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Implementation of Pulse Compression Techniques for Atmospheric Radar Applications

[1] Shaik Benarjee, [2] K.Prasanthi, [3] M.Durga Rao
[1] M.Tech (DECS), Dept. of ECE, [2] Assistant Professor, Dept. of ECE, [3] Scientist/Engineer-SE, RADG
[1] Sri Padmavathi Mahila Visvavidyalayam, Tirupati-517502
[2] Sri Padmavathi Mahila Visvavidyalayam, Tirupati-517502
[3] National Atmospheric Research Laboratory (NARL), GADANKI, Tirupati

***Abstract* - Pulse compression techniques are used to avail the benefits of improving detection capability with long pulse widths and at high range resolutions in Radar systems. The Pulse compression technique plays a very important role while designing a radar system. Short pulses are essential to get the advantage of high range resolution but to achieve the better SNR, the radar systems requires high pulse widths. In order to have trade-off between SNR and range resolution pulse compression is inevitable. Pulse compression techniques were implemented to reduce the range side lobes using various coding techniques like Binary phase coding (Barker codes) and Complementary codes etc. The "Matlab" is used as a software.**

***Keywords* – Barker code, Complementary codes, Range resolution, Pulse compression, SNR.**

I. INTRODUCTION

Pulse Compression is a signal processing technique which is used in Radar Systems to reduce the peak power of a radar pulse by increasing the pulse length, without giving up the range resolution associated with a shorter pulse.This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse. In these technique, a long duration pulse is used which is either frequency or phase modulated before transmission and the received signal is passed through a filter to accumulate the energy into a short pulse. High signal to noise ratio is achieved by passing a signal into a matched filter. However, the matched filter output i.e. auto-correlation function of a modulated signal is associated with range side lobes along with the main lobe. These side lobes are unwanted outputs from the pulse compression filter and may mask a weaker target which is present nearer to a stronger target. Hence, side lobes affect the performance of the radar detection system. Digital pulse compression technique consists of binary phase coding (barker code), Complementary codes etc. The performance depends on its auto-correlation function for digital pulse compression technique.

II. RADAR AND ITS TYPES

The word "RADAR" is an acronym derived from the words "Radio Detection And Ranging". It is a system which is used to detect the presence of objects such as aircraft, ships, spacecraft, vehicles, people, weather formations, and terrain with the help of electromagnetic waves. Radar transmits the electromagnetic waves or radio waves into space and receives the echo signal reflected from objects. Signal processing algorithms are applied on the reflected echo, the reflecting objects can be detected and also the location and the speed of the objects can be estimated.

Depending on the number of antennas, Radars are classified into two categories.

1) Monostatic and 2) Bistatic.

Monostatic has same antenna system for both transmit and receive where as the Bistatic has dedicated transmit and receive antenna systems. Radars are most often classified by the types of radars they use.

1) Continuous wave and 2) Pulsed Radar

A continuous waveform (CW) is the simplest radar waveform which transmits the signals continuously while receiving target echoes on a separate antenna. The advantage of CW is the measurement of unambiguous Doppler. However, the target range measurement is entirely ambiguous due to continuous nature of the waveform. Most of the modern radar systems employ a pulsed waveform which provides range information accurately. The pulsed radar uses a train of pulsed waveforms. The primary advantage of pulsed radar is that can share the same antenna (Mono-static) for transmission and reception of signals. A pulsed waveform is shown in Figure 1.

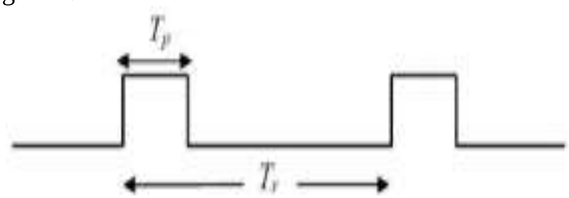

Figure 1. Pulsed Radar waveform

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Unambiguous range: The range from which a transmitted pulse can be reflected and received before the next pulse is transmitted.

