Airborne AESA Radar's ECCM and Self-defense Jamming Analysis

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Abstract

The peculiar character of flexible beam control and advanced waveform design of Active Electronically Steered Array (AESA) system brings powerful ECCM (Electronic Counter-Counter Measures) ability for airborne fire-control radar. This paper introduced all kinds of ECCM of airborne AESA radar first, especially for Low Probability of Intercept (LPI) technique and Space-Time Adaptive Processing (STAP) technique, then, it explored self-defense jamming approaches of combat aircraft in modern aerial warfare.

Keywords: airborne AESA radar; ECCM; LPI; STAP; self-defense jamming

1. Introduction

In the modern warfare of achieving mastery of the sky, in order to destroy enemy's weapon system, and ensure own weapons operate well, combat aircrafts often use multiple ECM, including stand-off supported jamming (SSJ), escort supported jamming (ESJ), self-defense jamming (SDJ) and so on. In the face of electronic reconnaissance in full spatial domain and whole temporal domain and electronic jamming in wide bandwidth with high strength at all time, in order to play a normal role, airborne fire-control radar must have strong and effective anti-jamming measures. The application of AESA system improved airborne fire-control radar's ECCM ability extremely, and the advance of air warfare weapons presumed that finding is equal to destroying. Facing to the new airborne fire-control radar's threat, combat aircraft must find new jamming measures. If ECM equipments outside of aircraft are power multiplier, then self-defense jamming equipment is amulet of battle aircraft. Aiming at the ability and application of airborne fire-control radar in combat, in order to defeat airborne AESA radar in modern aerial warfare, Engineers should analyze anti-jamming measures and find its weakness, then accordingly research new airborne self-defense jamming techniques actively.

2. Airborne AESA radar's ECCM

The research of airborne AESA radar's ECCM focused on spatial domain, time domain, frequency domain, modulation domain, energy domain and joint multiple domains, and ECCM techniques cover with the design of radar system and sub-system (shown in figure 1). ECCM in spatial domain mainly include Ultralow side-lobe antenna, side-lobe cancellation (SLC), side-lobe blanking (SLB), mono-pulse tracking, beam agility and radar netting; ECCM in time domain mainly include range-gated, front edge tracking, PRF jittering; ECCM in frequency domain mainly include frequency changing in wide bandwidth, narrowband filtering (PD, MTD, MTI), spectrum spreading; ECCM in modulation domain mainly include linear frequency modulation (LFM), phase-coded and signal parameters agility; ECCM in energy domain include CFAR, AGC, clipping strong signal, power management, recognition on target's amplitude fluctuation property.

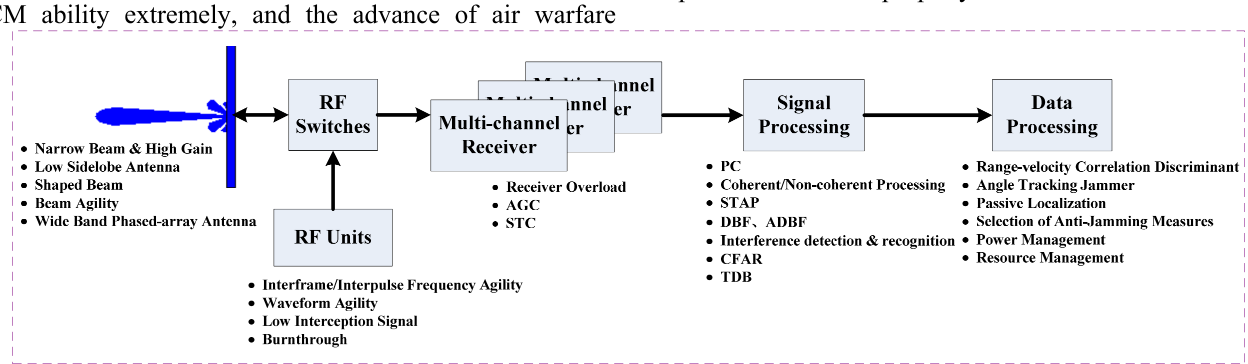

Fig.1. The main anti-jamming measures of airborne AESA radar

The following paper emphatically analyzed ECCM of airborne AESA radar from LPI technique and STAP technique.

