Survey of Radar Anti-jamming Technology and Its Research Status

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Abstract: Based on the current increasingly complex radar confrontation battlefield environment and radar countermeasure strategy, the basic principles and research status of various radar anti-interference technologies, as well as the basic problems, advantages and disadvantages that can be solved, are provided in detail. Reference.

1. Introduction

As one of the basic forms of modern warfare, the role of radar confrontation is to weaken or destroy the enemy's radar against combat units and their operational effectiveness, and strive to protect our combat units from damage. However, the form of war is increasingly complex and simple. The countermeasures adopted by the party interference strategy can no longer meet the needs of modern warfare. In the complex electromagnetic environment and external environment of modern warfare, to maximize the combat capability of our radar countermeasure units, we require our commanders to make accurate information on the information of our combat units and some local units. Evaluate and make the right decisions, and consider the enemy's behavioral strategy model from a global perspective. These backgrounds require decision makers to have a thorough understanding of radar countermeasures and opposition strategies. On this basis, this paper describes the common radar anti-anti-strategy and has important significance for the research of radar countermeasure strategy.

Usually, radar anti-jamming technology can be distinguished from two categories: technical and tactical, and technical anti-jamming measures can be divided into two categories: (1) intercepting the jamming signal outside the receiver, that is to say, making the jamming signal unable to enter the receiver. (2) If the jamming signal finally enters the receiver, it is necessary to make use of the various characteristics of the jamming signal and the target signal from the jamming signal. The desired target signal information is extracted from the signal. The carriers of the above anti-jamming measures are the main systems of radar, such as radar antenna, radar signal processing system, radar transmitter and receiver system, etc. The traditional radar anti-jamming technology will be divided into four categories.

2. Radar Anti-jamming Technology Based on Antenna

There are many kinds of anti-jamming technologies based on radar antenna, including low sidelobe antenna, narrow-beam high gain antenna, sidelobe blanking, sidelobe cancellation and monopulse angle measurement. Next, we will introduce them one by one [1].

2.1 Low sidelobe antenna

Low sidelobe antenna is mainly aimed at sidelobe interference. Sidelobe jamming mainly aims at the side lobe of radar transmitting signal, so that jamming can enter from the side lobe to achieve the purpose of jamming. Low sidelobe antenna has two kinds of antennas: low sidelobe transmitting antenna and receiving antenna. Low sidelobe transmitting antenna is mainly used to reduce the probability of the enemy intercepting our signals when transmitting signals. Long-range support jamming and follow-up jamming are the main ways to enter radar receiver through side lobe, so they are usually used when the enemy carries out side lobe jamming such as anti-long-range support jamming and follow-up jamming. Low sidelobe antenna weakens the chances of interference signal entering from sidelobe. Jiang Yi, a scholar of Harbin Engineering University, has put forward optimization measures for low sidelobe antenna arrays, including optimization of element position, simplification of element search algorithm and hybrid optimization of large-scale sparse array. However, the research on sparse array is not mature at present, so it is not sure whether the optimized result is the optimal result [2]. A large planar array antenna for fast moving is developed in document [3]. However, because of its simplicity, the requirement for ultra-low sidelobe of the antenna is not well met. Document [4] adopts narrow-sided waveguide slot array antenna, and a 5-element small array model is established through a series of simulations to shorten the development cycle of low sidelobe antenna.