The unambiguous Range (R_u) is given by,

$R_u = cT_r/2$

Where, T_p is the pulse duration and

T_r is the pulse repetition time.

c is the speed of light.

Two factors that are considered to be important for Radar waveform design are

1) Range resolution, and
2) Maximum range detection.

Range resolution: The ability of radar to separate two reflecting objects on a similar bearing but at different ranges from the antenna. The degree of range resolution depends on the transmitted pulse width, the size and types of targets, receiver's efficiency and indicator. Pulse width is the primary factor in range resolution. For a well designed Radar system, with all other factors at maximum efficiency should be able to distinguish between the targets which are separated by one-half the pulse width time τ.Therefore, the range resolution of a radar system can be calculated theoretically from the following equation,

$$S_r \geq C_0.\tau/2$$

The maximum detection range: It depends upon the received echo strength. In order to get high echo strength, the transmitted pulse should consist of more energy for long distance transmission. The amount of delivered energy to a distant target is the product of two things.

1) Output power of the transmitter
2) Duration of the transmission

Therefore, pulse width constraints the maximum detection range of a target. The received signal strength is proportional to the pulse duration. So, shorter duration pulses achieve better range resolution. The range resolution R_{res} is expressed as:

$$R_{res} = c/2B$$

Where,

B is the bandwidth of the pulse.

III. PULSE COMPRESSION

Radar pulse compression also refers as a family of techniques which is used to increase the bandwidth of radar pulses. In the radar receiver, these echoes are 'compressed' in the time domain that results in a range resolution which is finer than that of an uncoded pulse. Pulse compression radar transmits a long pulse with pulse width T and peak powerP_t, which is coded using frequency or phase modulation to achieve a bandwidth B that is large as compared to that of an uncoded pulse with the same duration. The transmit pulse width is chosen to achieve the single pulse transmit energy, given by E_{t1}=P_tT, that is required for target detection or tracking. The received echo is processed by using a filter which yields a narrow compressed pulse response with a main lobe width of $1/B$ that doesn't depend on the duration of the transmitted pulse. The pulse compression ratio is defined as the ratio of the transmit pulse width to the compressed main lobe width. The pulse compression is approximately TB, where TB is defined as the time bandwidth product of the waveform. Typically, the pulse compression ratio and the time bandwidth product are as large as compared to unity. In simple words, energy content of low-power pulse, long-duration will be comparable to that of the high-power pulse, short-duration.

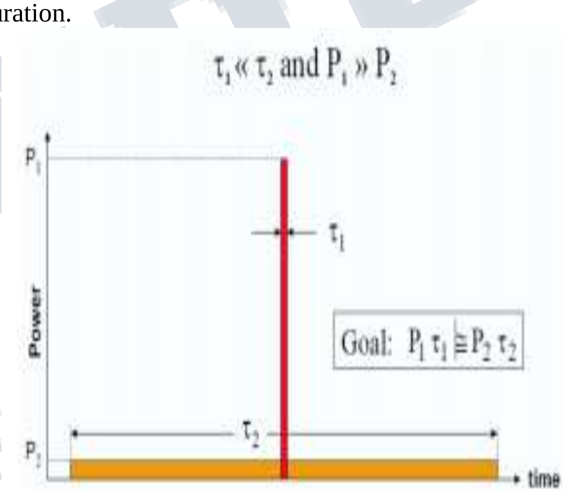

Figure 2. Transmitter and Receiver ultimate signals

Figure 2 illustrates two pulses having same energy with different pulse width and peak power.

a) Why RADAR Pulse compression?

To determine a target's shape and size, radar should have sufficient resolution. Resolution is proportional to the pulse width, so for high resolution applications a short pulse needs to be utilized. The shorter the pulse, the more accurate the range measurement is. Also the maximum range (pulse energy), which is proportional to both peak power and time duration of the pulse, has a serious drawback. The drawback is that when the pulse width gets shorter to improve resolution, the pulse energy is also reduced. Keeping the peak power fixed degrades the range performance. This can be solved easily by

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increasing the power. But, unfortunately, increasing the peak power creates severe problems in the design of high resolution radars, because the technological limitations of the transmitter affect peak power more than that of the average power or the energy of the single pulse.

