Research on frequency domain pulse compression of LFM signal

He Panpan
Kunming Shipborne Equipment Research and Test Center, Kunming, Yunnan
824577638@qq.com

Abstract. Pulse compression technology can effectively solve the contradiction between the maximum operating distance and range resolution. LFM is a common means of pulse compression technology. In this paper, the frequency-domain pulse compression of LFM signal is carried out, and the feasibility of frequency-domain pulse compression technology is verified by MATLAB simulation and experimental data.

1. Introduction
In recent years, the navy of various countries has actively carried out underwater weapons such as torpedoes and mines, which has brought great threat to our submarines and ships. In order to improve the survival ability of submarines and warships in the face of torpedo threat, it is necessary to strengthen the research on torpedo alarm sonar. The two key technical indexes of torpedo alarm sonar are the maximum operating distance and range resolution[1]. Among them, the maximum operating distance refers to the maximum distance that sonar can effectively find the target and measure its data under certain conditions, which can be increased by increasing the maximum transmitting power of sonar transmitter[2]. However, because the maximum transmitting power of the sonar transmitter is affected by the transmitter itself, it is impossible to increase infinitely. Therefore, the average power of the transmitting signal of the sonar transmitter is usually increased by increasing the pulse width, so as to achieve the effect of increasing the maximum operating distance. Range resolution refers to the ability of sonar to distinguish two targets which are very close to each other, which depends on the signal bandwidth. However, when the signal bandwidth increases, the range resolution of sonar increases. In order to improve the maximum operating distance and range resolution of a signal at the same time, it is required that the signal should have a large pulse width and a wide bandwidth at the same time. In the ordinary pulse system, the product of time width and bandwidth is a constant, so it is impossible to obtain a long maximum operating distance and a high range resolution at the same time. In order to solve this contradiction, a new technology must be adopted- Pulse compression technology[3-5].

When the sonar transmitter transmits the signal, the pulse compression technology uses the wide pulse signal to improve the average power of the transmitted signal, so as to obtain the far maximum operating distance. When receiving the signal from the array, the pulse compression technology compresses the wide pulse signal into the narrow pulse signal through the matched filtering method, thus obtaining the high range resolution. Therefore, pulse compression technology can effectively solve the contradiction between the maximum distance and high range resolution. According to the modulation mode of the transmitted signal, the pulse compression technology mainly includes linear frequency modulation, nonlinear frequency modulation and phase coding. Among them, LFM[6-7] is
the most commonly used pulse compression signal because it is easy to produce, and the pulse shape and signal-to-noise ratio are not sensitive to Doppler shift after compression. In this paper, the LFM signal is taken as the research object, and the pulse compression technology is studied by the commonly used frequency domain pulse compression method.

2. Principle of pulse compression
Pulse compression refers to transmitting wide coded pulse and processing echo to obtain narrow pulse. It is an application combining matched filtering and related receiving technology. Pulse compression can be divided into time domain pulse compression and frequency domain pulse compression.

2.1. Time domain pulse compression
Time domain pulse compression is realized by convoluting the received signal with the matched filter pulse response. Suppose the received signal of the array is $s(n)$. The pulse response of the matched filter is $h(n)$, which is the deconvolution conjugate of the received signal $s(n)$. Then the output $y(n)$ of the matched filter is the convolution of the received signal $s(n)$ and the matched filter impulse response $h(n)$, which can be expressed as:

$$y(n) = s(n) * h(n)$$

2.2. Frequency domain pulse compression
The convolution calculation in time domain is equivalent to the multiplication calculation in frequency domain. Therefore, the realization block diagram of digital pulse compression in frequency domain is shown in Fig. 1.

![Block diagram of digital pulse compression in frequency domain](image)

Figure 1. Principle block diagram of digital pulse compression in frequency domain.

