Variable Bandwidth Receiving Method of Civil Aircraft Radar Signal Based on FPGA Technology

Ming-fei Qu(✉) and Dong-bao Ma

College of Mechatronic Engineering, Beijing Polytechnic, Beijing 100176, China

Absrtact. Traditional variable bandwidth receiving method has the problem of digital channel division confusion, which leads to the low anti-interference performance of the receiving method. Therefore, this paper designs a variable bandwidth receiving method of civil aircraft radar signal based on FPGA technology. After measuring the distance between two carrier frequency signals, the frequency modulated civil aircraft radar signal is continuous wave. Then, according to the signal bandwidth, the radar scattering surface characteristics of the radar signal bandwidth are obtained. Then, the FPGA technology is used to divide the digital channel, determine the number of effective signals, detect the shape of interference echo, and set up the variable broadband receiving module, so as to realize the design of civil aircraft radar signal variable bandwidth receiving method. The experimental results show that the anti-jamming degree of the proposed method is 9.384% ~ 17.426% higher than that of the two existing receiving methods under different jamming intensities, which proves that the proposed method is more suitable for civil aircraft radar signal receiving field under different jamming intensities.

Keywords: FPGA technology · Civil aircraft · Radar signal · Variable bandwidth

1 Introduction

With the continuous development of electronic information technology, civil aircraft need to adapt to more complex electromagnetic environment. In the complex electromagnetic environment, the radar signal receiving equipment of civil aircraft often receives multiple radar signals with different bandwidth in its monitoring bandwidth. In order to separate radar signals effectively, it is necessary to have multi-channel receiving ability. At the same time, due to the uncertainty of the bandwidth and position of the radar signal, civil aircraft also needs to have the ability to realize the variable bandwidth receiving technology.

In the early days, the radar signal receiving equipment of civil aircraft is to receive the radar signal in the way of single channel receiving, or on the basis of single channel receiver, they are used in parallel [1]. However, such radar signal receiving equipment of civil aircraft often needs to constantly change the local oscillator of the equipment in the search process because of the uncertainty of channel and the jump of radar signal

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when detecting and collecting radar signals. However, due to the limited search speed, it is easy to cause the omission of radar signal, which leads to the failure of the search equipment to intercept the complete radar signal. This indicates that the single channel receiver has been difficult to adapt to the needs of modern development through simple modification of architecture and improvement of details [2].

The radar signal receiving equipment of civil aircraft is mostly multi-channel receiver, which can achieve full probability radar signal interception. Their structures are similar to each other. Most of the front ends use the classic superheterodyne structure for reference, but the specific radar signal receiving and processing flow is different. Reconnaissance antenna is used to detect and receive radar signals within a certain frequency band.

FPGA (Field Programmable Gate Array) technology is a product of further development on the basis of PAL, GAL and other Programmable devices. As a semi-custom circuit in ASIC field, it not only solves the shortcoming of custom circuit, but also overcomes the shortcoming of limited gate number of original programmable device. FPGA technology has a programmable delay digital unit, which is widely used in communication system and various electronic equipment. Therefore, combined with the above research background, this paper designs a variable bandwidth receiving method for civil aircraft radar signal based on FPGA technology. The design idea of this method is as follows:

(1) After measuring the distance between two carrier frequency signals, frequency modulated continuous wave of radar signal of civil aircraft.
(2) According to the signal bandwidth, the radar scattering surface features of the radar signal bandwidth are obtained. Then, FPGA technology is used to divide digital channels to determine the number of effective signals and detect the shape of jamming echoes.
(3) Set up the variable broadband receiving module, so as to realize the variable bandwidth receiving of civil aircraft radar signals.

