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Introduction

1.1 Development of Modern Radar

With the development of microelectronics, very large scale integrated converters (VLSICs), new materials, and advanced productive technologies, modern radar techniques have progressed dramatically. Major development trends in the modern radar are given as follows:

1. **Digitization**. Digitization of the modern radar is not only represented by significantly improved speed of radar signal processing as a result of the rapidly developed VLSICs but also radio frequency (RF) digitization. Indeed, phase shifters in conventional phased array radars are now gradually being replaced by direct digital synthesizers (DDSs). Due to the rapid development of DDSs, they can directly generate RF excitation signals and send them to the power amplifier in a radar transmitter. That is to say, RF excitation signals in different initial phases directly generated by DDSs in various channels are sent respectively to each transmitter to amplify their power before being sent to each antenna. After being filtered and amplified in digital receivers, RF signals are sampled directly by high-speed analog-to-digital (A/D) converters. The digital receivers can obtain digital baseband signals via digital quadrature conversion without using mixers.
2. **Integration**. To work effectively in modern warfare, various radar techniques and tools, such as pulse compression, adaptive frequency agility, coherent integration, constant false-alarm-rate (CFAR) circuit, low-probability intercept (LPI), polarimetric information processing, spread spectrum, ultra-low sidelobe antenna, multiple transmitting waveform design, digital beamforming (DBF) or adaptive digital beamforming (ADBF), and sidelobe cancellation (SLC), should be integrated in the modern radar system.
3. **Multifunction**. With the rapid improvement of radar techniques, the radar system is required to have good detecting, tracking, and identifying capabilities for

Synthetic Impulse and Aperture Radar (SIAR): A Novel Multi-Frequency MIMO Radar, First Edition.
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various targets. In addition, it should have the capability of guiding and targeting for the weapon system. Furthermore, high survivability should be offered in a complex electromagnetic environment.

With the development of stealth techniques, anti-radiation missiles (ARMs), electronic countermeasures (ECMs), and low-altitude penetration [1–6], new challenges and higher demands are expected. As traditional radars are incapable of dealing with these challenges, new countermeasures must be adopted. In order to deal with these “Four Threats,” modern radar is required to employ a series of advanced techniques, such as pulse compression, SLC, and coherent integration. Since stealth aircraft has been successfully applied in recent local wars, anti-stealth techniques have become a “have-to-solve” issue.

Current stealth technologies are mainly focused on structure stealth design, impedance loading, absorbing material coatings, and absorbing penetrating materials to reduce radar cross-section (RCS). These techniques are widely acknowledged as useful measures for centimeter wave radars. However, it has little impact for electromagnetic waves of longer wavelengths (such as meter waves). Since the RCS of a target is related to the radar wavelength with the form $\mathrm{RCS} = n\lambda$ [7], where n depends on the geometrical shape of the target and has a value between 0 and 2, and λ is the wavelength. At the international conference on radar systems in 1985, Moraitis analyzed the influence of radar frequency on the detection of stealth targets. The results show that the RCS of stealth aircraft is higher at the metric band than at the S-band by 15–30 dB. Meanwhile, the impedance loading cannot be carried out since the metric band is the resonance region of the airframe. Absorbing material coatings are influenced by frequency characteristics. Currently, the effective frequency is between 1 and 20 GHz, with the coating thickness lying between 1/10 and 1/4 wavelength. For the metric wave, it is impossible for the coating thickness to be up to an order of 10 cm. Therefore, the absorbing material coating is not a threat to the metric radar. The absorbing penetrating materials also cannot be applied effectively in the metric wave due to the frequency characteristics of the materials. Thus, the metric wave radar has a good capability in detecting stealth targets.

However, traditional metric radars have difficulties in meeting the requirements of modern warfare due to their wide beams, poor positioning accuracy, and especially their inability to track and guide multiple targets. In recent years, radar researchers are trying to improve the performance of resolution, low-altitude detection, anti-jamming, multiple target detection with the metric radars. However, these efforts are only improvements to the traditional radar system, so it is difficult to meet their desired purposes. Only the Synthetic Impulse and Aperture Radar (SIAR, “RIAS” in French) invented by ONERA in the late 1970s was an entirely new four-dimensional (range, azimuth, velocity, and elevation) multifunction (surveillance and tracking) radar system [8–15] To overcome the inherent weakness of low angular resolution, the large sparse array is employed in this metric wave radar. Due to its new transmitting signal system and advanced signal processing techniques, the isotropic illumination for the whole space can be performed with a large antenna array, which has strong directivity. Aperture synthesis and impulse synthesis for signals with large time widths are performed at the same time, so an LPI can be realized.