2.2 Narrow beam, high gain antenna

Narrow beam antenna and high directional gain antenna have the characteristics of narrow beam antenna and high gain antenna, which can effectively control the interference radiation area and the interference ratio. Therefore, the energy density of narrow-beam antenna is higher and more concentrated in a specific direction. These characteristics can not only increase the radar's countermeasure distance and reduce the ground reflection to reduce the multipath effect, but also control and improve the signal-to-interference ratio of the radar's received signal and reduce the illumination volume of the jammer's jamming beam to the radar's received signal beam, so as to achieve the effect of anti-jamming. Based on UWB technology and Vivaldi antenna, Du Lixia, a scholar from East China Jiaotong University, proposed an optimization method for slotting T-grooves on both sides of the antenna and cutting the dielectric substrate to achieve miniaturization and high gain. However, this antenna only stays in the simulation stage and has not been tested [5].In reference [6], a broadband high gain millimeter wave antenna array is designed and implemented to optimize the narrow beam high gain antenna. Shi Lingling, from Nanjing University of Posts and Telecommunications, proposes a double-layer forward-fed parabolic reflector antenna, which not only retains the advantages of symmetrical pattern and structure of the forward-fed antenna, but also solves the occlusion effect. The disadvantage of this antenna is that only H-plane fan is selected for the antenna structure the shape horn antenna, double-layer forward-fed paraboloid and so on have not been further optimized [7]. Document [8] presents a W-band one-dimensional waveguide scanning slotted antenna with narrow beam and low side lobe, which is suitable for high resolution imaging detection system based on W-band FMCW radar with narrow beam, low side lobe and beam scanning antenna. Based on the analysis of Yagi antenna in document [9], a novel narrow-beam high gain antenna is proposed, and the beam of this antenna is effectively limited to 65 degrees. Within this range, a better gain is obtained. However, over-emphasis on gain optimization leads to the reduction of bandwidth, which affects the detection of some small and weak targets.

2.3 Sidelobe cancellation

In the design of low sidelobe antenna, the level will have a great impact on the design of the antenna. In order to obtain an ideal low sidelobe antenna, sidelobe cancellation technology is often used. The sidelobe cancellation technology can not only eliminate the interference from the sidelobe, but also not affect the performance of the antenna main lobe. The block diagram of the sidelobe cancellation system is shown in Fig. 1.It has two receiving channels of radar pulse echo, one is the main receiving channel and the other is the auxiliary receiving channel. In the system, the main antenna and the auxiliary antenna of the radar are connected respectively. Ideally, the transmission gains of the main receiving channel and the auxiliary receiving channel are balanced. The interference signals coming from the side lobe of the radar antenna and the interference signals coming from the auxiliary antenna can be cancelled by a subtractor, so that the interference received by the side lobe of the antenna can be suppressed, and the performance of the main lobe of the radar antenna will not be greatly affected. However, for small and weak targets, when the target pulse signal received by the main antenna of the radar is too small to be smaller than the interference signal received by the auxiliary antenna, the echo signal will be cancelled, which is the defect of sidelobe cancellation technology. Xie Binbin, a scholar from Xi'an Institute of Navigation Technology, proposed a generalized sidelobe cancellation algorithm based on orthogonal basis transformation to solve the difficulty of constructing blocking matrix in general sidelobe cancellation algorithms. This algorithm can greatly improve the adaptability of the algorithm [11].The structure of generalized sidelobe canceller (GSC) is analyzed in reference [12]. Based on this structure, a STAP algorithm using prior knowledge is proposed to solve the problem of weak and small target signal cancellation. The characteristic of this algorithm is that it does not need the inverse of covariance matrix, so the processing speed is optimized. However, the algorithm must be based on sufficient prior knowledge, and whether it can achieve the desired effect in practice has not been verified.