2 Variable Bandwidth Receiving Method of Civil Aircraft Radar Signal Based on FPGA Technology

2.1 Continuous Wave of FM Civil Aircraft Radar Signal

The simple rectangular pulse radar transmits a single frequency sine wave signal during pulse modulation. The signal frequency of pulse compression radar increases linearly during pulse modulation. The carrier frequency of frequency continuous wave radar system increases or decreases in the whole signal period. Pulse compression radar system has the advantages of high ranging accuracy. Its range resolution is directly proportional to the bandwidth of the transmitted signal. The larger the bandwidth of the transmitted signal, the higher the range resolution. FMCW is a radar system widely used in anti-collision radar [3]. Continuous wave can be divided into constant frequency continuous wave, frequency shift keying, phase shift keying and linear frequency modulation continuous wave. Among them, the frequency of the transmitted signal in the constant frequency continuous wave mode is single, and only the Doppler frequency of the target can be obtained after mixing. Therefore, it can only measure the velocity, but has no ranging ability, so it can not be used in the anti-collision radar. Compared with the above types of radar, LFMCW has the advantages of no range blind zone, wide signal bandwidth, simple transceiver system and high sensitivity, so it is most widely used [4, 5]. De slope is an effective way to process the frequency domain continuous wave of FM civil aircraft radar signal. The radar mixes the target echo signal with the local oscillator signal to get the beat signal. For the point target, the beat signal is a single frequency signal. Then, the baseband digital signal is processed by low-pass filtering and amplification of beat signal, and the obtained digital signal is processed by Fourier transform for spectrum analysis. The range information of target relative to radar can be extracted from the frequency domain information. When the radial velocity is 0, then:

$$L = \frac{2AQ}{PJ} \tag{1}$$

In formula (1), L is the frequency domain of radar signal, Q is the relative distance between radar and target, A is the baseband signal, P is the phase shift range, and J is the peak value of radar signal. Because the relative speed of radar and target is very small relative to the speed of light, and the multi cycle time is also relatively short, the change of radar received signal strength caused by the change of relative distance between radar and target during the cycle can be ignored, that is, the amplitude change of spectrum peak value of multi cycle echo beat signal can be ignored. For the chirp signal, only the peak value of the chirp signal changes with the time, that is to say, the variation of the echo phase of the chirp signal is ignored The larger the degree, the larger the envelope frequency. Its working principle is shown in Fig. 1.

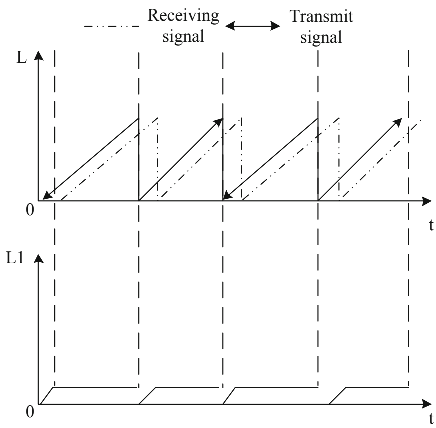


Fig. 1. Schematic diagram of frequency modulation

It can be seen from Fig. 1 that the continuous wave in the frequency domain of the signal of civil aircraft is related to its peak within a fixed distance, while the maximum peak is related to the motion state of the target within the receiving distance. In modern civil aircraft, the method of separating stationary target and moving target is often used to suppress clutter. When the aircraft is in flight, there is relative motion between the aircraft and the obstacles it faces. Therefore, in the process of frequency modulation, the error caused by relative motion should be solved first [6].

The clutter that radar may encounter when working includes fixed clutter and moving clutter. The Doppler frequency of fixed clutter and slow moving clutter is almost zero, the amplitude and phase of the signal after phase detection will not change with time or change slowly with time, while the amplitude and phase of the moving echo after detection will change greatly with time. In this case, the same range unit of the adjacent repetition period can be subtracted, and the fixed target can be completely cancelled and the slow moving echo can be eliminated The moving clutter is also attenuated to a great extent, and only the moving echo is retained, thus completing the frequency domain continuous wave working steps of FM civil aircraft radar signal.

