requires high-voltage power supplies (kV) beside reliability problems and safety issues, big size, heavier, more expensive.

The first option does not look feasible; let us go for the next and last option, which is increasing the interval time T_0, well increasing T_0 contradicts with range resolution. What is range resolution? The nominal range resolution is the distance beyond which two reflectors must be separated so that their echoes can be seen as two separate pulses [2]. So we need to increase T_0 to increase transmitted energy and receive a narrow pulse to improve range resolution. Here comes pulse compression. Pulse compression is to send a long pulse to increase transmitted energy and compress it to a narrow one sub-pulse at the receiver to improve range resolution.

Range resolution = $T_0/2r$, where r = range of a target. Range resolution = (1/2r)*(1/BW) where BW = $1/T_0$ bandwidth of the transmitted pulse. So by increasing the Bandwidth of transmitted pulse the range resolution will improve.

Pulse compression

As mentioned earlier, increasing the duration of the transmitted wave results in increasing average transmitted power; and shortening the pulse width results in greater range resolution. Pulse compression is a way to combine the best of both techniques by transmitting a long coded pulse and processing the received echo to get a shorter pulse. This increases detection capability like a long-pulse radar system while keeping the range resolution of a narrow-pulse radar. This increases the average power of the radar without increasing the pulse repetition frequency, thus decreasing the radar's unambiguous range.

Phase coded waveform

The phase-coded waveform divides the pulse into subpulses of equal duration and each having a certain phase. The code sequence selects the phase of each subpulse. The most popular phase-coded waveform, called binary or biphase coding, has two phases. The binary code is made up of 0s and 1s or +1s and -1s, and the phase of the signal alternates between 0 degrees or 180 degrees based on the code sequence. There are usually discontinuities in the coded signal at the phase-reversal points because the transmitted frequency is not typically a multiple of the reciprocal of the subpulse width. The transmitted signal is compressed into the width of subpulse by either matched filtering or correlation processing.

Barker Codes.

Optimal binary sequences are binary sequences whose autocorrelation peak sidelobe is the minimum possible for a given code length.A special class of binary codes is known as Barker codes. The benefit is that autocorrelating or match filtering for these codes gives a main lobe peak of N and a minimum peak sidelobe of 1, where N is the number of subpulses (length of the code). Only a small number of these codes exist. Table 1 lists all known Barker codes and those having a minimum peak sidelobe of 1. Ideally, these codes could be used for pulse compression radars if longer lengths existed. However, the longest known Barker codes are of length 13, so pulse compression radar using these Barker codes would be limited to a maximum compression ratio of 13 [5][6][7].

Code Length	Coded signal
2	10, 11
3	110
4	1101,1110
5	11101
7	1110010
11	11100010010
13	1111100110101

Table 1. Existing Barker code.

Side Lobe Reduction

Unfortunately after matched filtering, the peak sidelobe for Barker code of length 13 is –22.28 db, which is not acceptable. In order to suppress the sidelobes there are generally two methods. One is utilizing an additional weighting network after the matched filter; the second is to design a mismatch filter by using linear programming (LP) algorithm. To get satisfactory results (acceptable PSL) the length (the number of taps) must be long enough. Now this has a price of high complexity of filter hardware (and consequently affects area, cost and power consumption) and great loss in signal to noise ratio and widening the main pulse width (degrading the resolution).

An adaptive FIR is placed next to a matched filter pulse. The FIR is implemented via two approaches: least mean square (LMS) and recursive least square (RLS). For a 20-tap LMS and RLS there is net decrease in the peak sidelobe level of 8db and 11 db respectively [4]. Increasing the number of tapes of FIR can attain higher reduction in peak sidelobe level.

Proposed Technique

As we can see in figure 2 the barker code of length 7, the peak is positive in phase and the sidelobes are negative in phase. And this is because the input wave is positive and negative in phase.

