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Introduction

1.1 Overview

Synthetic aperture radar (SAR) is a type of imaging radar that receives wideband echoes at different positions through relative movement between the loading platform and the target. Within a certain accumulating period, SAR obtains a two-dimensional (2D) image of the target after coherently processing the received echoes, which allows high-resolution observation of the real image of the target.

The resolution of the 2D image of the target is normally expressed as range resolution and azimuth resolution. In the range direction, high resolution can be achieved by employing the pulse compression technique in the transmitted linear frequency modulation signal, which has a large time-width and bandwidth product. In other words, similar to conventional radar, SAR improves the range resolution by employing the pulse compression technique on the transmitted and the received linear frequency modulation signal. In the azimuth direction, one radar sensor of uniform motion in a straight line is used to transmit and receive the pulse signal at interval positions with a certain pulse repetition frequency, and then a high azimuth resolution is obtained by a coherent processing of the received echoes. To achieve a high resolution, a synthetic aperture equivalent to an actual huge but unrealizable array aperture is constructed based on the track produced from the relative movement between the target and the radar.

As shown in Figure 1.1, the range resolution of the radar is normally defined as the minimum distance between two points that can be distinguished. If the arrival time of the leading edge of the pulse echo at a distant point is later than the arrival time of the trailing edge of the pulse echo at a near point, then these two points are considered distinguishable. Therefore, the range resolution of two distinguishable points is given by

$$\Delta R_g = \frac{\Delta R_s}{\sin \eta} = \frac{c\tau_p}{2 \sin \eta} \tag{1.1}$$

where τ_p is the signal pulse width, c is the light speed, and η is the incident angle between the antenna and the ground.

It can be seen that the pulse width is required to be very narrow to achieve a high-range resolution. However this will dramatically reduce the average power level of the radar system and will make the signal-to-noise ratio (SNR) of the echo of the observed target too low. A pulse compression technique is commonly employed in SAR to avoid

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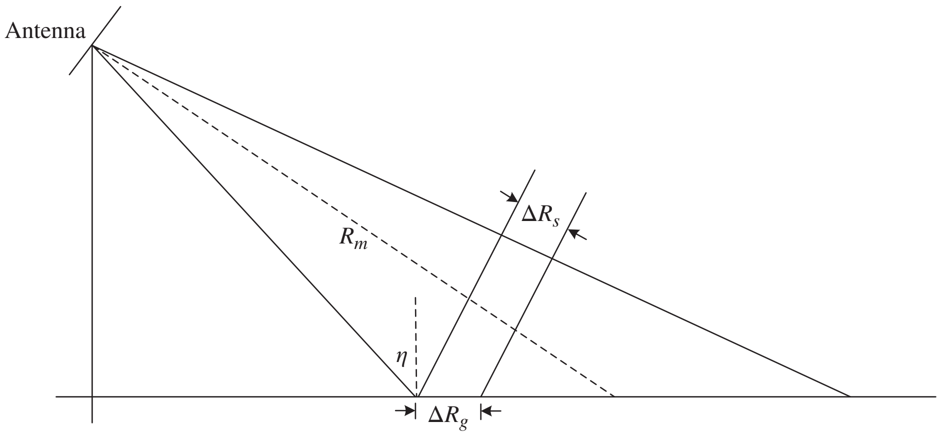

Figure 1.1 Sketch of range resolution.

this problem. Consequently, a relatively wider pulse can be used to realize both high resolution and high SNR.

In SAR, the linear frequency modulated signal transmitted can be expressed as

$$\mu(t) = rect\left(\frac{t}{\tau_p}\right) e^{j2\pi\left(f_c t + \frac{1}{2}kt^2\right)} \tag{1.2}$$

where τ_p is the signal pulse width, f_c is the center frequency of the carrier, and k is the slope of the linear modulated frequency. The bandwidth of the signal is then $B = k\tau_p$. After matched filtering, the pulse width τ_p is compressed into *1/B,* and the resolution is improved to

$$\Delta R_g = \frac{c}{2B\sin\eta} \tag{1.3}$$

For azimuth resolution, the motion of the radar antenna with the platform forms a SAR virtual antenna array, while the physical antenna serves as a unit of the array. During the motion, the echo of the target is sequentially received and recorded, and the phase difference caused by the wave path difference of multiple antenna positions is compensated by signal processing. Therefore, the echoes of the same point target can be stacked in phase, and azimuth compression is performed to realize high azimuth resolution.