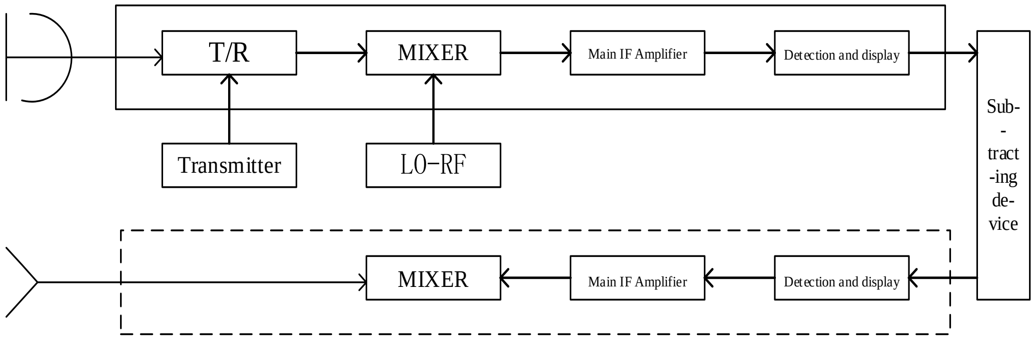

Figure 1. Sidelobe cancellation technique schematic diagram

2.4 Sidelobe blanking

Side-lobe blanking is a very similar method to side-lobe cancellation, which mainly aims at the pulse interference with low working ratio. The advantages of sidelobe blanking technology are simple and easy to implement. The system and sidelobe cancellation technology are also two independent channels. The difference is that they are different from sidelobe cancellation technology in the way of signal processing. The principle of sidelobe blanking technology is to compare the amplitude of the echo signal received by the main channel with that received by the auxiliary channel, and then use the principle of selection to eliminate interference. In the case of clutter interference and high work ratio interference, the main lobe is closed most of the time, so the sidelobe blanking technology is only effective for pulse interference with low work ratio. The schematic diagram is shown in Fig. 2.

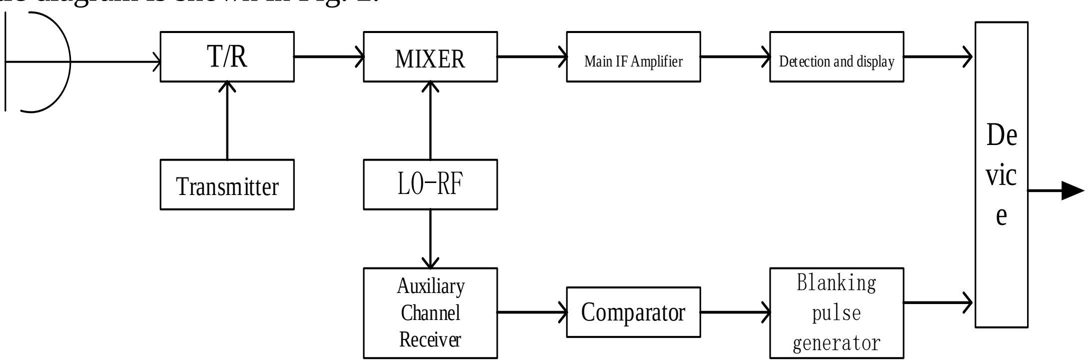

Figure 2. Principle diagram of sidelobe blanking technology

2.5 Monopulse Angle Measurement Technology

The principle of monopulse angle measurement technology is that the radar echo signal is received by multiple antennas at the same time. By comparing the amplitude and phase of the received signal of each antenna, the angle and azimuth information of the target is finally calculated. Monopulse angle measurement is a common method of azimuth measurement in radar signal processing, and it has good effect on angle jamming. Compared with other technologies, monopulse angle measurement technology is more complex in structure and implementation technology [13].

3. Anti-jamming Technology Based on Radar Transmitter

The anti-jamming technology used in radar transmitter is mainly aimed at active anti-jamming, especially for the main lobe. Typical anti-active jamming technologies are as follows:

3.1 Frequency agility Technology

Frequency agile radar is a very popular radar, which mainly aims at narrowband aiming jamming. The carrier frequency of each transmitted pulse of frequency agile radar can be changed randomly or in a limited frequency band according to a predetermined rule. Therefore, when jammed, the frequency agile radar can quickly adjust the working frequency of the radar to counter radar jamming. Frequency agile radar has the best effect on narrowband aiming jamming, but the effect on broadband blocking jamming is poor. In reference [14], a correction method based on minimum entropy is proposed. Doppler spectral entropy is introduced as an index to measure the phase mismatch of the echo of frequency agile signal. This method aims to solve the problem that the incoherent signal of radar is treated as a destroyed coherent echo signal in the P2P random frequency agile mode. The disadvantage of this method is that only Costas sequence is used to generate random samples in the experiment. Consideration of the actual situation needs to be further strengthened. Based on the existing frequency agility and RCS amplitude weighted method to suppress angular scintillation, Lucheng, a scholar of Naval Aviation Engineering College, proposed a rank detector pretreatment method, which achieved good results under the condition of uniform distribution of scattering points. However, the actual scattering point model is more complex and needs further study. In [15]. Literature [16], firstly, the characteristics of inter-pulse agile frequency signal are analyzed, then the velocity of target is compensated and further coherent processing is carried out to make inter-pulse agile frequency signal coherent. Finally, coherent accumulation is used to improve the signal-to-noise ratio of signal. This method has better effect when the number of pulses is small, but the effect is unsatisfactory when the number of pulses increases. Zhou Zhi, a scholar of the Electronic Equipment Test Center, has obtained the agile bandwidth needed to de-correlate different multi-path path differences by analyzing the decorrelation characteristics of frequency agility in 2017, and has been simulated and verified. The shortcoming is that the external electromagnetic environment factors are not taken into account in the simulation [17].