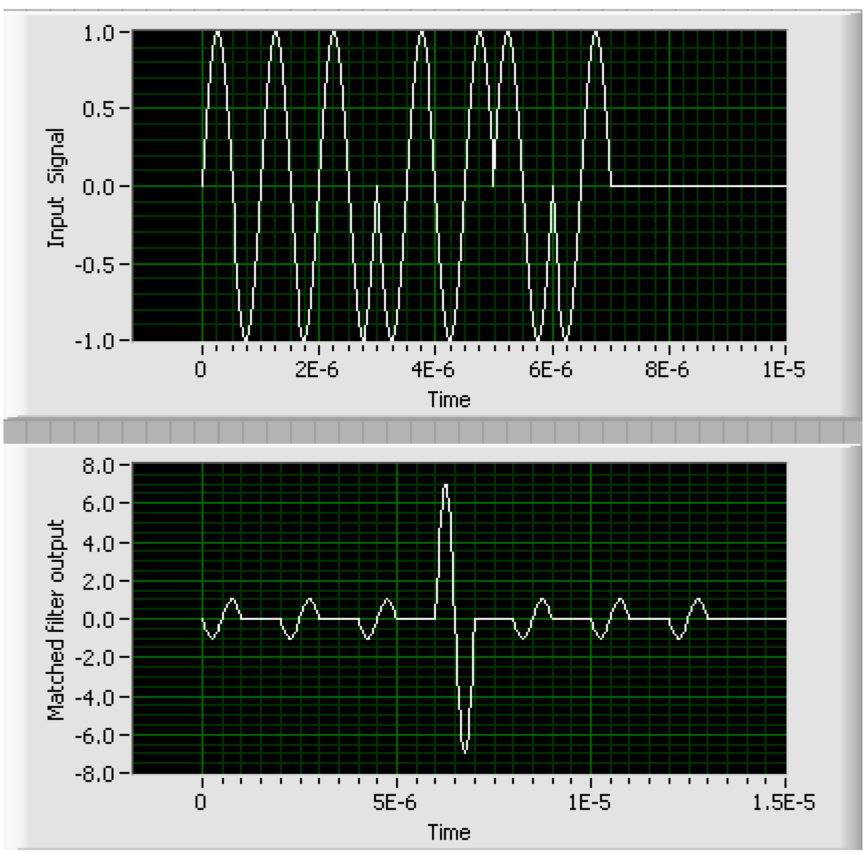

Figure 2. Barker code of length 7

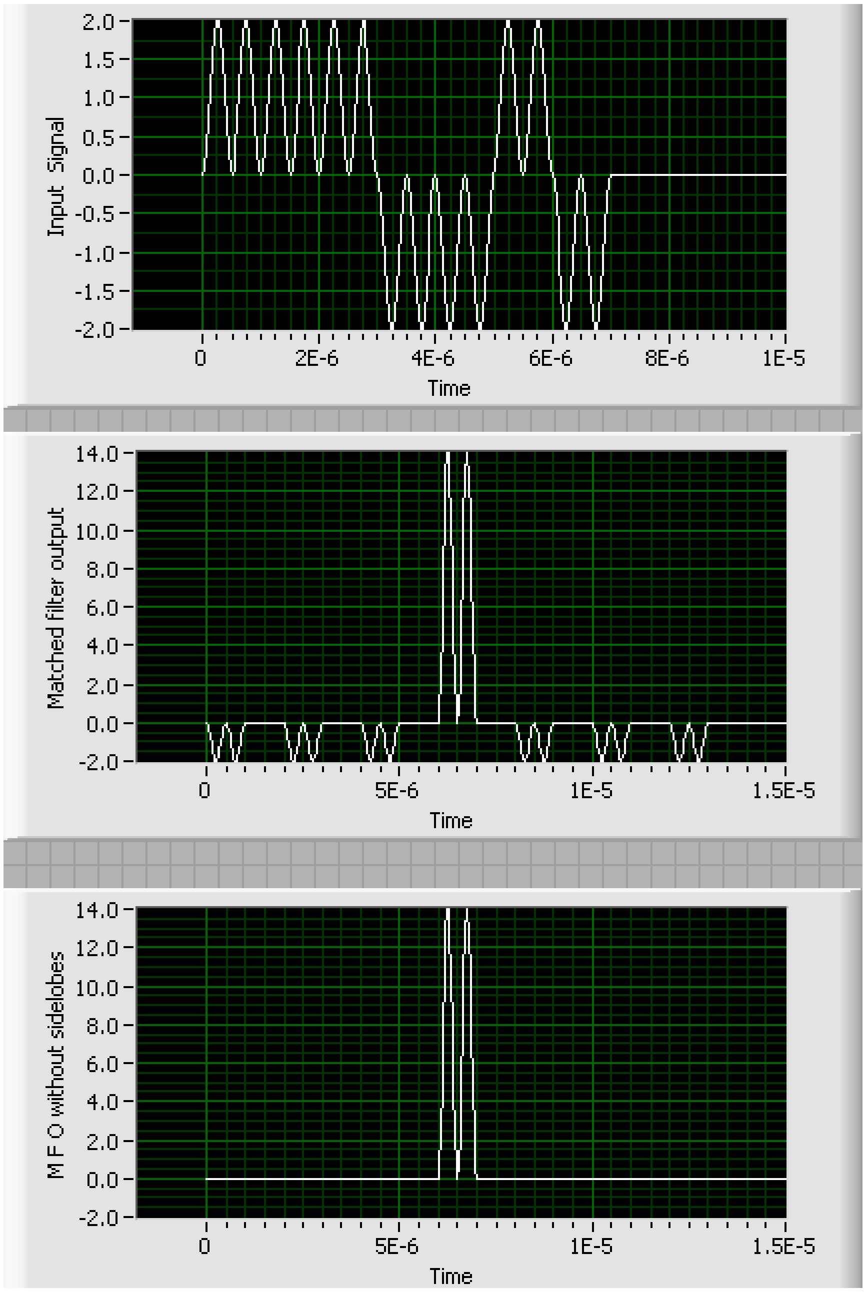

Figure 3. Barker code with Amplitude Shifting

So what happen if we also add Amplitude shifting to transmitted wave besides phase modulation. By amplitude shifting the positive phase are multiplied by +1 to be shifted up above zero and the negative phase is multiplied by –1 to be shifted down below zero. Then the peak output, which is positive in phase and positive in amplitude, is shifted up above zero in magnitude and positive in phase while the sidelobes which are negative in phase and negative in amplitude will be shifted down below zero and negative in phase.

So the result of this idea is that the peak is in one side (the positive side above zero) and the sidelobes are on the other side (negative side below zero) as shown in figure 3. By using a simple circuit we take only the positive side, which is the peak that has zero side lobes. This circuit could be as simple as that of a diode that passes the current in one side as shown in figure 3. This technique can be used effectively with pulse compression that yields negative phase sidelobes.

Code Length	Coded signal	Sidelobe level (Barker code)		Sidelobe level (proposed technique)	
2	10, 11	1	-6.0 db	No side lobe	No side lobe
3	110	1	-9.5 db	No side lobe	No side lobe
4	1101,1110	1	-12.0 db	1	-12.0 db
5	11101	1	-14.0 db	1	-14.0 db
7	1110010	1	-16.9 db	No side lobe	No side lobe
11	11100010010	1	-20.8 db	No side lobe	No side lobe
13	1111100110101	1	-22.3 db	1	-22.3 db

Table 2. Comparison of sidelobe level traditional signal and modified signal