2.1. LPI technique

Flexible beam control technique and advanced waveform design technique make airborne AESA fire-control radar have congenital advantage on realizing LPI property. The measures of reducing interception probability mainly include the following two ways.

- radiation control and power management

If radar opens the transmitter, it can be detected by interception receiver. So the mostly effective tactics is non-radiating at all. Actually, if the demand of stealth is more than the demand of searching and detecting target, and if airborne LPI radar can get battlefield situation information from information sources outside or inside of aircraft, the radar is

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always on non-radiating state or works at abruptly radiating state. Power management is the basic technique in all the LPI techniques. The mission of the power management is reducing the peak power to the absolute minimum value on the premise of guaranteeing detecting task along with target closing gradually, power management must reduce peak power accordingly. Airborne LPI radar can be enhanced by trading both long coherent integration time and wide instantaneous bandwidth for reduced peak power (shown in figure 2). High antenna gain, reduced side-lobe levels, high duty factor, and increased receiver sensitivity can likewise be traded for reduced peak power.

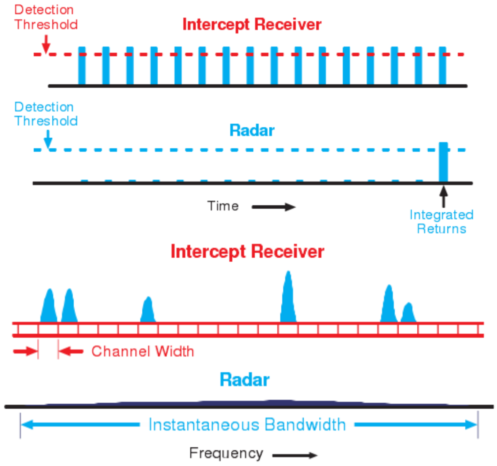

Fig.2. Trading for reduced peak power

- flexible waveform design

The main measure of realizing LPI property on waveform for airborne radar is spectrum spreading technique. For example, radar transmits LFM signal, and compresses the target's echo signal into narrowband signal with high peak power through matching filter at receiver port, then improves SNR at receiver port. Further, except for angle of arrival, all of the parameters can be varied randomly from one coherent integration period to the next without reducing detection sensitivity. Randomizing any of the parameters can confuse the classification process. That is particularly true for those intercept systems which classify signals by comparing their parameters with parameters stored in threat tables.

2.2. STAP technique

Signal processing is the most important part in the field of improving airborne AESA radar's anti-jamming ability, and it's most capable of breaching traditional ECCM technique. STAP is a kind of closed-loop clutter suppression method, it can realize planar filtering in spatial domain and temporal domain, and it's a researching hotspot in modern signal processing field. STAP refers to the extension of adaptive antenna technique to processors that combine the signals simultaneously received on multiple elements of an antenna array and from multiple pulse repetition periods of a coherent processing interval. STAP offers the potential to improve airborne radar performance in several areas. First, it can improve low-velocity target detection through better main-lobe clutter suppression. Second, STAP can permit detection of small targets that might otherwise be obscured by side-lobe clutter. Third, STAP provides detection in combined clutter and jamming environments.

