Application of Pulse Compression Techniques to Monostatic Doppler Sodar

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Abstract: An active phased array Doppler sodar with distributed low peak power transmit modules requires pulse compression to provide high sensitivity and fine range resolution. A long transmitted pulse, however, has accompanying problem of near range blind zone. A pulse compression Doppler sodar transmits coded long pulse and compresses the echo-signal resulting in fine range resolution. Barker-coded pulses with matched filter were examined in relation to uncompressed pulses to determine the performance and benefits of pulse compression. The pulse compression technique reduces the peak transmitted power compared to the classical transmission for the given range. The technique also permits the suppression of sidelobes to levels that are acceptable for operational and research applications.

I. INTRODUCTION

Doppler sodar transmits a short pulse of duration τ (typically a few tens of milli-seconds) of intense sound (typically 20 W) up into the atmosphere at a pulse repetition time T of a few seconds (typically 2 - 8 seconds). The upward propagating sound gets scattered in all directions due to temperature and wind fluctuations occurring at a scale equal to half the transmitted wavelength. In the case of monostatic Doppler sodars, where the same antenna is used for both transmission and reception, the backscattering is due to temperature fluctuations alone. The Doppler shift of the echo-signal is used to deduce the wind components. In a triaxial monostatic Doppler sodar, three antennas oriented in the three directions are used to deduce the total wind vector profile. The typical height coverage of the classical Doppler sodar systems is about 1 km from ground and with a range resolution of about 30 m. This pulse duration τ multiplied by the transmitter power gives the energy sound. In principle, the energy is required to be as high as possible to cover larger height range. This is usually achieved by either increasing the transmitted power or increasing τ . Highpower transmitters present problems because it requires high-voltage power supplies beside reliability problems and safety issues, big size, heavier, more expensive. Pulse compression, in principle, is to send a long pulse in coded form to comply with the demand of more energy and compress it to a narrow sub-pulse at the receiver to improve range resolution. The amount of compression possible is equivalent to the time-bandwidth product $(B\tau)$ of the code (Skolnik, 1980). The increase in echo-signal power is proportional to the code length while the range resolution is inversely related to bandwidth.

II. PULSE COMPRESSION

The transmitted pulse is modulated by using frequency modulation or phase coding in order to get large timebandwidth product (Bradley, 1999). Phase modulation is the widely used technique in Doppler sodar systems. In this technique, a form of phase modulation is superimposed on the long pulse increasing its bandwidth. This technique allows discriminating between two pulses even if they are partially over lapped. The echo-signal is compressed through a filter, whose output is similar to that of an uncompressed transmission. In the phase coded pulse compression, the long pulse of duration τ is divided into N sub-pulses each having a width τ_0 . An increase in bandwidth is achieved by changing the phase of each subpulse. The phase of each sub-pulse is chosen to be either 0 or π radians. The output of the matched filter will be a spike of width τ_0 with an amplitude N times greater than that of long pulse. The pulse compression ratio is $N = \tau/\tau_0 \approx B \tau$, where B $\approx 1/\tau_0$. The output waveform extends to either side of the peak response, or central spike. The portions of the output waveform other than the spike are called time side-lobes. The easiest way to encode the signal is to use a particular type of phase shift keying that makes the carrier phase change only between two values (0 and π) according to a

sequence of binary digits. Figure 1 depicts the resulting waveform when a carrier $\sin(wt)$ is multiplied by a sequence of bits c(t) composing the code. The total sequence establishes the length of the pulse. The duration of a single symbol/bit is called «subpulse» and is related to the bandwidth of the encoded signal (the shorter the subpulse, the greater the bandwidth). The phase change (0 or π) is obtained at each subpulse τ_0 or its multiples N τ_0 . This linear operation instantaneously gives $m(t) = \pm 1 \sin(wt)$.



A special class of binary codes is known as Barker codes. The benefit is that auto correlating or match filtering for these codes gives a main lobe peak of N and a minimum peak side lobe of 1. Only a small number of these codes exist. Table 1 lists all known Barker codes and those having a minimum peak side lobe of 1. The longest known Barker

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codes are of length 13, so pulse compression sodars using these codes would be limited to a maximum compression ratio of 13 (Woodman et al., 1980).

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

Table1: Barker code sequences

2.1Range Sidelobes and Weighting: A major drawback to the application of pulse compression is the presence of range sidelobes which tend to smear the returns in range. Suppression of range sidelobes is critical, especially in applications for sodars where the observed targets are distributed in nature and often have strong and steep gradients in reflectivity. Sidelobe suppression, in general, is achieved by tapering the matched filter response by weighting the transmitted waveform, the matched filter, or both in either frequency or amplitude. The weighting is usually applied to the matched filter which causes a loss of signal-to noise ratio (SNR) due to the mismatched section. The following measures are often used to quantify the performance of range sidelobe suppression techniques [Cheong et al, 2006; cohen et al, 1990]. Peak sidelobe level (PSL) is defined as

$$PSL=10\log \frac{\text{peak side lobe power}}{\text{total main lobepower}} \qquad (1)$$

Integrated sidelobe level (ISL), a measure of the energy distributed in the sidelobes, is defined as

Barker cods are biphase codes having the property that after passage through a matched filter, the resulting sequence has sidelobes of unit magnitude (PSL=1/N). Barker codes have the attractive property that their sidelobe structures contain the minimum energy that is theoretically possible and this energy is uniformly distributed among the sidelobes.