By examining barker code of lengths 2,3,4,5,7,11,and 13, lengths 2,3,7 and 11 found to have negative phase sidelobes and consequently the proposed technique can be applicable.

Peak side lobe PSL = 20 log (SL/P), where P is peak level and SL is the sidelobe level.
PSL = 20log(1/N) = -20log(N), where N is the code length.

By using the proposed technique, barker code of lengths 2,3,7 and 11 will be ideal with peak equal to N, and zero sidelobes as shown in table 2.

Proposed technique Implementation

1. Coherent demodulation

With coherent demodulation systems, the incoming signal is compared with a replica of the carrier wave. The comparison is performed by multiplying the incoming signal with a replica of the carrier.

The difficulty with coherent detection is the need to keep the phase of the replica signal, termed local oscillator, "locked" to echo carrier. This is not easy to do. The carrier signal will be **S(t) = A*sin(wt)**, now by multiplying **S(t)** with **sin(wt)** the carrier frequency will be multiplied by two and the output will be shifted either above zero or below zero depending on the phase difference. If they are in phase then a positive shift occurs on the other hand when they are out of phase a negative shift occurs as shown in figure 4. This is our goal to have the positive phase shifted up while the negative phase shifted down, to accomplish that the received signal must be multiplied with the local oscillator reference that is in phase with the positive phase. For moving targets this method cannot be used due to the change in the frequency of the echoes based on the speed of the targets, which is known as Doppler effect.