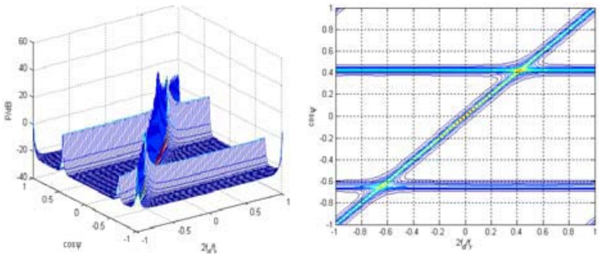

Fig.3. space-time spectrum of clutter and jamming

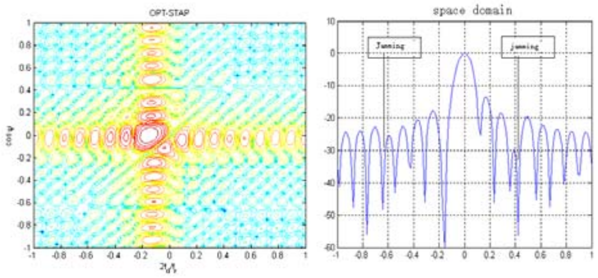

Fig.4. Processing results of STAP

The established model with clutter and jamming are shown in figure 3, and the effect of clutter suppression and jamming counteract by STAP are shown in figure 4. From the simulation results, we can find that STAP have the ability to suppress clutter and jamming at the same time, and can improve detecting ability of airborne radar in clutter and jamming environment.

3. Exploring for airborne self-defense jamming

The airborne AESA radar countermeasure belongs to system of systems (SoS) countermeasure. The countermeasure system should destroy enemy's data link system first, and force its radar to open transmitter, then SoS countermeasure becomes formation countermeasure or single aircraft countermeasure. Aiming at all kinds of anti-jamming measures introduced in above paper, if battle aircraft can get target's working mode and application way well, self-defense jammer can take jamming measures accordingly, namely, taking multiple aircrafts cooperative jamming or jamming outside of the platform (including expandable jamming, towed decoy jamming) in spatial domain; taking transmitted modulating jamming, fast and accurate frequency-spot jamming in wide bandwidth, duplication jamming in frequency and modulation domains; and taking smart noise jamming, synchronous jamming, disordered pulse jamming and so on in time and energy domains. In the course of project designing, the key problems are how to intercept airborne fire-control radar with LPI property, and how to recognize all kinds of air-to-air working modes well and take optimum jamming measures accordingly.

3.1. Reconnaissance to airborne LPI radar

Airborne radar adopted LPI technique brought forward higher demand for interception receiver. Interception receiver must cover with wide airspace and wide frequency domain, and have higher sensibility and ability to detect complex signal and recognize multiple targets in space. Self-defense jammer can combine digital array reconnaissance and channelized detecting techniques to improve system's sensitivity in wide space and wide frequency domains; take digital channelized and IFM techniques to improve detecting ability for spreading pulse signals; and take de-interleaving method based on fuzzy clustering to recognize multiple targets in space.

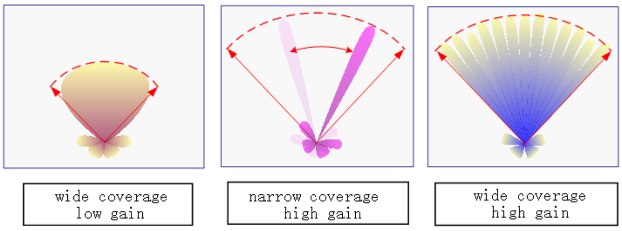

Fig.5. Space coverage and antenna gain

Digital array technique replaces traditional simulative beam-form by digital beam-form at receiving and transmitting mode, and has super flexibility. Digital array technique applied in ESM field solves the conflict between high interception probability and high sensibility preferably, and it can form several beams with high gain, as well as cover wide reconnaissance airspace instantaneously at the same time.

Digital Channelized receiver based on poly-phase filtering technology used multi-rate signal processing structure and multi-channel parallel processing technique. The receiver improved real-time signal processing ability and high probability interception ability in wide band. Instantaneous Frequency Measurement (IFM) receiver has higher frequency resolution, but no multi-signal parallel processing ability just like channelized receiver. One kind of approach combined these two technique's advantages is shown in figure 6, it can resolve the problem of cross channel detection for wide bandwidth signal with high sensitivity.