2.2 Feature Extraction of Variable Wideband Radar Scattering Surface

It is very important to obtain radar scattering surface characteristics of radar signal bandwidth in the whole process of receiving radar signal. Generally speaking, in order to be able to receive signals of different frequency bands and different bandwidths, current digital receivers all have multi-channel receiving capability. For the multi-channel receiver, the radar signal bandwidth change judgment module can be located either before the original sampling signal enters the multi-channel receiving module or after the processing of the multi-channel receiving module [7]. In order to judge the signal bandwidth before the receiving module, panoramic monitoring is needed for the input, and in order to judge the signal bandwidth after the receiving module, channel judgment is needed for each subchannel. But both of them are time-frequency detection. Short time Fourier transform, wavelet transform and other classical methods can be used in the spectrum feature extraction module to analyze the spectrum of the original sampling signal in real time. The specific process is shown in Fig. 2.

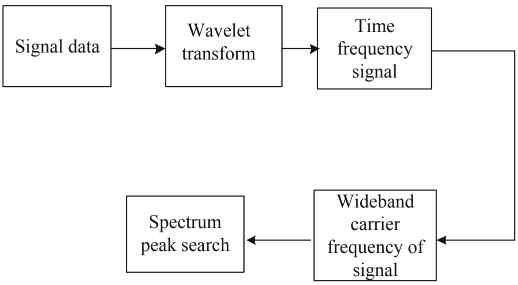


Fig. 2. Signal acquisition process

As can be seen from Fig. 2, after the broadband signal passes through the channelization module, the bandwidth of the broadband signal is greater than that of a single subchannel, and the signal spectrum is cut by multiple adjacent subchannels. Taking the wideband LFM signal as an example, the signal detection module of the left subchannel will detect the signal energy first, then the middle subchannel and the right subchannel in turn, and the signal occurrence time of each subchannel will be partially overlapped in the first place. But at this time, the parameters measured in each sub channel are incomplete or even wrong, so it is difficult to obtain the real parameters of broadband LFM. According to the theory of electromagnetic wave, the intensity of electromagnetic wave is determined by the intensity of electric field. Then the expression formula of RCS is as follows:

$$\delta = l \underset{H \to \infty}{im} \times 4\pi H^2 \left| \frac{W_1}{W_2} \right|^2 \tag{2}$$

In formula (2), δ is the area of radar cross section, H is the radar signal target with feature extraction, W_1 and W_2 are the intensity of incident electric field and scattering electric field respectively. The scattering modes of scattering sources include mirror echo, edge diffraction echo, traveling wave echo, creeping wave echo, tip diffraction echo, dihedral angle scattering, corner body scattering, cavity scattering, etc. [8].

RCS is calculated by theoretical calculation and practical measurement. The theoretical calculation includes geometric optical approximation, physical optical approximation and geometric diffraction theory. The scattering cross section of radar is closely related to the shape, size, structure, material and polarization mode of the radar. At the same time, it is also the fluctuation function of the frequency and angle of incidence of the incident electromagnetic wave. When other conditions are constant, the larger the target size is, the larger the radar cross-section is. For a certain radar frequency and fixed angle of view, the radar cross-section of the target is determined by the polarization mode. The time delay, Doppler frequency shift and amplitude factor attenuation in radar echo signal are all related to the distance and motion state of the target relative to the radar. Based on the above description, the acquisition step of the scattering surface feature of variable wideband radar is completed.

2.3 Using FPGA Technology to Divide Digital Channel

FPGA technology has the advantages of high integration, strong logic implementation ability, good design flexibility, short development cycle and fast working speed, which is widely used in the field of radar signal processing. Using FPGA technology to divide the digital channel is one of the important links in the design of civil aircraft radar signal variable bandwidth receiving method.

Because each subchannel filter has a certain center frequency and bandwidth, the channel decision for each subchannel can make a rough judgment on the signal frequency band and bandwidth [9]. Therefore, the channel decision is equivalent to depicting a discrete time-frequency diagram. It focuses on when signals appear in some subchannels. The common channel decision methods are energy detection and autocorrelation detection. Energy detection belongs to the non coherent detection of signal, which can be carried out in time domain or frequency domain. Time domain detection is to accumulate the time domain signal, and then compare with the time domain detection threshold to determine whether the signal exists.