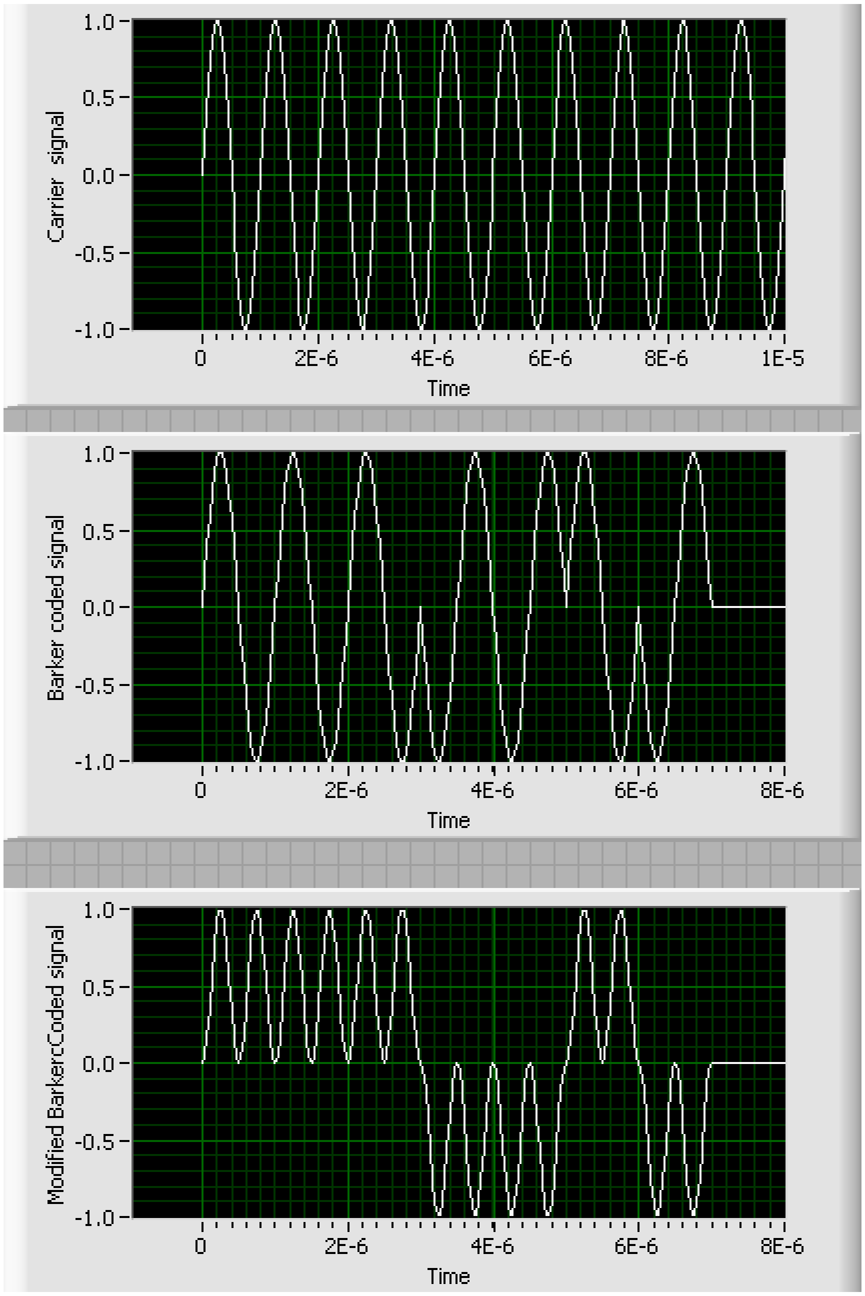

Figure 4. Waveform generation

2. Differential phase-shift-keying (DSPK)

Since coherent detection is not an easy to establish and can't be implemented with moving targets because of Doppler effect for each echo the alternative is to employ another form of modulation, differential phase-shift-keying (DSPK). Differential PSK is actually a simple form of coding. The modulating signal is not the binary code itself, but a code that records *changes* in the binary code. This way, the demodulator only needs to determine changes in the incoming signal phase. Because the drifts associated with local oscillators occur slowly, this is not difficult to arrange.