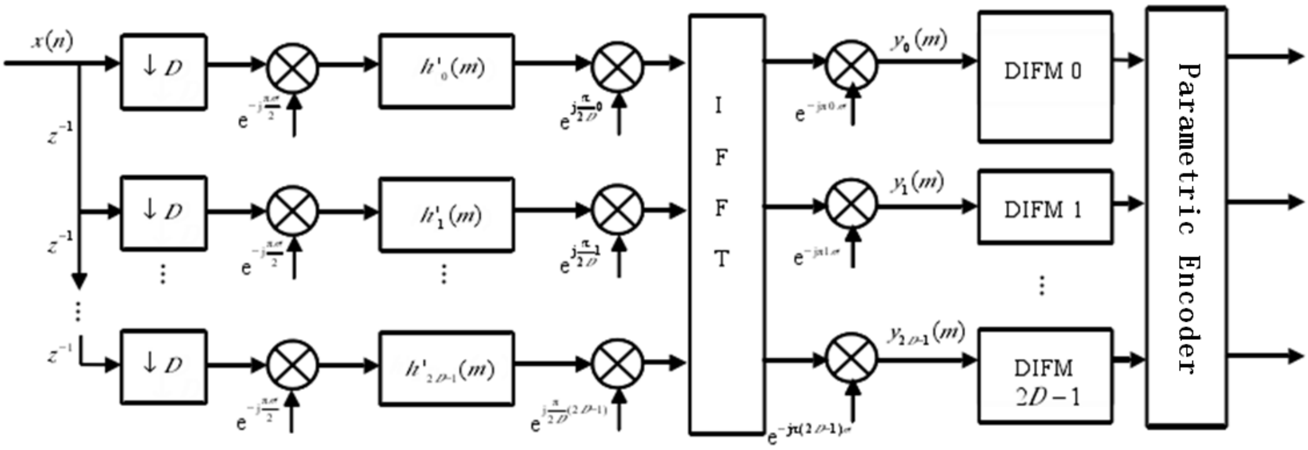

Fig.6. Structure of digital channelized IFM receiver

Whereas parameters of waveform can be randomized, target's position is steady, it can't change suddenly. Besides, at a given work mode, every pulse parameter, such as RF, PW, PRI and intra-pulse property, can vary just in a definite range. For these ideas, we can design a comprehensive de-interleaving method based on fuzzy clustering, and this method can realize effectively recognition for radar with agility property between pulses in complex electromagnetic environment.

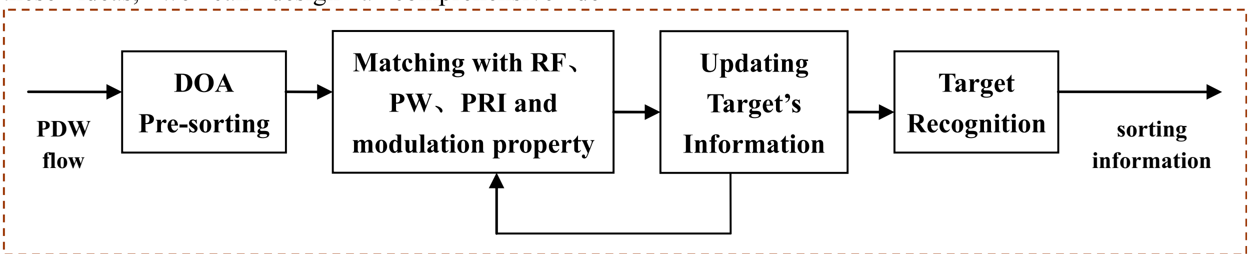

Fig.7. Framework of signal sorting

3.2. Jamming to airborne AESA radar

Self-defense jammer can't know enemy radar's signal and data processing mode, but it can recognize various air-to-air work mode through analyzing the characteristic of radar waveform and the pattern of beam scanning. If beam scanning pattern is regular and waveforms choose high and medium PRF by turns, we can deduce radar operates at VS, VSR, RWS or TWS mode. If beam scanning is irregular and choose high, medium and low PRF by turns, it can be considered as SAM or TAS working mode. If the radar beam points to aircraft self continually and uses MPRF waveform which has determinate emitted bandwidth, it can be considered as STT working mode. Thus, the air-to-air working mode of airborne AESA fire-control radar can be separated into searching and tracking mode for engineers to consider self-defense jamming problems.

- Jamming to searching mode

When airborne fire-control radar operates on searching mode, self-defense jammer can use Doppler noise jamming to suppress its detection range and use multi-false-target jamming to disorder its detection process.