1.2 Basic Features of SIAR

The basic concepts of SIAR can be summarized as follows:

1. By encoding the signals of each omnidirectional radiation element, the isotropic radiation of the entire space is ensured with a large antenna array with strong directivity; that is, the beam pattern of the transmit signal is not formed in the spatial domain.
2. Signal components of each transmitting element are separated in the receiving system based on their codes. The time delay is calibrated via the elements in the space, and then the signal components are coherently combined again to generate narrow pulses of target echoes, namely the equivalent transmitting beam patterns.

SIAR uses multiple antennas to transmit orthogonal signals with multicarrier frequencies. These signals have unique characteristics in wavelength selection, antenna types, Doppler processing, and beamforming [16]:

1. **Operating at the meter wave band**. Though the radar with meter wave is suitable for long-range detection, the angular resolution is low and the accuracy of angular measurement is inaccurate due to the limits of the antenna size. Without taking into account the angular resolution, there are many advantages of meter wave radar:
   (a) Appropriate pulse repetition frequency (PRF) is selected to ensure that range ambiguity (hundreds of kilometers) and velocity ambiguity (several Mach numbers) can be avoided. In other words, the Doppler processing can be realized with no range ambiguity.
   (b) It is difficult to significantly reduce the RCS of targets (whether their shape or coating) by using stealth techniques.
   (c) It is easy to make a filter because of the weak ground clutter and narrow frequency spectrum.
   (d) It is able to obtain high output power for transmitters at a low cost.
   (e) It is difficult for enemies to use airborne jammers due to the large antenna aperture at the meter wave band and electromagnetic compatibility.
   (f) It has better countermeasures against ARM.
2. **Using large sparse array antennas**. Low angular resolution is the main obstacle for meter wave radars. An SIAR experimental system employs 25 transmitting array elements and 25 receiving array elements, which are uniformly distributed on two circles with diameters of 90 and 45 m respectively. If the wavelength is 3 m,

the azimuth angular resolution of the array will be about 1.2°, which ensures the desired angular resolution. Meanwhile, taking into consideration the cost and the complexity of implementation, the number of antenna elements should not be too large. Due to the requirement of detecting targets in all directions, SIAR chooses a large sparse circular antenna array with a limited number of elements.

3. **Omnidirectional transmission**. Each transmit antenna emit signals simultaneously at different frequencies to ensure that the radiation energy is uniformly distributed in space and coherent speckles cannot be formed. Comparatively, the conventional phased array radar operates at the same carrier frequency so spatial coherent speckles representing the transmitting pattern are formed.
4. **Doppler processing**. The conventional radar needs to steer the beam. The number of echo pulses at one beam direction is small so only a limited number of pulses can be provided to integrate because of the time constraint. Since SIAR does not adopt physical focusing and beam scanning, and provides a continuous surveillance for the entire airspace, the coherent integration time theoretically is only determined by the system coherent performance and target's velocity. The higher the number of pulses provided for integration, the higher the resolution achieved via Doppler processing. For general surveillance radars, if the antenna rotates at 6 rpm, the data rate is 10 seconds. For SIAR, if the pulse repetition interval is 3 ms and the number of integration pulses is 256, the Doppler resolution is 1.3 Hz and the data rate of each target is 0.768 seconds. It is far above the level of a general surveillance radar.
5. **Transmit beamforming**. Namely, the transmit pattern is generated at the receiving end through impulse synthesis processing, and "impulse compression" is carried out based on the multicarriers.
6. It is able to simultaneously form multiple searching beams covering the whole spatial space and multiple tracking beams to perform the monopulse measurement for each target. SIAR is particularly suitable for detecting and tracking multiple targets since it incorporates surveillance and tracking as a whole.
7. SIAR is a four-dimensional (4D) radar. It can be used to obtain the range, velocity, azimuth, and elevation of targets.