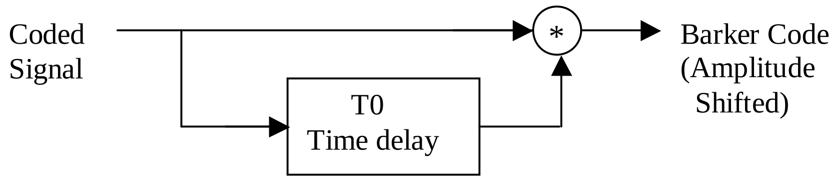

Figure 5. Phase differential circuit

So instead of transmitting the signal in the form of PSK, it is transmitted in the form of DPSK. At the receiver side we use the phase differential circuit shown in figure 5. It is noted here that the transmitted signal will be increased with one sub pulse by transmitting the first sub pulse twice.

Table 3 shows the code of the transmitted signal and the code of the signal after using the circuit in figure 5. The output of the phase differential circuit is nothing but a barker code with amplitude shifting technique applied on the signal.

Coded Signal	Barker code (Amplitude Shifted)
110	10
1110	110
11110110	1110010
111101001001	11100010010

Table 3 Transmitted coded Signal and Barker Code with Amplitude Shifting

3. Transmitter side

Modified signal can be generated at the transmitter side instead of being generated at the receiver side. A mixer or a dc restorer can be used for that job as follows.

3A. Mixer

Mixing the carrier with itself yields a signal that is either completely shifted above zero or completely shifted below zero. Being shifted up or down depends on the phase difference between the two input signals in the mixer. In this method the two signals are selected to be the same identical carrier so the output of the mixer is a signal that is shifted up completely. However the output frequency is double the carrier frequency. The advantage of this method is that the local oscillator generate a carrier with half the require frequency.

This shifted up signal is entered to the match filter that will be either multiplied by one or minus one. Since the signal in the match filter is multiplied by plus one and minus one then the signal is consider to be ac signal

3B. Dc restorer

The purpose of dc restorer is to add a dc level to an ac signal as shown in figure5. A dc voltage is equal to the built in voltage of the diode. The dc voltage supply Vb is used to allow the capacitor to be charged to Vp, where Vp is peak voltage of the carrier signal.

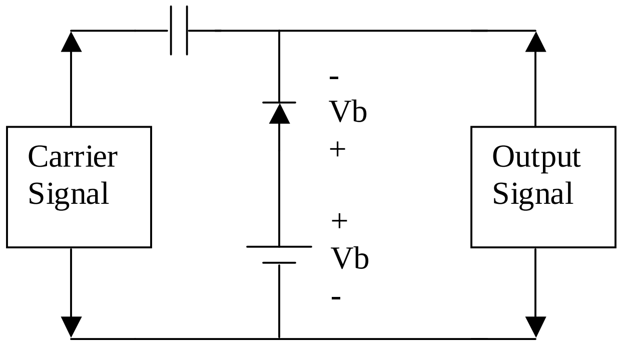

Figure 5. Positive dc restorer

With this simple circuit the output signal will be carrier plus the dc voltage supplied by the capacitor The dc level added is equal to the peak of the signal much insure that the signal is shifted up completely.

Conclusion

The proposed technique has no sidelobes and no loss in the SNR and eliminates the use of mismatch filter. Eliminating mismatch filter reduces the match filter hardware complexity that means less area, power consumption and cost. Also, elimination of mismatch filter improves the performance of compression process. The proposed technique can be used in radar, sonar and ultrasonic applications.

Future work

For long range detection the energy has to be high which means longer pulses, and for high resolution the sub pulse width has to be very small. Then the use of long codes with small sub pulse width is crucial. By extending this idea we can implement wave multiple layers to be able to have barker code of lengths larger than 13. Each layer will be either 2,3,7 or 11. In this way barker code length will be the multiplication of barker code length of each layer. So by using two layers barker code, barker code of lengths 2*2, 2*3, 2*7, 2*11, 3*3, 3*7, 3*11, 7*7, 7*11 and 11*11 can be implemented. Consequently another main achievement for the proposed technique is Barker extension.

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