The PD processing of airborne fire-control radar uses coherent pulses signal. If the jammer can modulate every echo pulse’s phase with noise, there’s no relativity between pulses and every spectrum line of echo pulse is broadened. When modulation intensity is strong enough, the spectrum lines can spread to the entire Doppler frequency domain and cover whole Doppler echo pulses. The bandwidth of self-defense noise jamming can be set to be very narrow, so the efficiency of jammer’s power is very high. This noise modulation mode is commonly called Doppler noise jamming. Today, Doppler noise jamming is usually carried out by DRFM technique. The simulation of Doppler noise jamming to APG-77 radar’s HPRF working mode shows that it can suppress radar’s detection range efficiently without very high ERP.

If self-defense jammer generates Multi-False-Targets which enter into radar’s receiver, the radar computer’s computational load will increase whatever method used to resolve range ambiguity. If Multi-False-Targets are more enough, the signal and data processing system of radar will be saturation. On one hand, it increases the difficulty for radar intercepting real targets. On the other hand, it also decreases radar’s interception probability for real targets. False-Targets and radar pulses are in phase can make false pulses to be coherent integrated equally. Multi-False-Target jamming is usually carried out by DRFM technique, too.

- Jamming to tracking mode

The purpose of jamming for tracking mode is to destroy radar’s locking state, and isn’t to cover its location by noise jamming. It usually tends to use deceptive jamming. Airborne AESA fire-control radar is multidimensional tracking system which includes range, velocity and angle tracking. Airborne radar can identify jamming signals by correlating range and velocity information. Airborne self-defense jammer must use range-velocity simultaneous pull-off jamming to destroy the radar’s range and velocity tracking system efficiently. Though radar’s range and velocity information is deceived at the same time, however, it can acquire the precise angle information because the beam points to the target all the same. So, it is necessary to add false angle information in simultaneous pull-off process.

Airborne AESA radar has higher anti-jamming ability for Single-Radiation angle deceptive jamming by using mono-pulse tracking technique. Multi-sources jamming technique is the most basic method for mono-pulse radar countermeasure. Through making waves’ DOA (Direction of Arrival) distort at mono-pulse antenna, the mono-pulse tracker departs angle from real target. This kind of techniques includes blinking jamming, cooperative jamming, cross-eye jamming, terrain-rebounding and so on. Another jamming technique to mono-pulse radar is cross-polarization jamming. It reverses the direction of angle error signal which is given by the tracking filter of mono-pulse radar. Obviously, mono-pulse radar is very hard to be jammed, and the most of the above methods are difficult to be achieved from technique and application. Generally, angle tracking operates after detecting and tracking on range and velocity dimension. If the detecting, tracking, and controlling circuitries of radar are destroyed, the angle tracking effect also becomes bad on a certain extent. So, in order to achieve deceptive jamming for mono-pulse angle tracking radar, airborne self-defense jammer should make great efforts for developing multi-sources jamming technique outside of aircraft firstly. New single-source jamming methods which destroy the angle tracking system through jamming range, velocity and AGC control circuit tracking system whose anti-jamming abilities are weak relatively need to be researched too.

The peculiar working mode such as TAS, MTT of airborne AESA radar are different from STT working mode. They don’t track target continuously but discontinuously track with a way of high data rate revisiting. To destroy this kind of tracking mode, airborne self-defense jammer should design better jamming strategy system and resource management system. The jammer must recognize the same target rapidly and transmit the jamming signals instantly when the radar revisit every time, furthermore, the jamming signals which jammer transmits between two adjacent times must be correlated, then, the jammer can deceive tracking radar continuously.

4. Conclusion

The dispute between ECM and ECCM is a lasting combat. There's no jamming can't be restrained, and no radar can't be jammed. Facing to the threat of airborne AESA fire-control radar, engineers of the new generation airborne self-defense jammer must study rapidly on interception technique for LPI radar and jamming technique for mono-pulse angle tracking radar, especially the discontinuously tracking mode, then our combat aircrafts can gain the initiative in the future aerial warfare.

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