Research on Signal Processing Method of X-band Multifunctional Phased Array Radar

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Abstract. The signal processing algorithm is an important component of the three major technical fields of radar, and it occupies an important position in the radar system. It is the basis for phased array radar to achieve multi-function. The rapid development of modern signal processing technology has greatly promoted the development and application of radar technology. Modern radar simulation systems can simulate and optimize signal processing algorithms, and quickly adjust system parameters; because it adopts modularization and systematically encapsulated, it can be used repeatedly in different environments or platforms. The continuous development of modern signal processing technology has improved the performance of the radar system, especially in improving the radar's target detection capability and anti-jamming performance. Because signal processing occupies a very important position in radar systems, this paper studies the signal processing in radar systems. This paper analyzes the signal processing process of the multifunctional phased array radar, and conducts corresponding analysis and research on the key technologies.

1. Introduction

Compared with traditional mechanical radar, phased array radar has a huge difference, which mainly reflects two major aspects [1]. Phased array radar uses electronic scanning technology to achieve inertial scanning and flexible beam agility; combined with fast-developing signal processing technology, it can achieve integrated search alert, multi-target tracking, target feature recognition, radar imaging, etc. Multiple functions in one. In actual scenarios, the phased array radar system is extremely complex in terms of function and structure, and the use of field research methods has been far behind the development of modern radar technology. Therefore, computer technology is more widely used in the simulation research of radar systems [2]. As a key subsystem of the radar simulation system, the radar signal processing system has an extremely important impact on the overall function and performance of the radar. The development of modern signal processing technology has promoted the performance of radar systems, especially the radar's target detection ability and anti-jamming performance. The research and simulation realization of signal processing algorithm is a key link in the radar simulation system, and it is the basis for multi-functional phased array radar to realize multi-target detection, target feature recognition, target tracking and interception. With the continuous development of military science, multi-functional phased array radar has become more and more important in modern electronic warfare [3]. Therefore, this paper studies the signal processing technology of the multifunctional phased array, and has achieved certain research results.
2. Phased array radar system analysis and signal processing flow

2.1. Analysis of Phased Array Radar System
The antennas of the phased array radar can be divided into linear arrays and planar arrays according to their arrangement. The number of array elements can be as few as a few or as many as tens of thousands. The specific number can be determined according to the specific environment [4]. Figure 1 is a linear equidistant array antenna composed of 16 array elements. The radar antenna used in the research project of this paper is shown in Figure 1. It is an equidistant linear array element composed of 16 spontaneously transmitted and self-received array elements. These array elements emit coherent electromagnetic wave signals and use the coherence principle of electromagnetic waves in space to form energy-concentrated beams, and then use computer programs to control the phase of the currents fed back into each array element, thereby forming the possibility to change the radar beam direction Effect [5]. During the receiving time, the array element sends the received radar echo signal to the host computer, and then completes the search, measurement and tracking of the target by the radar through the processing of the signal processor. In addition, the greater the number of antenna elements, the greater the number of beams formed under the same scanning range.

After the radar receives the echo, it must be down-converted to convert the echo signal into an intermediate frequency signal before the corresponding signal processing can be performed. For phased array radar engineering projects, the usual signal processing sequence to be done is: digital beam forming, pulse compression, moving target detection, constant false alarm, clutter map, dot trace aggregation, etc., and finally the dot trace information is transmitted to the host computer display [6].

2.2. Signal processing flow
The guided search task of the radar only needs to obtain the beam position and distance of the target, therefore, only the echo signal of the channel needs to be processed [7]. The signal processing flow is shown in Figure 2.

When the guided search fails or the manual multi-pulse search command is received, the radar arranges the multi-pulse guided search task, performs pulse accumulation, and uses the Keystone method to perform range correction, and then performs subsequent signal processing on the corrected echo signal and records [8]. The beam position and distance where the target appears, and the channel signal processing flow are shown in Figure 3.
Obtain the current receiver output, beam direction, sampling interval, etc.