3.2 Frequency diversity

The principle of frequency diversity technology is to divide the radar working frequency into several frequency bands with large difference and work together in the same time period. After increasing the bandwidth of frequency diversity, the bandwidth of aiming jamming is less than that of diversity, so the other channels of diversity can continue to work. At the same time, widening the bandwidth of diversity will force jammers to widen the bandwidth of jamming, and the power spectral density of jamming will decrease, so as to increase the anti-jamming performance of radar. Finally, the frequency diversity radar signal and single-frequency radar signal will increase the anti-jamming performance of radar. It's more complicated than that. This can effectively reduce the probability of radar signal being detected by the enemy, and increase the anti-jamming performance of the radar. Fig. 3 is a schematic diagram of a frequency diversity radar system.

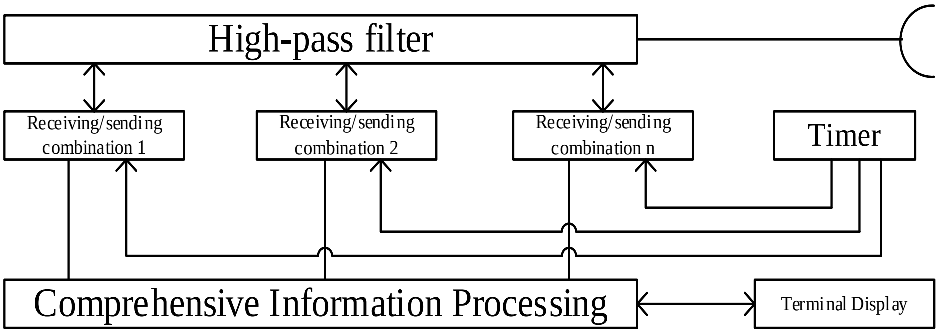

Figure 3. Block diagram of frequency diversity radar system

Document [18] proposes a ship target tracking method based on frequency diversity to solve the influence of first-order sea clutter on ship target detection with a certain radial velocity. Although this method can reduce the detection error, the tracking initial position error is larger than that of the traditional method, so the average error has not been greatly reduced. In 2016, Wu Xuzi of Xi'an University of Electronic Science and Technology (Xi'an University of Electronic Science and Technology) Aiming at the problem of introducing linear frequency deviation between horizontal array elements in traditional frequency diversity array radar, a beamforming method based on pitch frequency diversity technology is proposed and verified by simulation. The result is narrower than that of traditional MIMO radar [19].

3.3 Pulse Compression Technology

Pulse compression technology is one of the key technologies of radar signal processing, which can effectively solve the contradiction between radar range and range resolution. The principle of this method is to transmit a pulse with a larger pulse width when transmitting radar signal, so as to achieve an ideal range. When receiving the echo signal, the echo signal is compressed to make the original wide pulse signal into a narrow pulse signal, so as to achieve an ideal range resolution. Pulse compression technology plays an important role in radar anti-jamming strategy, which is mainly aimed at suppressive jamming. Pulse compression also has a certain anti-deception ability. Pulse compression technology is widely used in radar signal processing at present. Figure 4 shows the system block diagram of pulse compression. Literature [20] proposes a piecewise pulse compression method, which is suitable for radar tracking mode, estimates the computational requirement of the improved algorithm and compares it with the computational requirement of non-piecewise pulse compression, but only compares it with computational resources and proves the superiority of piecewise pulse compression, while the anti-jamming performance is not further elaborated; Literature [21] uses the iterative least squares method to calculate the pulse compression. The output is optimized to obtain better ratio of main lobe to side lobe and narrower width of main lobe. The bi-directional weighted ultra-low side lobe pulse compression algorithm is discussed in reference [22]. In view of its shortcomings, the algorithm is improved on the basis of spectral correction technology, and the performance in more complex environment needs further research.

