Research on Sidelobe Suppression Method in LFM Pulse Compression Technique

Guofu Wang¹, *, Tiantian Tang¹, Jincai Ye¹ and Faquan Zhang²

¹Guilin University of Electronic Technology, Guilin, China
²Wuhan Textile University, Wuhan, China

*Corresponding author e-mail: 130102424@qq.com

Abstract. System sensitivity and range resolution are a pair of contradictory performance during target detection. In this paper, pulse compression is used to resolve the contradiction between range resolution and sensitivity. A frequency leak occurs in the compressed signal, so that weak targets of the matched filter output may be masked by adjacent strong target side lobes. It is common to suppress the side lobes by adding a window function. Through MATLAB simulation, it is found that when the signal-noise ratio is large, after adding the window function, the small target submerged by the large target side lobes cannot be detected. In this paper, an adaptive pulse compression (APC) technique based on minimum mean square error (MMSE) is used to suppress side lobes. The simulation proves that APC algorithm suppresses side lobes more effectively.

1. Introduction
Pulse compression is the design of a waveform and its corresponding matched filter, so that the response of the matched filter to the echo of a single point scatter can concentrate most of the energy in a very short time. Thus providing good distance resolution. The rate can also be used to obtain high emission energy with long pulses. However, after pulse compression, the output signal of the matched filter will produce a frequency leak. When there is a weak target near the strong target, it is likely to be submerged in the side lobes of the strong target. So the study of side lobes suppression methods is the key to pulse compression technology.

Traditionally, window functions have been used to suppress side lobes. But as people's demand for distance resolution has increased, many new side-lobe suppression techniques have been proposed. Adaptive pulse compression is a key content studied in recent years. Adaptive pulse compression is to use the distance image of the target as a priori information. The iterative algorithm adaptively sets the matched filter parameters for each distance unit to achieve the suppression the effect of high side lobes.

2. The principle of pulse compression
Pulse compression can decouple the transmitted waveform bandwidth and time width and make the two parameters of sensitivity and range resolution independent. One of the most common options is the LFM waveform, which modulates the frequency of long pulses during transmission. Figure 1 shows an ideal linear frequency modulated pulse compression process. (1) shows the envelope of the wide pulse, (2)
shows the frequency modulation of the bandwidth \( B = f_2 - f_1 \) (3) shows the time delay characteristic of the matched filter, and (4) shows the pulse envelope after compression.

![Figure 1. Ideal LFM pulse compression](image)

When pulse compression is used, keeping the pulse width unchanged while increasing the bandwidth that can make the detection distance unchanged while significantly improving the range resolution.

3. Adaptive pulse compression and side-lobe suppression method

3.1. Pulse compression and its side-lobe suppression

Pulse compression is a special matched filter. This filter is characterized by its impulse response and the transmit waveform modulation function is the same, but it is flipped and conjugated in time. So its impulse response matches the specific transmit waveform modulation.

For the same length of signal, the frequency domain pulse compression scheme requires less computation, and in order to suppress the side lobes, window processing is required to select the frequency domain. Frequency domain does not require additional memory, and the amount of computation is small, so this paper chooses to do it in the frequency domain. Since the matched filter is a linear time-invariant system, its output can be expressed as the convolution of the input signal and its impulse response by a mathematical expression.

\[
y(t) = x(t) \ast h(t) = \int_{-\infty}^{\infty} x(t \cdot h(t - s))ds
\]

\( x(t) \) is the input signal, \( h(t) \) is the impulse response (copy) of the matched filter. Due to the strong correlation with \( h(t) \) and \( s(t) \), at \( t = T \), the energy of the signals on the respective frequency components can be superimposed on each other. But for noise, its randomness causes its power to not be superimposed.