The most significant technical feature of SIAR is that **it can realize nondirectional emission and form multiple "stacked" beams simultaneously**. Therefore, the long-time coherent integration can be achieved simultaneously at all beam directions so as to improve the ability to detect dim targets (especially stealth targets).

1.3 Four Anti Features of SIAR

1.3.1 Anti-stealth of SIAR

Modern radar faces the challenge of targets with very small RCS, such as cruise missiles, stealth targets, and reentry InterContinental ballistic missile (ICBM) warheads.

Improving the radar detection ability has always been a hot topic, and it becomes especially important with the advancement of stealth techniques. To improve detection ability, it is not enough to increase the transmitted power. This new-style radar principle, waveform design, and signal processing are also needed.

The general radar usually uses coherent integration techniques or noncoherent integration techniques to improve detection ability, but the number of pulses available for integration is mainly limited by antenna scanning due to beam scanning. For example, if the radar beamwidth is 2°, the beam scanning speed will be 6 rpm and the radar repetition frequency will be 300 Hz, so the number of integrated pulses is less than 17. For three-dimensional (3D) radars, the number of pulses available for integration is much lower. In order to suppress the clutter, sometimes only part of the pulses can be integrated so the signal-to-noise ratio (SNR) improvement gained through integration is limited.

Since transmit and receive beamformings are realized through signal processing at the receiving end, impulse synthesis in SIAR can keep the beam at certain directions (even one direction). Therefore, multiple beams or stacked beams (including transmitting beams and receiving beams) can be simultaneously achieved at the receiving end. These beams can even cover the entire spatial space without beam scanning and always track targets. This is equivalent to the “burn-through” operational mode in conventional radar, though the conventional radar only operates in one direction in the “burn-through” mode. Since there is no beam scanning in SIAR, the integration time is only determined by the target’s velocity and the radar parameters, independent of the beam scanning time on the target. Therefore, SIAR can obtain a larger number of coherent integration pulses. Furthermore, the signals with a large time-bandwidth can be used in an SIAR system to increase the average power of transmitted signals [16, 17], improving the detection range and resolution capability of the radar.

SIAR has two advantages in anti-stealth as follows:

1. The stealth technique has an insignificant influence in the meter wave band. Moraitis has analyzed the impact of signal frequency on external shape stealth techniques. The results showed that the RCS of stealth targets at the meter wave band is higher than at the S-band by 15–30 dB [5].
2. System sensitivity can be improved via long-time coherent integration; therefore it is beneficial to the detection of dim targets. Its emission energy is dispersed in space and the energy is only 1/Ne (Ne is the number of antenna), as much as the directivity energy of a conventional radar with the same transmitting power. In theory, only Ne pulses are required to compensate for the loss of energy during the omnidirectional transmission, but the number of coherent integration pulses goes up to several hundreds and even several thousands, far more than that of the conventional radar. Therefore, the energy can be accumulated via long-time observation to achieve anti-stealth performance.

1.3.2 Anti-reconnaissance of SIAR

Before implementing synthetic electronic jamming or transmitting ARM to the radar system, it is important to confirm the working state of the radar according to its radiation information to implement effective jamming or attack. In order to avoid jamming and attacking, modern radar must have high anti-reconnaissance performance. In this respect, SIAR is mainly characterized by Chen [16]:

1. Since SIAR adopts omnidirectional radiation, the mainlobe and sidelobes are the same in space. Therefore, reconnaissance aircraft cannot gain any radar information in the way that beam scanning based on the mainlobe in a traditional radar does.
2. SIAR is able to realize long-time coherent integration, and lower transmission power is required for the fixed detection range compared to a conventional radar. If signals with a large time-bandwidth product are employed, SIAR achieves lower average radiating power. Therefore, it has good invisibility and cannot be easily scouted.
3. SIAR is an active array radar. Its frequency codes and phase codes from each transmit element are different, vary at random, and belong to complex waveforms. Thus, even though the signal is captured, it is difficult to obtain detailed parameters of radar waveform. The position of the transmit array element and its operating frequency in particular cannot be obtained, so the reconnaissance receiver is unable to obtain the transmitting pattern.
4. The array elements of SIAR are very simple and distant from each other, so SIAR has a better concealment performance.