As shown in Figure 1.2, suppose the radar moving distance is L_s (the distance of the antenna beam beginning to illuminate the target to leaving the target), and the size of the antenna in the azimuth direction is D. If λ is the wavelength of the radar wave, the maximum length of synthetic aperture is determined by the actual antenna beam width θ_B, the distance of the target R, and the wavelength of the system, as expressed by Eq. (1.4).

$$L_s = \theta_B R = \frac{\lambda R}{D} \tag{1.4}$$

For synthetic aperture, transmission and reception of the radar pulse are considered as two-way propagation. The phase difference between two arbitrary array elements to the target is twice that of the single-way transmission, hence the equivalent bandwidth

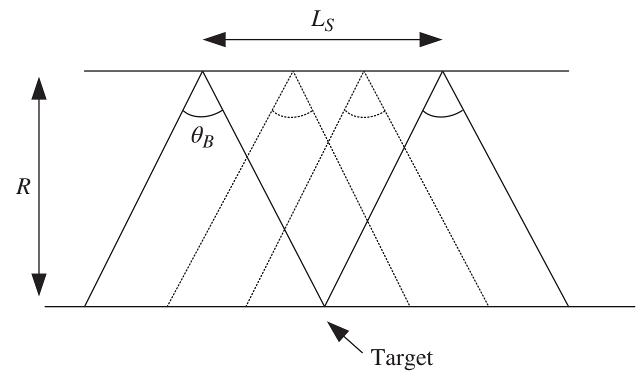

Figure 1.2 Diagram of synthetic aperture.

of synthetic aperture is given by

$$\theta_s = \lambda/2L_s \tag{1.5}$$

After synthetic aperture processing, the azimuth resolution can be improved to

$$\Delta R_{az} = \theta_s R = \frac{\lambda R}{2L_s} = \frac{\lambda R}{2} \cdot \frac{D}{\lambda R} = \frac{D}{2} \tag{1.6}$$

It is evident that the azimuth resolution of the synthetic aperture is irrelevant to the target distance because the further the distance, the longer the effective synthetic aperture and the narrower the formed beam. This is balanced out by the widening of the azimuth resolution unit caused by the increase of the distance, which keeps the size of the azimuth resolution unit unchanged.

From the previous discussion, SAR features a high resolution because the length of the synthetic aperture is equivalent to that of a large antenna aperture. To obtain a high-resolution 2D image, the echoes within the coverage area of the radar beam are collected and coherently processed. Broadly speaking, SAR is also distributed radar that sequentially samples a synthetic aperture to replace the distributed antenna aperture.

1.2 SAR Applications

1.2.1 Military Applications

As SAR system technology moves forward, the resolution increases from tens of meters to meters to submeters; the polarization modes vary from single polarization to multipolarization to full polarization; the radar waveband ranges from meter-wave band to microwave band to millimeter-wave band to submillimeter-wave band. Furthermore, SAR has covered military, civil, and scientific applications, where the platforms include unmanned aerial vehicles (UAVs), helicopters, fixed-wing manned aircraft, satellites, and missiles. To fulfill different requirements, different operation modes are realized by the antenna beam scheduling, for instance, strip-map SAR, spotlight SAR, scan SAR, moving target detection (MTD), inverse SAR (ISAR), and interferometric SAR (INSAR). At different operation modes, useful information is interpreted and extracted from

SAR images, including military intelligence, mapping, marine meteorology, hydrology, geology, forestry, and object deformation. SAR plays an important role in military applications and is an indispensable and irreplaceable sensor for mapping the surface of the earth, due to its availability for high resolution, in all types of weather, and at all times.

1.2.1.1 Military Intelligence

SAR plays a very important role in obtaining military intelligence. SAR mounted on different platforms has different characteristics in military applications.