According to the properties of the Fourier transform

\[
\text{FFT}\{x(t) \ast h(t)\} = S(f) \cdot H(f)
\]

When both signals are correctly sampled, the compressed signal \( y(t) \) can be expressed as

\[
y = \text{FFT}^{-1}\{S \cdot H\}
\]
The $FFT^{-1}$ is Fourier inverse transformation. The normalized complex transmit signal is in the form of $s(t)$

$$s(t) = a_1 \exp \left( j2\pi \left( f_0 t + \frac{\mu}{2} t^2 \right) \right)$$

The $\tau$ is pulse width, $\mu = B/\tau$, and $B$ is bandwidth. Consider a target with a distance of $R$, from which the radar receives an echo of $s_r(t)$

$$s_r(t) = a_1 \exp \left( j2\pi (f_0 - \tau_1) t + \frac{\mu}{2} (t - \tau_1)^2 \right)$$

Where $a_1$ is proportional to the target's RCS, antenna gain and distance attenuation. The time delay $\tau_1 = 2R/c$.

Since the output function has the sinc characteristic, side lobes appear on both sides of the main lobe, and the conventional window function is used for processing. The commonly used window functions mainly include rectangular window function and Hamming window functions, Hanning window functions, Blackman window functions, Kaiser Window functions. Below we use MATLAB to simulate the effects of several window functions on the main lobe broadening and the peak side lobe ratio.

![Figure 2. Common window function simulation diagram](image)

The simulation adds five common window functions to the signal. For the three main indicators of the window function characteristics, the main lobe width (relative to the rectangular window), the peak side lobe and peak gain loss statistics are as follows.

| Window type  | 3dB main lobe spread | Peak side-lobe(dB) | Peak gain loss |
|--------------|----------------------|--------------------|---------------|
| Rectangle    | 1.0                  | 13.3               | 0.0           |
| Hanning      | 1.7                  | 31.5               | 6.1           |
| Hamming      | 1.5                  | 42.6               | 5.4           |
| Kaiser       | 1.2                  | 24                 | 3.4           |
| Blackman     | 1.9                  | 45.5               | 6.9           |
It can be seen from the simulation graph and the characteristic statistics table that Hamming and Blackman have better suppression effect on the first side lobes. But Blackman makes the main lobe broader and the frequency recognition accuracy is lower and peak gain loss is also the largest. So consider it comprehensively we choose to add Hamming function. In case of main lobe broadening and peak gain loss is small, it has the best peak side lobe level.

3.2. Adaptive pulse compression algorithm
The difference between the adaptive pulse compression and the traditional pulse compression is that the traditional pulse compression relates the received signals in the current stage to the radiated signals, while the adaptive pulse compression process is the previous stage based on the minimum mean square error. Taking the estimated impulse response as the original data of the current phase, a unique corresponding "matched filter" coefficient \( w(l) \) is designed for each distance unit in the processing window.

The estimated value of the distance element \( l \) of the APC algorithm is \( \hat{x}(l) \)

\[
\hat{x}(l) = w^H(l)\hat{y}(l)
\]

Where \( l=0,1,2,\ldots, L-1 \), \( L \) is the length of the processing window. N-point echo signal, the sample value of the radar echo signal at the point \( l \) of the unit: \( \hat{y}(l) = [y(l), y(l + 1), \cdots, y(l + N - 1)] \), \( \hat{x}(l) = [x(l), x(l + 1), \cdots, x(l + N - 1)]^T \) is the continuous N-point sampling echo impulse response.

Based on MMSE criterion, the cost function is constructed

\[
J(l) = E[|x(l) - w^H(l)\hat{y}(l)|^2]
\]

\( J(l) \) is the gradient of \( w^H(l) \), which is set to zero, and \( w(l) \) is

\[
w(l) = \rho(l)(C(l) + R)^{-1}s
\]

\[
C(l) = \sum_{n=-N+1}^{N-1} \rho(l + n)s_n^*s_n^H
\]

In the formula, \( \rho(l) = |x(l)|^2 \), \( R = E[\hat{V}(L)\hat{V}^H(l)] \) is the covariance matrix of noise \( N \times N \), \( s_n \) that the signal \( s \) is translated by \( n \) units. Adaptive pulse compression matches the filter coefficient \( w(l) \) with the echo signal instead of matching the transmitted signal. The more iterations, the better side lobe suppression effect. But the amount of calculation will also increase. Figure 3 is the flow diagram of two iterations of the adaptive pulse compression algorithm.
4. The simulation results

In the process of target detection of nonlinear nodes, the third harmonic of target radiation is usually weak, and the useful signal is accompanied by various noise interference. Therefore, we accumulate the pulse of the echo signal to improve the SNR of the target echo signal. In this paper, 150 pulses of coherent accumulation are set, so that the SNR improvement can reach 23.01dB.