Frequency domain detection is to convert the time domain input to the frequency domain, then carry out some accumulation, and then compare with the frequency domain threshold to determine whether the signal exists. Frequency domain detection accuracy is high, but the algorithm is complex and resource consumption is high. Time domain detection algorithm is simple, but the accuracy is not high. Both have their own advantages and can be applied in different occasions. Frequency domain detection is to detect the signal from the spectrum, so as to determine whether there is a signal in the subchannel. The length of external input data is unknown, so the length of output data of subchannel, that is, the length of input data detected in frequency domain, is also unknown. In the actual detection, the input data needs to be windowed to fix the length of the input data points. According to the different ways of data windowing, the frequency domain detection method can be roughly divided into three cases, as shown in Fig. 3.

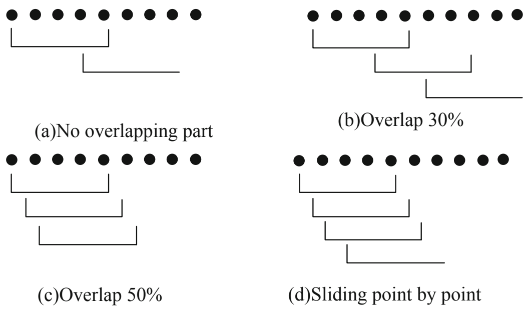


Fig. 3. Schematic diagram of data point sliding

As can be seen from Fig. 3, different overlapping methods will present different detection results after windowing detection. The higher the overlap degree of the sliding window, the greater the amount of computation, but too little overlap of the sliding window will lead to the loss of signal information.

In practical application, the balance between calculation and detection performance should be considered comprehensively. On the premise of ensuring reliable detection, the method with appropriate calculation should be selected. Finally, the output is compared with the set threshold to determine whether there are valid signals and the number of valid signals. The signal received by radar receiving equipment is non cooperative signal, and the key information is unknown. In the design of digital channelized receiver, the blindness of channel division occurs, which leads to the problem of cross channel when reconnaissance receives non cooperative signal [10].

Single stage Digital Channelization structure, usually the sub channels are evenly divided, only providing a single sub channel bandwidth. If the bandwidth is too wide, the signal is channelized in the frequency domain and distributed in multiple adjacent subchannels, resulting in distortion of the output signal. When the channel is divided into wide channels, the SNR gain of narrow channels is small, which makes the subsequent signal processing difficult. Autocorrelation detection method is also a practical channel detection decision method. The main process of the detection method is to first perform some autocorrelation operations on the received data, then accumulate the autocorrelation results, and finally compare the cumulative value with the threshold. From the detection process of autocorrelation method, we can see that it has the characteristics of time-domain energy detection method for accumulation, and frequency-domain energy detection method for some kind of operation. Considering that the received signal is a complex signal, it does not affect the actual effect:

$$Y = U^{2\pi Ej} + m \tag{3}$$

In the formula (3), Y is the complex signal type of civil aircraft, U is the signal amplitude, E is the carrier frequency, j is the sampling period, and E is the zero mean additive white Gaussian noise.

To sum up, it can be seen that the theoretical basis of this method is that the signal is not correlated with noise. The autocorrelation method has the advantages of high efficiency and fast detection of signal in time domain energy detection method, and also has the advantages of detection of signal in frequency domain energy detection method in the case of low signal-to-noise ratio. In engineering implementation, digital filter is not an ideal filter, there is a transition band between passband and stopband, and there is excessive band overlap between channelized channels. For multiple signals arriving at the same time, they overlap in time domain and do not overlap in frequency domain. Channel division is to use this feature to separate signals.

2.4 Setting Variable Broadband Receiving Module

Setting up the variable broadband receiver module is one of the important links in designing the bandwidth receiving method. The single-channel monopulse tracking receiver is an important part of the radar signal processing system, which is mainly used to receive and track the radar signal and other signals, so as to realize the automatic tracking of the target.