In conclusion, SIAR has good anti-reconnaissance performance.

1.3.3 Anti-ARM of SIAR

With the rapid development of ARM, it now has the fatal capability to destroy all high radar-like power radiation sources within 500 MHz to 20 GHz, which becomes a serious threat to the survival of the radar system. Dealing with ARMs is one of the important research topics that modern radars should face.

There are two main approaches anti-ARM [18]: one is the “hard” countermeasure, namely intercepting or destroying adversary ARMs by launching missiles, which requires the radar system to have very high sensibility and instantly find targets like ARMs (especially stealth ARM) with a very small RCS; the other is the “soft” countermeasure, namely taking advantage of active decoys and radar systems to form an active decoying system, and luring the ARMs into a safe impact area to ensure that the radar works as usual. For example, the AN/MPQ-53 phased array radar used in the American Patriot air-defense system employs an active decoy.

To avoid ARM attacks, the main advantages of the SIAR radar system are as follows:

1. SIAR can instantly find the attacking ARM (including the stealth ARM). The ARM has the resonant effect in the meter wave band, which significantly increases its scattering cross-section (RCS). For example, for a missile with several meters, the RCS is about 0 dB m^2 in the very high frequency (VHF) band [19] and less than -10 dB m^2 in 1000 MHz; that is to say, the target's RCS in the VHF band and microwave band differs by 10 dB due to the resonant effect. Figures 1.1 and 1.2 show the results of experimental data processing by the meter wave radar during one ARM outfield test [18], and it becomes obvious that the echoes from a missile and an airplane are commensurable. It shows that the meter wave radars have a great advantage in finding the incoming ARM in a timely manner. SIAR has the

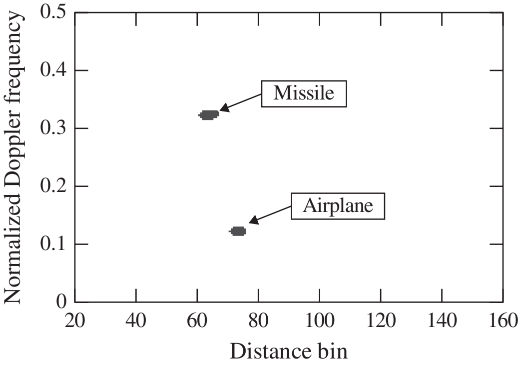

Figure 1.1 Contours of range of Doppler

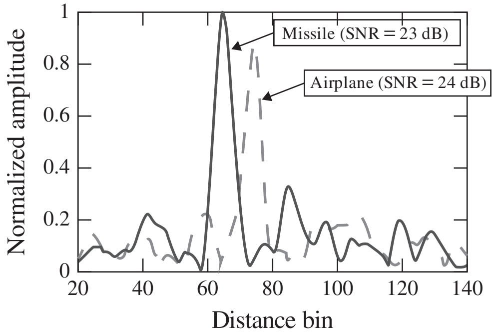

Figure 1.2 Processing results of the Doppler channel of airplane and missile

same advantage in the meter wave band. In addition, since SIAR can implement long-time coherent integration and the number of integration pulses can be up to hundreds, it not only has high sensibility to ARMs but also strong capability in velocity resolution when detecting ARM-like high-speed moving targets, which is beneficial to distinguish, find, and finally intercept or destroy the ARM timely in the spatial pace.

2. The passive seeker of ARM uses monopulse technology to track and destroy radiation sources, making SIAR difficult for it to track. Since SIAR works in the meter wave band and is restricted by the size of the seeker on the antenna aperture, even the most advanced ARM presently has difficulty in dealing with the radar working below 500 MHz (except by carpet bombing).
3. SIAR can apply frequency sparse technology to insert deception signals and use active decoy systems to avoid the ARM's attack.
4. SIAR belongs to large array radars, and its transmitting and receiving units can be detached. Even if a few array elements are damaged, it can work as usual with little impact on its performance. Furthermore, due to its simple structure and completely identical transmitting and receiving array elements, SIAR is very easy to repair.