We set the same parameters, set three targets with close distance, the distance is [121, 135, 151], the cross sectional area of the scatterer is [18, 6, 21], set the pulse width to 10 microseconds, and the bandwidth to 20 megahertz. Three simulation experiments were carried out with the above parameters, and the results are shown in the figure below.
Figure 6. The signal after APC pulse compression

Figure 4 is the pulse compression diagram without adding a window; Figure 5 is the result diagram after adding the hamming window function; Figure 6 is the signal after APC pulse compression. The simulation results show after adding the window function that the side lobes on both sides of the main lobes are restrained, but the main lobes are widened. The range resolution of signal detection is affected to a certain extent, so that only two targets can be detected after pulse compression. The simulation image after adaptive pulse compression processing has good side-lobe suppression effect and can distinguish and detect three targets at the same time. The side lobe peaks under different SNR conditions are drawn, as shown in figure 7.

Figure 7. Hamming window and APC algorithm peak side lobe ratio comparison

As can be seen from figure 7, when the signal-to-noise ratio is low, the hamming window and APC algorithm have similar side-lobe suppression effect. However, after pulse accumulation, with the increase of signal-to-noise ratio, the side lobe suppression effect of windowing is weak, and APC algorithm is obviously better than windowing treatment. For example, when the SNR is 30dB, the side lobe peak ratio of the added window function is about -30db, while the side lobe peak ratio of the APC algorithm is about -40db. It can be seen that in the case of high SNR, the side lobe suppression and target detection effect of adaptive pulse compression is better than that of window function. It is better applied in signal processing.
5. Conclusion
In the process of nonlinear node target recognition, the contradiction between sensitivity and range resolution is solved by chirped pulse compression and compression. The compression process is performed in the frequency domain, and the output of the matched filter is calculated by FFT. For the frequency leakage phenomenon, this paper suppresses side lobes by adding window function and APC algorithm. In the process of selecting the window function, through the analysis of the relevant performance, we select the Hamming window. But when the signal-to-noise ratio is large, the weak target will still be submerged in the side lobes of the strong target. At this time, the adaptive pulse compression technique based on MMSE is adopted. Through MATLAB simulation, the three scatterers targets are detected, which indicates that when the signal-to-noise ratio is large, the APC algorithm can suppress the side lobes better than the traditional windowing process, and reduce the error in the target recognition process.

Acknowledgements
This work is supported by the National Natural Science Foundation of China under Grant number 61761009. I would like to express my gratitude to all the teachers in the laboratory for their guidance and help, and for their valuable advice during the process of writing the paper. Secondly, I would like to thank all my classmates for their communication with me, which gave me better ideas to solve problems.

References
[1] Jau Pei Hung Signal processing for harmonic pulse radar based on spectrum technology, IET Radar, Sonar and Navigation, v 8, n 3, p 242-250, 2014.
[2] Xu Yiyu, Third harmonic detector technology research [D]. Nanjing University, 2007.
[3] Zhai Qinglin, Zhang Jun, Fu Qiang, LFM pulse compression technology and its application in radar system [J] Modern electronic technology 2007 (1).
[4] Tang Yu, Simulation research on how to improve the range resolution of pulse compression radar based on phase coding, Applied Mechanics and Materials, v 143-144, p 634-638, 2012.
[5] Zeng Xianggui, Sodelobe Suppression Technology Basing on APC [D] Graduate School of National University of Defense Technology, 2014
[6] Jau, Pei-Hung, Tsai, Zuo-Min, Kuo, Nai-Chung, Kao, Jui-Chi, Lin, Kun-You, Chang, Fan-Ren, Yang, En-Cheng, Wang, Huei, Signal processing for harmonic pulse radar based on spread spectrum technology, IET Radar, Sonar and Navigation, v 8, n 3, p 242-250, 2014.