When radar antenna is receiving signals, its target does not always appear in the center of radar antenna beam. In general, the target will enter the antenna beam at 3 dB point, and then leave the antenna beam from 3 dB point. In this way, the target echo is double-modulated in the directivity diagram, and its expression formula is:

$$k = \frac{S_r \times \sigma_{0.5}}{\Omega} \tag{4}$$

In the formula (4), k is the number of received pulses of radar signal, S_r is the radar pulse frequency, $\sigma_{0.5}$ is the half power point width of radar beam, and Ω is the rotation speed of radar antenna. The radar with the same frequency band and the same model will cause synchronous jamming while the radar with the same frequency band and different model will cause asynchronous jamming. Through the observation of radar display, we can clearly see the different effects of two kinds of same frequency jamming on Radar: when two radars have the same or integral multiple pulse repetition period, the jamming echo presents concentric circle shape, which is called synchronous jamming.

If the pulse repetition periods of two radars are different and not integral multiple, the jamming echo presents the shape of rotating petals, which is called asynchronous jamming. When the channelization module processes different signals, according to the modulation type, carrier frequency, bandwidth and other parameters of the signal, the signal will appear different distortion in the cross channel frequency domain.

The radar antenna emits electromagnetic pulse or continuous wave to the aircraft or target in the air. When the signal propagates to the aircraft, the energy of the signal beam expands to the air. The signal strength of any point in the signal beam can be expressed by energy density. When the signal irradiates and passes through the aircraft surface, part of the incident energy is absorbed as heat energy, the other part of the energy completely passes through the aircraft parts, and the rest is re radiated in all directions by different conductive surfaces on the aircraft. The reradiation electromagnetic signal is generated by the surface current oscillation generated by the electromagnetic field oscillation of the incident radar signal that irradiates the target, which is usually called the scattered or reflected signal. The setting step of the variable broadband receiving module is completed.

3 Experimental Study

3.1 Experimental Preparation

In order to verify the stability of the civil aircraft radar signal variable bandwidth receiving method based on FPGA technology, the experimental comparison is carried out, and the experimental environment is set up as shown in Table 1.

Table 1. Experimental environment

Experimental environment	Application server	Database server	Client
Hardware parameters	Windows Server 8 × 2core 2.1 GHz Proc CPU 16G	IBM eServer P570 16× 2.1 GHz Proc CPU 48G	CPU: P41G Memory:2G
Software parameters	Apache-Tomcat-6.0 JDK 1.7.0 PostgreSQL9.0	WebSphere OS:AIX5.3	Windows 2007 IE7.0
Network environment	VPN		

Using the above experimental configuration, the radar signal noise jamming type index is obtained, and the expression formula is as follows:

$$Z = \frac{2R \times V}{R + V} \tag{5}$$

Where Z is the reception rate of the interference profile, V is the total number of interference profiles, and P is the number of real interference profiles.

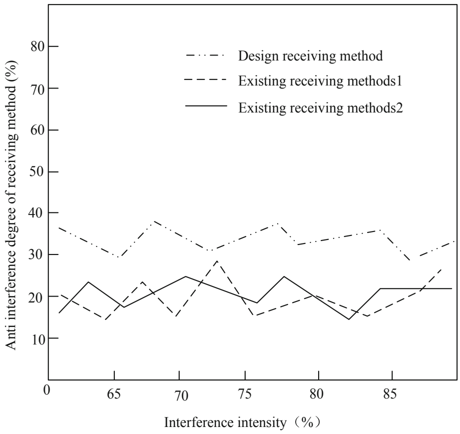
In order to enhance the contrast between the experimental results, the traditional deep learning-based radar signal receiving method for civil aircraft and the narrow-band IoT based radar signal receiving method for civil aircraft were compared, and the performance verification was completed together with the proposed method.

3.2 Experimental Result

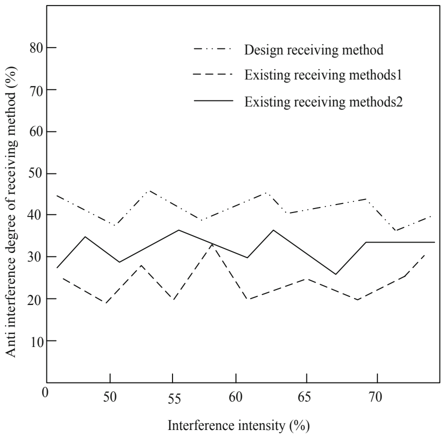
Based on the above attack type index, two existing receiving methods are selected to test the anti-interference performance with the designed receiving method. According to the same experimental parameters and under different interference intensity conditions, the experimental results are shown in Fig. 4.