As discussed above, SIAR possesses a certain warning ability, works in the meter wave band, and has potential advantages in regards to anti-ARM and anti-destruction.

1.3.4 Anti-interference of SIAR

There are many approaches to implement interference with radars, which can be categorized into two main kinds: active interference and passive interference. Improving the resolution and factors against clutters are effective measures to counter passive interference; however, the real threat to radar is active interference. Active interference has many forms, such as spot interference, deceptive interference, and noise barrage interference. Due to the particularity of the form of signals, noise barrage interference is the main issue in SIAR.

There are several advantages for anti-interference in SIAR systems:

1. Long-time coherent integration. Since SIAR adopts omnidirectional radiation, long-time coherent integration can be obtained in all directions. The number of pulses N_i for coherent integration in SIAR is up to the thousands, much more than that of conventional radars. For example, if $N_i = 4096$, the increment of the signal-to-interference plus noise ratio (SINR) after coherent integration is $10\log(N_i) \approx 36\,\text{dB}$.
2. Application of signals with a large time-bandwidth product. SIAR can employ signals with large time-bandwidth product (such as phase coding signal) to improve the signal-to-noise ratio. For example, if the time-width of a transmitting pulse is increased by 10 times, the SINR will be increased by 10 dB.

Therefore, compared to conventional radars, the SINR will be increased by 40 dB when employing the technologies above. As for active noise interference, the SIAR has more advantages over conventional radars, namely a better capability of suppressing interference.

3. Adaptive interference resetting. In theory, all array antennas can incorporate adaptive interference resetting processing, and so does SIAR. The adaptive processing incorporated in the receiving beamforming of SIAR is similar to that in a conventional DBF. The method is appropriate for dealing with multiple strong active interferences; that is to say, the results of adaptive processing will form a "null point" in the direction of interference as long as the receiver is not saturated.
4. Large absolute bandwidth. Since the antenna element required by SIAR is very simple, it is easy to enlarge its bandwidth. SIAR can work in frequency hopping with octaves in different repetition periods. For example, its central working frequency can hop from 100 to 200 MHz. SIAR obtains the absolute bandwidth compared with microwave radars and overcomes the drawback of the narrow absolute bandwidth of meter wave radars.

To sum up, SIAR can take full advantage of methods in time domain, frequency domain, and space domain to cancel out interference. Therefore, compared with conventional radars, it has more methods to anti-interference, namely a stronger anti-interference ability. A more detailed discussion will be given in Chapter 7.

1.4 Main Types of MIMO Radar

The concept of the MIMO (multiple-input multiple-output) radar originates from MIMO communications. The advantages achieved by MIMO communication have led to its application in the field of radar. Actually, RIAS invented by ONERA [3] and the sparse array SIAR developed by Chinese researchers were typical kinds of MIMO radar even before the concept of MIMO radar was put forward (this has been mentioned in references [20] and [21]). MIMO radar is mainly adopted from the idea of SIAR. They both transmit orthogonal signals by using multiple transmit antennas and receive echoes via multiple receive antennas. The transmitting directional pattern can be formed in the receiving end via signal processing. There are similarities and differences between the MIMO radar and the conventional phased array radar.

By using multiple transmit antennas to emit different kinds of signals, MIMO radar can achieve more advantages over conventional phased array radars. For example, after the transmit signals are separated at the receiving end, MIMO radar can synthesize a two-way antenna pattern and form monopulse tracking beams using both the transmitting array aperture and the receiving array aperture. This aspect is similar to SIAR, but the phased array radars cannot do it. The conventional phased array radars can be considered as SIMO (single-input multiple-output) radars, which form a one-way antenna pattern and tracking beam by using only the receiving array aperture, as does also the signal processing, which is for the receiving array only. For now, MIMO radar can be classified in many different ways. According to the distribution of the antennas, MIMO radars can be classified as the centralized MIMO radar and the distributed MIMO radar. Based on the method of coherent signal processing, a MIMO radar can be classified as the coherent MIMO radar and the noncoherent MIMO radar. The centralized MIMO radar usually adopts coherent processing and the distributed MIMO radar utilizes noncoherent processing because its antennas are dispersive in the position and the received signals from each channel are not coherent. According to the waveform of the transmitting signal, a MIMO radar can be classified as the multicarrier orthogonal waveform MIMO radar, the phase coding orthogonal waveform MIMO radar, and the nonorthogonal waveform MIMO radar. Distributed MIMO radars emphasize detection from different azimuths. Large objects such as an aircraft presents a smaller RCS viewed from the front and a larger RCS viewed from the side or back. The RCS of a stealth aircraft viewed from certain directions will be dozens of decibels more than that from the front direction. Figure 1.3 is the frequency-azimuth distribution of RCS measured at HH polarization (horizontal polarization transmitting and horizontal polarizing receiving) on the reduced-scale model of a certain target (B-2). As seen from the figure, the RCS viewed from the front is 10 dB lower than that from the normal direction of the wing. One major advantage of the centralized MIMO radar is that the transmit array aperture can be utilized to improve the degree of freedom and the related performance in received signal processing. If not