Atmospheric ionization phase compensation

Pulse compression

CFAR processing

Distance judgment

Record the beam position and distance value of the target and transmit data processing

Figure 2. Signal processing flowchart

Obtain the current receiver output, beam direction, sampling interval, etc.

Atmospheric ionization phase compensation

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Record the beam position and distance value of the target and transmit data processing

Figure 3. Multi-pulse search time and signal processing flow
2.3. Multifunctional phased array signal multilayer structure

Multifunctional radar signals can be divided into three levels: functional level, task level and waveform level. In the research, we carried out these three levels separately.

Inside the multifunctional radar, multiple relatively independent work processes are executed in parallel, and each work process corresponds to a function. In addition to sharing system resources such as time, energy, and computing, different functions can independently schedule beams and arrange transmission signals according to their own characteristics and laws to achieve their respective goals [9]. According to different requirements, the functions contained in multifunctional radars used in different fields may vary greatly. In a typical system, at least a search function and a target tracking function are included. Each function of the multifunctional radar is realized by performing a series of radar tasks. Each radar task corresponds to a certain beam direction and emission waveform, which is used to complete a basic link in the whole work process of the function or to achieve a specific purpose. The versatility of a multifunctional radar requires it to have the ability to generate and process multiple signals. In order to maximize the potential of the system, the multifunctional radar needs to select different emission waveforms for different tasks according to the characteristics of different environments and targets to achieve optimal information extraction.

After analysis, the structure of the multifunctional radar signal can be divided into three levels: functional layer, task layer and waveform layer, as shown in Figure 4.

![Figure 4. Multifunctional radar signal hierarchy](image)

3. Research on Multifunctional Phased Array Signal Processing Technology

3.1. Radar transmission signal generation

The coherent radio frequency signal used in this radar simulation system is expressed as follows:

\[
S(t) = \frac{P_s}{\sqrt{4\pi L_s}} g_{\text{ctl}}(\theta) \cdot \text{rect}\left(\frac{t}{T_p}\right) \cdot \exp\left(j\pi \frac{B_{Wg}}{T_p} t^2\right)
\]  

(1)

In the above formula, \( \text{rect}(t) \) represents the rectangular function, which is defined as:

\[
\text{rect}(t) = \begin{cases} 
1, & t \in (0,1) \\
0, & \text{other}
\end{cases}
\]  

(2)
Among them, $P_t$ is the peak power of the signal transmitter in the radar system, $L_t$ is the loss of signal transmission, $g_{rt}(\theta)$ is the radiation pattern of the radar system's transmitting antenna, $T_p$ is the pulse width of the coherent radio frequency signal, and $BW_g$ represents the frequency modulation bandwidth of coherent radio frequency signals.

3.2. Pulse compression
The pulse compression of the echo signal is achieved through matched filtering, which can improve the range resolution of the radar system while obtaining a longer range. This paper studies the radar simulation system, and realizes the pulse compression of the echo signal through the digital compression FFT method. The principle of this method is relatively simple and easy to implement. This method first performs FFT operation on the echo signal, multiplies the result by the digital frequency of the matched filter, and then passes through IFFT to achieve pulse compression.

The specific implementation steps of frequency domain pulse compression are as follows:

- Suppose the data length is K, the matching function length is M, and the calculation $\log_2(K + M)$ is rounded and expressed as N.
- The radar received signal is expressed as $x(n)$, $n=0,1,\ldots,K-1$, K is the length of sequence points. The signal $x(n)$ is filled with a sequence of length N, and the filling method is:
  $$x(n) = \begin{cases} x(n), & n = 0,1,2,\ldots,K-1 \\ 0, & n = K,\ldots,N-1 \end{cases} \quad (3)$$

Perform FFT processing on the zero-padded sequence, that is, $X(K) = FFT[x(n)]$.