III. METHODOLOGY

Time domain processing: If we choose to perform signal processing in time domain shown in figure2, we can extract the information from the received encoded signal(x(k)) as follows. As stated before this process is called correlation, it is a sort of weighted moving average of the received signal,

the weight being a copy of the encoded transmitted signal(y(k)) stored inside the correlation processor (Nathanon, 1999). It is possible to demonstrate that the correlation gives an output shortened in time, or «compressed», reducing the actual duration of the pulse to one subpulse length (neglecting the sidelobes). The position of the maximum and its amplitude give information about distance and reflecting properties of the target. Multiple echoes can be resolved if the time separation between two near received signals is greater than the subpulse length. The actual detection of an echo is obviously determined also by other factors noise, transmitted power, the attenuation due to the path and the reflecting characteristics of the targets, etc. In discrete time processing the correlation $(\rho(x, y))$ of the received signal x(k) with the discrete-time version of the coded transmitted signal y(k) can be written as

$$P(x, y) = x(k)*y(k)$$
(3)

Such a time domain process was developed by means of a MATLAB DSP tool box. The I (real) and Q(imaginary) streams of coded transmitted signal were combined in order to obtain the real amplitude of the received signal. Then a correlation was performed, in a system that used the Barker code. The processing power gain in decibels due to this correlation operation is about $GC=20\log\sqrt{N}$ (dB).



As we can see the figure 3 the Barker code of length 7, the peak is positive in phase and the sidelobes are negative in phase. And this is because the coded



Figure (3) Coded transmitted signal and matched filter outputs of Barker code length?

IV. IMPLEMENTATION

The simulation process uses the correlation function of MATLAB DSP toolbox for the measurement of range to a target using sodar. The MATLAB DAQ tool box supports the device objects *analog output*(AO) and *analog input*(AI) (Mehrl and Hagley, 1998; Hagley and Mehrl, 2001). To send

$$R = \frac{Cd\tau 0}{2} \tag{5}$$

The Barker coded transmitted signal with pulse length 100 msec and pulse repeat ion time of 4 sec is used for creating a received signal of attenuation factor a=0.5 and atmospheric white noise v(k) with standard deviation σ =0.05.Normalized cross-correlation of x(k) with y(k) is computed using MATLAB DSP tool box functions. Received signal is shown in figure 4 ,it was found that it is not at all apparent whether x(k) contains a delayed and attenuated echo of un coded y(k) much less where it is located in case of classical transmission. In case of normalized cross correlation of x(k) with Barker coded y(k) the presence and location of an echo are evident as shown in figure 5.Using MATLAB *max function* the time of flight in this case is observed at d=280.24 and the range of the target can be found using equation 5 is 680.58m.



V. RESULTS

Using the method described above, Barker codes were incorporated for testing the basic functionality of Doppler sodar system using simulation under controlled conditions. The central frequency (f0) was 2000Hz, two chips of equal length centered on f0 and spectral width is two times the equivalent bandwidth of the binary code was used for compression. Transmitted power, spectral width are calculated for uncompressed and compressed pulses at same resolution in order to evaluate the error performance .The 7-bit barker code provides a range resolution 2.43m compare to un coded transmitted pulse of range resolution of 17.01m. The table2 shows range resolutions and sidelobe levels for various Barker code lengths.

Barker code length	ΔR for 100 msec pulse length(τ)	Effective pulse width after compression(70)	Sidelobe level (dB)
2	8.5m	50msec	-6.0
3	5.66m	33.33msec	-9.5
4	4.25m	25msec	-12.0
5	3.4m	20msec	-14.0
7	2.43m	14.28msec	-16.9
11	1.55m	9.09msec	-20.8
13	1.3m	7.69msec	-22.3

Table2: Barker codes of different lengths and associated ΔR , $\tau 0$ and sidelobe levels

VI. CONCLUSIONS

A successful modification of the Doppler sodar system was presented that produces an increase in range resolution through pulse compression. The simulator incorporates Barker phase codes with matched filter (correlation processor) which decreases the average transmitted power compare to classical transmission. A major drawback to the application of pulse compression is the presence of range sidelobes which tend to smear the returns in range This highlights the need of explore other code/filter combinations that can suppress ISL even further. This can be achieved by changing code type, code length, filtering method or any combination of these. However, as code length increases, the Doppler tolerance of the signal decreases as moving targets can begin to significantly alter the phase of the signal causing additional errors.For long range detection the energy has to be high which means longer pulses, and for high resolution the subpulse width has to be very small. Then the use of long codes with small subpulse 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 and11*11 can be implemented. Consequently another main achievement for the proposed technique is Barker extension.

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