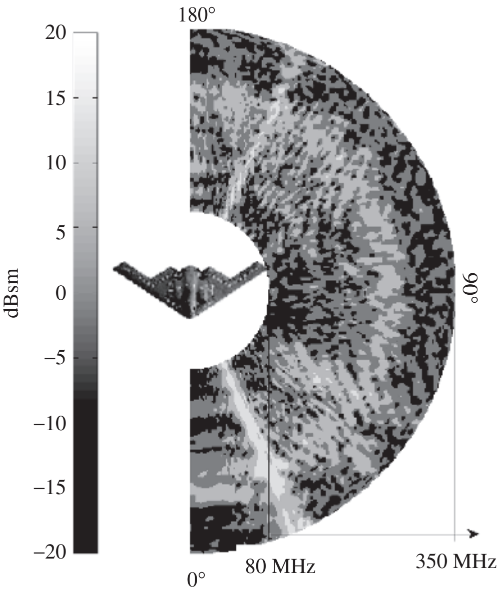

Figure 1.3 Frequency-azimuth distribution of RCS

emphasized already, all MIMO radars mentioned in this book refer to the centralized coherent MIMO radar.

1.5 SIAR and MIMO Radar

General array signal processing, such as direction of arrival (DOA) estimation and super-resolution, only has a one-way reception and the array is only relative to the receive array of the MIMO radar. A coherent MIMO radar uses multiple antennas to transmit signals simultaneously. After the radiation, signal components of the transmitting antenna are separated from each received signal at the receiving end, and the transmitting array aperture and the receiving array aperture are utilized simultaneously while array signal processing is carried out. This kind of two-way array signal processing is quite different from the traditional one-way array signal processing. The preliminary studies of two-way array signal processing are presented in the article.

Multiple transmitting and multiple receiving antennas are used in an MIMO radar so the degree of freedom can be greatly increased [22, 23]. For example, the maximum degree of freedom of a system with M transmitting elements and N receiving elements is $(M \cdot N - 1)$. A centralized MIMO radar with multiple transmitting antennas has a smaller array aperture compared to the netted radar. An MIMO radar puts more emphasis on the coherent processing of the transmitting signal while the netted radar focuses more on the plot fusion and coverage of the space with multiple radars to improve the target detection performance.

An MIMO radar also uses multiple antennas to transmit quadrature signals simultaneously to ensure energy coverage of the entire surveillance space. Therefore, the basic features of the MIMO radar are similar to the SIAR. If the MIMO radar works simultaneously with multicarrier frequencies, then its processing method is also similar to the SIAR. The common features of a coherent MIMO radar and an SIAR are given as follows:

1. Use of multiple transmitting and receiving antennas to transmit and receive different signals simultaneously. Each receiving antenna receives the target echoes of all transmitting signal components.
2. Ability to separate the transmitting signal components of each antenna at the receiver.
3. Ability to perform transmitting beamforming at the receiver by using transmit aperture, namely transmit aperture synthesis.

The major differences between the general MIMO radar and SIAR can be summarized as follows [24]:

1. Multiple transmitting antennas of the MIMO radar do not have to transmit multicarrier signals; they can transmit quadrature phase coding signals as well.