- Sample processing
The sequence after sampling the radar signal is expressed as:
  $$h_1(n) = K_e e^{i[2\pi f_0(n\frac{1}{T_p}) + nb(n\frac{1}{T_p})^2]} \quad n = 0,1,\ldots,M-1 \quad (4)$$

Among them, $K_e = \frac{B}{f_s} \cdot \frac{1}{\sqrt{D}}$ represents the coherent filter coefficient, B is the bandwidth of the radar transmission signal, $f_s$ is the sampling frequency of the transmission signal, pulse compression ratio $D = BT_p$, and $T_p$ is the pulse width of the transmission signal. $f_0$ represents the carrier frequency of the transmitted signal. In the coherent video simulation system, the carrier frequency of the transmitted signal can be set to 0, b represents the chirp slope of the transmitted signal, and $M = f_s T_p$ represents the number of sampling points of the radar transmitted signal.

3.3. Clutter suppression
In the working process, it will inevitably be affected by the enemy's interference signal, resulting in the radar system not being able to accurately measure the direction of the target signal. For multifunctional phased-array radar, some elements of the radar antenna array are selected as the auxiliary antenna array of the radar to form a side-lobe cancellation system for interference suppression. The sidelobe cancellation system can adaptively estimate the direction and signal power of the interference signal received by the radar antenna array, and calculate the weight of the auxiliary antenna array in the radar antenna array according to the minimum mean square error or other criteria. In this way, the combined pattern of the antenna array of the radar system is adjusted, and the direction of the interference signal in the pattern is set to zero, so as to achieve the purpose of suppressing the interference signal entering from the sidelobe of the radar antenna.

Clutter suppression is a very important part of radar signal processing. Effective clutter suppression is the premise and basis for the radar system to accurately detect the target. Moving target detection (MTD) is an effective means to suppress clutter.

Moving target detection is to let the radar echo pass a set of band-pass Doppler filters to suppress clutter. The center frequency of this set of band-pass filters covers the entire pulse repetition period. Common clutters include ground clutter and meteorological clutter. Wave etc. There are two common
implementation methods of MTD filter banks: one is to achieve by fast Fourier transform, and the other is to achieve by designing FIR filters. There are two common implementation methods of MTD filter banks: one is to achieve by fast Fourier transform, and the other is to achieve by designing FIR filters. However, the FFT filter does not have a good clutter suppression effect, because the FFT filter does not suppress the clutter at the zero Doppler frequency. For the ground clutter, most of them are static and are at zero Doppler frequency. Therefore, a moving target detection filter combined with MTI and FFT is required in engineering projects. After the echo signal passes through the MTI filter, the ground clutter at the zero Doppler frequency is almost eliminated, after which only FFT is needed to filter the target. However, the resulting problem is that the echo signal will be affected after passing through the MTI filter. The signal input to the FFT filter is not the original echo signal and will have a certain impact on the result. Since an efficient FIR filter can adaptively suppress the clutter according to the characteristics of the clutter, designing an effective FIR filter to suppress the clutter becomes the best choice. As digital signal processing technology and signal processing hardware platform can provide the necessary support, at present, the design of FIR filters can be implemented in engineering projects.

4. Conclusion
Multifunctional radars can perform multiple functions in parallel, have unknown behaviors and agile waveform characteristics. Current electronic intelligence systems cannot effectively describe and process their signals. With the more and more widespread deployment and application of multifunctional radars, the research of electronic intelligence signal processing technology for multifunctional radars is of great significance. This paper focuses on the research and analysis of the signal generation and processing process of the multifunctional phased array radar, and proposes a three-layer structure of the multifunctional phased array radar signal, aiming at the signal transmission, propagation and reception of the multifunctional phased array radar. The wave signal process is introduced in detail. Due to time constraints, the real-time interactive function of the radar simulation system has not been implemented or simulated. The radar simulation system can be improved and supplemented in the following aspects.

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