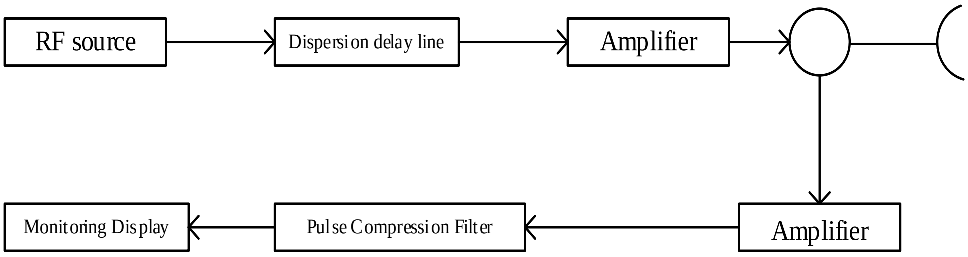

Figure 4. Block diagram of pulse compression system

3.4 Frequency Hopping Communication Technology

Frequency hopping communication technology is one of the spread spectrum communication technologies. Its principle is to use a series of pseudo-random sequences to regulate the carrier center frequency for signal modulation. These pseudo-random sequences have nothing to do with the signal. Through this method, the carrier frequency can jump regularly or irregularly in a set of frequencies.

Frequency hopping technology makes radar have strong anti-detection ability and anti-jamming ability. Radar using frequency hopping technology can communicate under high-speed, continuous and irregular hopping carrier, which makes it difficult for the enemy to detect and jam. Frequency hopping communication technology evades the influence of jamming signal on radar by constantly changing the frequency of radar carrier. If jamming occurs to frequency hopping system, the effect can be achieved only when the frequency of jamming signal is exactly the same as that of radar carrier signal at a certain time. At present, almost all radar can carry out frequency hopping communication. The principle block diagram of frequency hopping communication technology is shown in Fig. 5. Document [23] uses the theory of identification ability to study a set of uniformly distributed design criteria of available frequency hopping, including the design of optimal frequency and frequency range, in order to improve the low recognition rate of airborne radar.

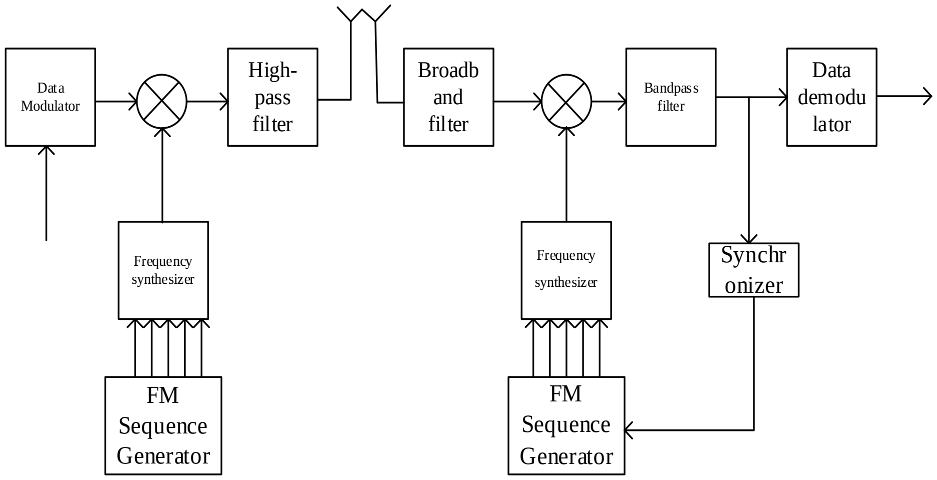

Figure 5. Principle of Frequency Hopping Communication Technology

4. Anti-jamming Technology Based on Radar Receiver

Compared with the first two kinds of anti-jamming technology, the anti-jamming technology based on radar receiver is simpler, more economical and more reasonable. The anti-jamming measures based on radar receiver are passive, so it is more difficult to be detected by enemy jammers. The anti-jamming technology based on radar receiver includes wide dynamic range receiver, instantaneous automatic gain control circuit, and wide-limited-narrow circuit and so on. Several main technologies and their research trends will be introduced below.