Neither adopting different carrier frequencies nor different codes, the goal is to separate the transmitting signal components in each channel at the reception.

2. For the MIMO radar, which emits the quadrature phase coding signals, each transmitting channel is separated in a way relevant to the code at the receiving end. For the SIAR, the separation is performed in the frequency domain.
3. The experimental SIAR system only has a 90-m aperture, which is a narrowband and fully coherent system. The MIMO radar could have a larger aperture so that it can constitute either the coherent or incoherent radar system.
4. The radiation signals of the MIMO radar from each channel are not always completely orthogonal and may be related to each other. In the experimental meter wave SIAR system, signals from 25 transmitting antennas are completely orthogonal.

Hence, SIAR is a kind of orthogonal waveform MIMO radar with a multicarrier.

1.6 Organization of This Book

It is because SIAR uses multiple antennas to transmit mutually orthogonal signals with multiple carrier frequencies that it is very different from the conventional radar systems in many aspects, such as operating principle, system configuration, signal processing method, and target parameters measure. Therefore, this book gives a systemic introduction of the system principle and techniques of this kind of radar. This book includes 11 chapters. Chapters 1 to 9 address the techniques of impulse and aperture synthesis with the experimental SIAR system in detail. The main content includes:

1. **Introduction to SIAR (Chapter 1)**. Chapter 1 mainly describes the basic features and the advantages of SIAR in “four anti” features and draws a comparison between the SIAR and MIMO radar.
2. **Radar Common Signal Waveform and Pulse Compression (Chapter 2)**. A radar signal’s mathematical form and its classification are first given in this chapter. Then the concept of the ambiguity function and radar resolution theory are introduced, which emphasize the analysis of common radar signal waveforms and their processing methods, such as the FM pulse signal, phase coded signal, stepped-frequency pulse signal, and, finally, orthogonal waveforms are introduced. This chapter is the basis of the SIAR waveform design and signal processing.
3. **System Design of SIAR (Chapter 3)**. Chapter 3 introduces the systemic design of SIAR, including its operating principles, transmitting impulse, and aperture synthesis, 4D ambiguity function, radar equation, experimental system constitution, and amplitude-phase correction. It also gives the trail results.
4. **Waveform and Signal Processing of SIAR (Chapter 4)**. Chapter 4 primarily presents the SIAR’s basic signal waveforms and its problems, and then analyzes the application of signals with large time-bandwidth products (linear FM signal and phase coding signal) in SIAR. This chapter stresses the performance of impulse compression based on phase coding signals. By using signals with a

large time-bandwidth product, SIAR not only improves the compression ratio of pulse but also meets the requirement of isotropic radiation. This chapter also focuses on the signal processing methods of SIAR. Pulse-to-pulse (pulse-group) frequency-code agility techniques are employed to reduce the range sidelobes. The mechanism of and the impact on the clutter suppression are analyzed, and corresponding solutions are proposed in this chapter.

5. **Long-Time Coherent Integration of SIAR (Chapter 5)**. Using the characteristics of SIAR as a basis, Chapter 5 introduces a long-time coherent integration technique based on motion compensation and time-frequency analysis. To improve the range resolution, this chapter also presents the long-time coherent integration method based on the step frequency impulse synthesis and signals with a large time-bandwidth product. A simple and effective pre-compensation technique is proposed to deal with the problem concerning the step frequency being sensitive to velocity. As one of the anti-stealth radars, the SIAR not only makes use of the fact that the stealth technique is not valid in the meter wave band but also employs the long-time coherent integration to improve the sensitivity of the system and the ability to detect dim targets.
6. **Digital Monopulse Tracking Technique of SIAR (Chapter 6)**. Chapter 6 systematically introduces the high-accuracy measurement of 4D parameters and the method of tracking in the SIAR. This chapter first describes the range measuring methods based on positive and negative pulses synthesis and lead-delay pulses synthesis, and suggests that higher measuring accuracy can be achieved without increasing the sampling frequency; it then discusses the angle measuring methods based on a digital monopulse amplitude comparison. In comparison with the conventional tracking radar system, the SIAR uses not only the receiving array aperture but also the transmitting array aperture to form tracking beams.
7. **Coupling and Decoupling between Range and Angle (Chapter 7)**. Chapter 7 first analyzes the coupling effect among range, azimuth, and elevation that occurs when producing the range sum and difference channels and forming the azimuth and elevation tracking beams by means of the time-space 3D matched filtering. Then a rule for transmitting frequency optimization of array elements is studied to overcome the coupling among range, azimuth, and elevation.
8. **Target Detection and Tracking in SIAR under Strong Jamming (Chapter 8)**. Chapter 8 mainly introduces self-adaptive nulling technology applied in the SIAR and studies the 4D track processing method of SIAR in active interference. The effect of the product of aperture and bandwidth (product of array aperture and interference signal, in the case of wideband interference, is actually the product of aperture and receiver bandwidth), the amplitude and phase errors in channels, and the quantization noise of A/D converters on the performance of interference cancellation in large sparse circular arrays are analyzed. Results show that the SIAR can comprehensively employ the anti-interference methods in the time, frequency, and spatial domains. The SIAR has more adequate countermeasures than conventional radars and possesses better anti-interference ability.