As can be seen from Fig. 4, although the degree of interference is constantly changing, the anti-interference degree of the proposed method is higher than that of the traditional method, which proves that the proposed method has higher stability and is more suitable for application in the field of civil aircraft radar signal reception.

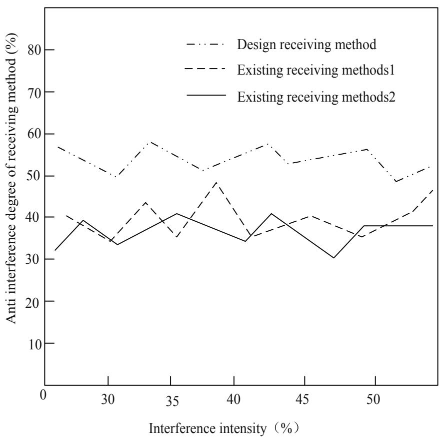
To sum up, the variable bandwidth receiving method of civil aircraft radar signal designed in this paper based on FPGA technology has a higher degree of anti-jamming, and can efficiently accept civil aircraft radar signal under different jamming intensity.



(a) Interference intensity 85%

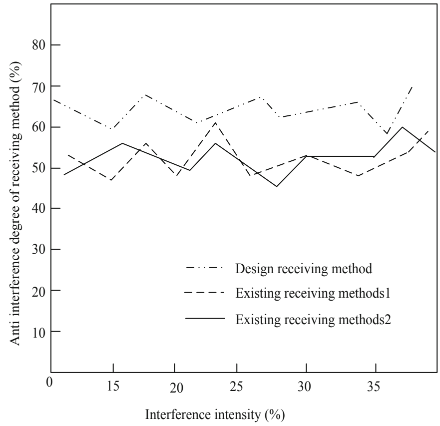


(b) Interference intensity 70%

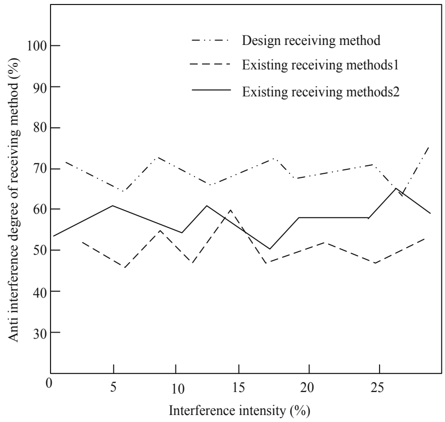


(c) Interference intensity 50%

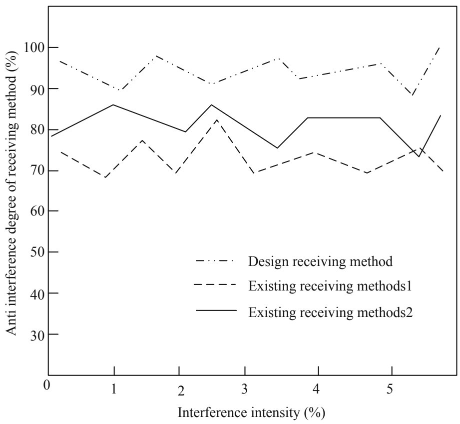
Fig. 4. Test results of anti-interference degree



(d) Interference intensity 35%



(e) Interference intensity 25%



(f) Interference intensity 5%

Fig. 4. continued

4 Conclusion

This paper designs a variable bandwidth receiving method of civil aircraft radar signal based on FPGA technology. The experimental results show that it has better anti-jamming performance and can receive radar signal more accurately in the process of aircraft navigation. At the same time, it enriches the research content in the field of civil aircraft radar signal reception.

Fund Projects. Key topics of Beijing Polytechnic

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