Frequency domain digital pulse compression technology is to complete the pulse compression of digital signal through frequency domain matched filtering technology. Firstly, the frequency spectrum $s(w)$ is obtained by Fourier transform (FFT) of digital input signal $s(n)$, and then it is multiplied by the complex number of frequency response $h(w)$ of matched filter, and then the multiplied signal is Fourier inverse transform (IFFT), that is, the signal $y(n)$ after pulse compression is obtained. The whole process can be expressed as follows:

$$y(n) = \text{IFFT}[s(w) \cdot h(w)] = \text{IFFT}[\text{FFT}(s(n)) \cdot \text{FFT}(h(n))]$$

3. Pulse compression simulation
In this paper, the frequency domain pulse compression simulation analysis of single pulse LFM signal is carried out, as shown in Figure 2 and figure 3. Among them, figure 2 is the simulation result of frequency domain pulse compression for single pulse ideal LFM signals, and figure 3 is the simulation result of frequency domain pulse compression for single pulse LFM signals with superimposed noise.
Figure 2. Pulse compression result of ideal single pulse sampling signal.

Figure 3. Pulse compression results of single pulse sampling signal with superimposed white noise.

It can be seen from Fig. 2 and Fig. 3 that for single pulse LFM signal, frequency-domain pulse compression technology can effectively compress wideband LFM signal into narrowband signal, and the peak position of narrowband signal is just at the end of wideband LFM signal.

Next, the frequency domain pulse compression simulation analysis of LFM signals of multiple pulses is carried out, as shown in Fig. 4 and Fig. 5. Among them, figure 4 is the simulation result of pulse compression in frequency domain for ideal multi pulse LFM signal, and figure 5 is the simulation result of pulse compression for multi pulse LFM signal with superimposed noise.

Figure 4. Pulse compression result of ideal multi pulse sampling signal.

Figure 5. Pulse compression result of superimposed white noise multi pulse sampling signal.

It can be seen from Fig. 4 and Fig. 5 that for the multi pulse LFM signal, the frequency domain pulse compression technology can also compress the wideband LFM signal into the narrowband signal, and each peak position of the narrowband signal is just the end of the wideband LFM signal.

Through the simulation and analysis of monopulse and multipulse signals, it can be seen that the pulse compression technology in frequency domain can compress the wide pulse signal sent by sonar transmitter into the narrow pulse signal, effectively solving the contradiction between the maximum operating distance and the range resolution.

4. Experimental verification

At last, the algorithm of comment pulse compression is verified by experiments. In this paper, the previous recorded data are processed. The experimental data is 6ms LFM signal, and the signal period is 50ms. The data of 0.5s is processed. The processing results are shown in Figure 6.
From Figure 6, it can be seen that the frequency domain pulse algorithm can compress the wide pulse signal into the narrow pulse signal, and the compression effect is related to the matching degree of the matched filter and the received signal of the array. When there are multiple peaks, the actual position of the signal can be further determined through practical experience or combining with the period before and after to improve the distance resolution.

5. Conclusion
Frequency domain pulse compression technology, using matched filtering method and related reception theory, can compress the wide pulse signal into the narrow pulse signal, which is a common method to improve the maximum operating distance and range resolution at the same time. In this paper, the effectiveness of frequency-domain pulse compression algorithm is verified by MATLAB simulation and experimental data analysis, which provides an important theoretical basis for the design of sonar.

References
[1] Tian, T. (2009) Sonar Technology. Harbin Engineering University Publishing, Harbin.
[2] Zheng, L. (2011) Analysis of digital pulse compression technology of LFM signal. Modern Electronics Technique, 34: 39–42.
[3] Chen, G. (2011) Simulation of LFM signal pulse compression technology. DA ZHONG KEJI, 10: 51-53.
[4] Cao, J. (2008) Research and implementation of broadband real-time pulse compression technology. Huazhong University of science and technology, Hubei.
[5] Lu, X. (2001) A method of matched filtering for LFM continuous wave. Journal of electronics and information, 24: 1216–1219.
[6] Zhu, W. (2013) Detection and parameter estimation of LFMCW signal. Journal of electronics and information, 35: 1562–1568.
[7] Qian, Y. (2006) Parameter estimation algorithm of LFMCW signal. Modern radar, 28: 40-43.