Table 1.1 Comparison of three SIAR experimental systems

	Experimental meter-wave SIAR system	Experimental ground-wave SIAR system	Microwave sparse array SIAR
Operating frequency band	VHF	HF	Microwave
Transmit antenna	Circular array, 25 array elements, the pattern of element antenna is omnidirectional	Linear array, 8 array elements, the pattern of element antenna has weak directivity	Sparse surface array, antenna element is subarray and vertically placed
Receive antenna	Circular array, 25 array elements	Single antenna	Single antenna (subarray), sector overlay
Transceiving position	Transceiving in same position, monostatic	Bistatic, receiving on ship	Separated transmitters and receivers
Signal waveform	Multicarrier pulse signal	Multicarrier FM interrupted wave	Multicarrier FM continuous wave
Coverage of radiant energy	Omnidirectional	Sector (azimuth coverage 120°)	Sector (in the same subarray, the subarray may phase scanning)
Range resolution	Medium	Low	High
Main processing mode	Coherent integration, receive DBF, transmitting pulse and aperture synthesis, and so on	Transmitting channel separation, FMICW range compression, transmitting pulse and aperture synthesis, and so on	Transmitting channel separation, pulse compression, transmitting pulse and aperture synthesis, wideband synthesis, and so on

FMICW = frequency modulation interrupted continuous wave.

9. **Effects of Array Error on the Performance of SIAR Tracking Accuracy (Chapter 9)**. Chapter 9 mainly analyzes the effects of three array errors on SIAR tracking accuracy: the errors of amplitude and phase between the transmitting and receiving array elements, the mismatching of the frequency band in receiving channels, and the unbalanced quadrature component in the same receiving channel.
10. **Bistatic Synthetic Impulse and Aperture Ground Wave Radar Experimental System (Chapter 10)**. In Chapter 10, synthetic impulse and aperture technology is extended to the HF band, and bistatic synthetic impulse and aperture ground-wave radar system are also introduced. At first, Chapter 10 focuses on the experimental radar system configuration, the working characteristics, and the design of operation parameters. It gives a general overview of operating principle and then analyzes its basic signal processing, synchronous processing methods, and transmitting synthesis processing. Final results of the radar principle testing are given.
11. **Microwave Sparse Array Synthetic Impulse and Aperture Radar (Chapter 11)**. In Chapter 11, synthetic impulse and aperture technology are extended to the microwave band, and a microwave sparse array SIAR is also introduced. Chapter 11 emphatically introduces the problems of array optimization in the microwave sparse array SIAR and discusses signal pre-processing methods, which are based on digital Dechirp. To achieve high-range resolution, inverse discrete Fourier transform (IDFT) coherent synthesis processing methods and spatial domain synthetic bandwidth methods are studied.

Combined with the functional requirements of radar, Chapters 10 and 11 introduce the popularization and applications of synthetic impulse and aperture technology, which are very different from the SIAR in signal forms and processing methods, thus enriching the connotation of SIAR technology. Table 1.1 compares the operating modes of the experimental system of meter wave SIAR, the experimental system of synthetic impulse and aperture ground wave radar, and the microwave sparse array SIAR.

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