The sensitivity of radar depends on the energy transmitted in the radar pulses. Sensitivity of radar can be expressed in terms of the average transmitted power, i.e., the peak power multiplied by the transmitter duty cycle. Although the peak transmitter power may be as high as several hundred kilowatts, since most radar transmits very short pulses, the average transmitted power may be much less than 1% of this value. Clearly this is not an efficient use of the available transmitter power.

Without the use of pulse compression, pulse widths cannot be reduced indefinitely. Extremely narrow pulse widths result in wide receiver bandwidths and the associated problems with noise. Large receiver bandwidths effectively de-sensitize the radar receiver and either force the transmitter to transmit higher levels of peak power to compensate, or accept the consequential reduction in range. There are always limits on the amount of peak power available from the transmitter, as high power transmitters suffer from the following problems:

1. They need high voltage power supply of the order of kilowatts (kW).

2. They face the reliability problems like cooling problems and other thermal issues.

3. Safety issues always arise from both electrocution and irradiation of these equipments.

4. They are huge in size, weigh more and are obviously very expensive.

Invariably, a reduction in pulse width leads to a reduction in the maximum range of the radar. In short, narrow pulse widths are desirable, but they are not always feasible. Pulse compression radars use specific signal processing techniques to have advantages of extremely narrow pulses widths whilst remaining within the peak power limitations of the transmitter. The advantages of narrow pulses enjoyed by pulse compression radar are superior range resolution and range accuracy.

IV. BINARY PHASE CODES

The Barker codes also known as Bi-phase codes mostly used in phase modulation for pulse compression in radar system. In binary phase codes, a relatively long pulse of width 'τ' divided into N smaller pulses; each is of width $\Delta\tau = \tau'/N$. Then, the phase of each sub pulse is randomly chosen as either 0 or π radians relative to some CW reference signal. It is used to characterize a sub pulse that has 0 phase as either "1" or "+". Alternatively, a sub pulse with phase equal to π is characterized by either "0" or "-". The compression ratio is given by $\S = \tau'/\Delta\tau$, and the peak value is N times larger than that of the long pulse. The goodness of a compressed binary phase code waveform depends heavily random sequence of the phase for the individual sub pulses.

One among the family of binary phase codes that produce compressed waveforms with constant side-lobe levels equal to unity is the Barker code. Figure 3 illustrates the concept for a Barker code of length seven. A Barker code of length n is denoted as Bn.

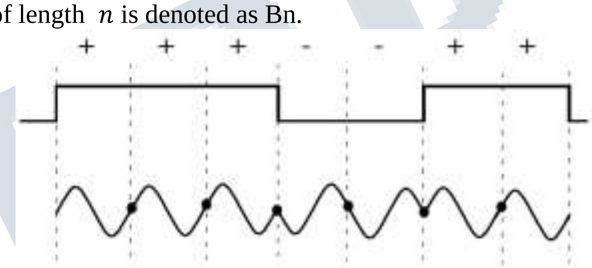

Figure 3. Binary phase code of length 7.

There are only nine known Barker codes that share their unique property; they are listed in Table1. Barker codes have the property of producing main lobes that are higher than the side lobes by a factor of codelength.Note that B2 and B4 has complementary forms that have the same characteristics. Since, there are only nine Barker codes; they are not used when radar security is an issue.

In general, the auto-correlation for a Barker code will be 2N$\Delta\tau$ wide. The main lobe is equal to N. There are (N-1)/2 side lobes on either side of the main lobe; this is illustrated in Figure 4 for a B_{13}. Here, the main lobe is equal to 13, while all side-lobes are unity.