4.1 Width-Limit-Narrow Circuit

The "wide-limited-narrow" circuit is mainly used to combat wideband noise FM interference. The principle of the circuit is that the signal passes through the broadband intermediate amplifier and then cascades with the broadband limiter and the narrowband intermediate amplifier matching the pulse width of the signal. The schematic diagram is shown in Fig. 6.

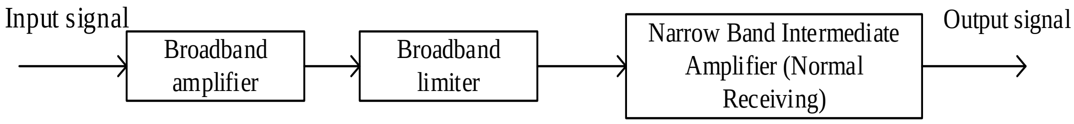

Figure 6. Composition block diagram of "wide-limited-narrow" circuit system

4.2 Instantaneous Automatic Gain Control Circuit System

Instantaneous Automatic Gain Control (IAGC) circuit is an anti-overload circuit. It is mainly used in the IF part of radar receiver. Its aim is to prevent the IF amplifier overload of radar receiver from strong interference signals such as equal amplitude interference, wide pulse interference and low frequency amplitude modulation interference. Its working principle is similar to that of the conventional automatic gain control circuit. Negative feedback principle is used to adjust the transmission gain of IF amplifier based on the change of receiving interference signal level. The difference between IAGC and AGC is that the response of IAGC is faster. Its schematic diagram is shown in Figure 7.

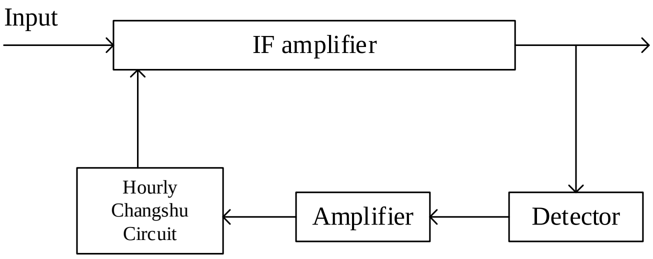

Figure 7. Principle block diagram of instantaneous automatic gain control circuit

5. Anti-jamming Technology Based on Signal Processing

Signal processing technology is a technology that uses the knowledge of modern signal processing to process the signals received by radar receivers, and also applies to radar receivers. Signal processing technology can greatly improve the anti-jamming ability of radar receiver. Common signal processing anti-jamming techniques are as follows:

5.1 Accumulation Technology

The principle of anti-noise jamming of accumulative accumulation technology is that the signal received by radar receiver is sampled many times and superimposed. Because the sampled noise is independent and irrelevant, the power of the superimposed signal will exceed the power of the noise. Accumulation technology can be divided into coherent accumulation and non-coherent accumulation. The former takes the amplitude and phase information of signals into account and superimposes them, which makes the signal-to-noise ratio increase more.Literature [24] proposes a motion compensation method for accumulating and utilizing Missile Inertia information in a short time to solve the influence of range walk and Doppler expansion on the coherent accumulation performance of targets caused by high-speed missile movement. This method has certain guiding significance, but does not consider the influence of interference. Qian Lichang, a scholar of Beijing University of Technology, proposes two methods to improve the coherent accumulation. One is time and phase synchronization method based on direct wave parameter estimation, the other is weak target detection method based on long-time coherent accumulation of agile waveform, which makes coherent accumulation more convenient in technical implementation. The disadvantage of this method is that the errors in target parameter measurement and coherent accumulation are not estimated and studied [25].