Table 1. Barker codes

Length (N)	BarkerCode	PSL (db)
2	+-	-6.0
2	++	-6.0
3	++-	-9.5
3	+-+	-9.5
4	++-+	-12.0
4	+++-	-12.0
5	+++-+	-14.0
7	+++--+-	-16.9
11	+++---+--+-	-20.8
13	+++++--++-+-+	-22.3

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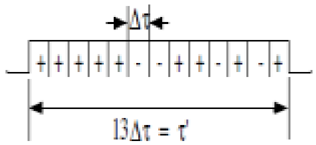
The most side-lobe reduction offered by a Barker code is -22.3 dB, which may not be adequate for the desired radar application. However, Barker codes can be combined to generate much longer codes.



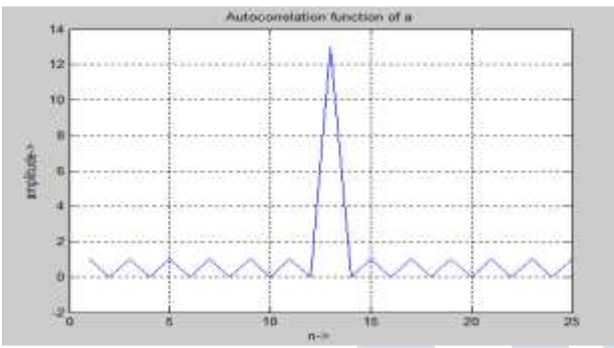


Figure 4. Barker code of length 13 and its corresponding autocorrelation function

V. COMPLEMENTARY CODES

Complementary codes or sequences consist of two sequences of same length whose a periodic autocorrelation functions have sidelobes equal in magnitude but opposite in sign.The sum of two functions has a peak of 2N and a side lobe level of zero.In practical,side lobel level is not equal to zero.
Known complementary sequences are listed in Table 2.

TABLE 2. COMPLEMENTARY SEQUENCES

Length	Code 1	Code 2
2	11 (3)	10 (2)
4	1110 (E)	1101 (D)
8	11101101 (ED)	11100010 (E2)
16	1110110111100010 (EDE2)	1110110100011101 (ED1D)
32	1110110111100010 1110110100011101 (EDE2ED1D)	1110110111100010 0001001011100010 (EDE212E2)

Consider two sequences i.e., code 1(ED) and code 2 (E2) of length 8. The sum of two codes has a peak of 2N and a side lobe level of zero.The output for complementary sequence of length 8 which is processed in Matlab software is shown in below Figure 5.

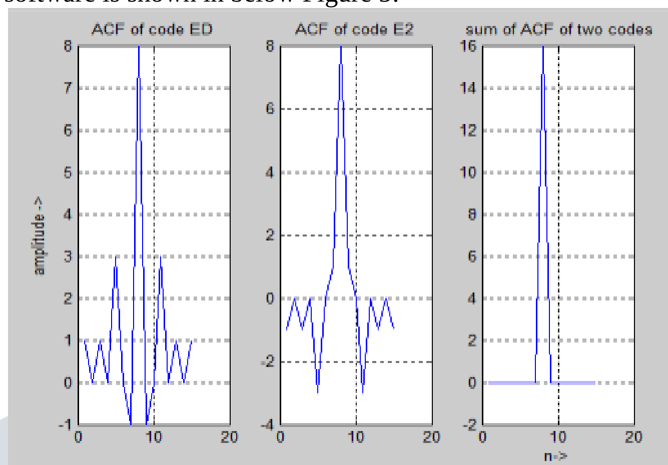


Figure 5. Autocorrelation function of complementary sequence of length 8.

VI. CONCLUSION

This paper presents a method for reduction of side lobes in RADAR technology.Comparision of various side-lobes has been simulated in the case of both barker and complementary sequences. It is seen that side lobes are different while using different types of pulse compression technique.In case of Barker codes there are only nine codes which satisfies the unique property.Barker codes are not used when radar security is an issue. Complementary sequences are used rather than Barker. The reduction of side lobes are better in complementary and have a lot of applications.The advantages of using pulse compression techniques are superior range resolution, range accuracy, increases the average power and maintains detection capability with high range resolution.

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