5.2 Related technology

When the signal processing system is in a harsh environment, the related technology is generally used. The principle is to calculate the autocorrelation coefficient of the received signal, that is, to calculate the correlation between the received signal and the same signal after a period of time; or to calculate the correlation coefficient between the received signal and the reference signal of the receiver, that is to say, to calculate the correlation between the received signal and the local reference signal after a period of time. Relevant technologies can not only improve the anti-jamming ability of the radar system in harsh environment, but also make use of natural jamming and signals transmitted by the enemy.

5.3 Constant False Alarm Processing (CFAR)

Constant false alarm (CFAR) processing technology is widely used in modern radar. Its main function is to improve the radar's ability to work under various jamming conditions, such as cloud and rain clutter, meteorological clutter, ground (sea) clutter and so on. The radar adopts constant false alarm processing, especially two threshold processing schemes in constant false alarm technology, which can make the radar have the ability of resisting strong noise interference and improving background display. Literature [26] presents a two-dimensional CFAR detection algorithm based on clutter background segmentation module, detector selection module and two-dimensional CFAR detection module, and verifies the effectiveness and practicability of this algorithm. The disadvantage of this algorithm is that it does not consider the more complex practical situation further. Literature [27] deals with CFAR based on unit average selection. An improved CFAR target detection algorithm based on SOCA-CFAR is proposed to solve the occlusion effect when large targets occupy multiple spectrum units.

5.4 Moving Target Display (MTI) and Moving Target Detection (MTD)

In short, the technology of moving target display is to cancel the two echo signals of adjacent period by using the difference of radar echo between moving target and stationary target. Because the pulse amplitude and phase of adjacent period of moving target are usually different, the echo signal of stationary target will be cancelled and the moving target signal will be retained; and moving target detection is the technology of moving target display. Upgraded, it is usually cascaded by MTI filter banks based on FFT to improve the clutter suppression ability of MTI technology. MTI technology and MTD technology have good effect on passive jamming. Moody target detection and tracking system based on bistatic radar is designed and implemented by Chinese Academy of Sciences scholar Murdi et al. In order to improve the performance of airborne radar moving target detection, an airborne radar moving target detection algorithm based on sparse sample selection is proposed. Its disadvantage is that the testing system is stationary and can be improved. One-step dynamic improvement to meet future needs [28].Yu Xiaohan, a scholar of Naval Aviation University, first analyzed the Sparse Fourier Transform (SFT), and then further systematically analyzed the implementation method of Sparse Fractional Fourier Transform (SFRFT). Finally, a radar maneuvering target detection algorithm based on fast and high resolution sparse SFRFT is proposed in radar signal processing. However, this algorithm has not been combined with the actual radar system, so it needs further study [30]. Scholars Tohidi and others, aiming at the problems of inadequate Doppler estimation accuracy and low recognition resolution in traditional MTI technology, are running in radar system. Compressed sensing technology is used to process echoes, and the effectiveness of this method is verified by simulation. The disadvantage of this method is that there are still great challenges and breakthroughs in target tracking, data fusion and array radar application [31].

5.5 Interference Source Homing (HOJ)

The technology of jamming source seeking is one of the most active anti-jamming methods. Its basic principle is to track and destroy the jamming signal from jammer by missile. The jamming source seeking is also called passive tracking jamming source. The use of jamming source-seeking technology can make the enemy not dare to jam our radar easily.

6. summary

With the development of science and technology, radar countermeasures are faced with more and more complex electromagnetic spectrum, more and more complex battlefield environment factors and more complex countermeasures strategies. The Strategy Research of radar countermeasure must not stay in the past. Facing the future requirements of electronic countermeasures, this paper gives a detailed introduction to all the commonly used strategies of electronic countermeasures. It can be seen that radar jamming and anti-jamming systems are becoming more and more diverse, and the factors that need to be considered in radar countermeasure operations are becoming more and more complex. Therefore, it is necessary to have a comprehensive understanding of radar jamming and anti-jamming measures in order to meet the needs of future battlefields.

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