By providing reliable intelligence gathering and surveillance, spaceborne SAR performs reconnaissance missions, including military maneuvering, military target and enemy troops surveillance, and military assessment. Spaceborne SAR with different wavebands, polarizations, and resolutions has many functions in military applications [1].

Due to high mobility and time continuity of the platforms, manned aircraft and UAV SAR can make up for disadvantages in satellite observation. Airborne SAR therefore has a wide application in intelligence reconnaissance [2]. Furthermore, the features of airborne SAR include a short development cycle, rapid implementation of the most advanced techniques, ultra-high resolution, and large-scale search. All of these features drive the application of airborne SAR for tactical reconnaissance [3].

Missile-borne SAR can obtain real-time images of ground scenery in flight or real-time images of the earth and objects along the track of the missile flying to the target [4, 5]. By comparing with the reference map installed on the missile, the longitudinal or lateral deviation of the missile from the target or the predetermined track can be obtained, which further guides the missile. Missile-borne SAR has become a hot topic because it can effectively improve the terminal guidance precision of medium- and long-range attack weapons, such as camouflaged underground missile launch silos, ground objects in fog-covered areas, etc.

1.2.1.2 Moving Target Detection

Battlefield information includes not only the precise location of the enemy, the facilities, and the deployment of the enemy troops but also the enemy tanks, armored vehicles, mobile artillery, mobile missile launchers, helicopters, cruise missiles, and the activities of mobilization and supply of the enemy troops. SAR can extract the information of moving targets from geographical objects [6]. Different from a static target, a moving target has a certain radial velocity and Doppler frequency. During imaging, it can possibly move out of the image. To retain the moving target in the image, a key mission of MTD is to remove the stationary clutter, or clutter of the geographical object. By combining SAR imaging techniques with features of MTD including airborne moving target detection (AMTD) and ground moving target detection (GMTD), SAR can obtain high-resolution images of the scene and detect the moving target within the scene as well, which is of particular importance for practical applications.

1.2.1.3 Military Topography and Mapping

SAR imaging also offers an accurate and fast means of military mapping. Through processing of SAR images, military mapping can be provided for a variety of purposes (topographic scales 1 : 10,000 and 1 : 50,000), such as quickly drawing and repairing overseas areas, basic mapping of combat command in hot-spot areas and surrounding areas, providing a target location for modern weaponry and precision-guided weapons, and radar image reference mapping for target matching guidance.

1.2.1.4 Detection of Marine Meteorology and Hydrology

A radar image is very sensitive to marine structure. Therefore, qualitative and quantitative analysis of the interaction, the mechanism, the results of the wind field, the marine wave, and the ocean current can be performed to detect marine meteorology and hydrology. Different types of sea have different marine features and coastline. An electromagnetic wave emitted by radar is very sensitive to such parameters as the geometric structures of the marine wave and marine roughness. Based on different backscattered waves, SAR can be applied in medium-scale sea feature detection and large-scale sea feature recognition, such as water mass and peak area. Marine changes caused by moving targets under the water (for instance, a submarine) can also lead to changes in the radar images.

1.2.2 Civil Applications

Incident radar waves of SAR at different wavebands and polarization modes have different effects on detection of the same geometric object. More accurate target features can be detected on the echoes from geometric objects at different wavebands and the copolarization and cross-polarization information in linearly polarized status.

SAR can be widely used in resource exploration and research; environmental monitoring and research; disaster monitoring; agricultural yield estimation; hydrological and geological exploration; engineering surveying; marine monitoring, for example, detecting floods, drought, storm surges, and other major natural disasters; and marine research.

1.2.2.1 Geological Exploration

SAR images provide very fruitful geological and mineral information, such as geological structure; lithology; and the presence of a concealed geological body, which is especially useful in detecting the geological structure of a volcano, a meteorite, or a fault and in detecting metal deposits in the structural belts. With the development of polarization and coherence technology, SAR can be used in measuring and researching crustal deformation, seismic inoculation, plate movement, and ground subsidence.

1.2.2.2 Oceanographic Research

SAR can obtain continuous data and images of the marine and Arctic sea ice during all types of weather and at all times, so marine transportation and worldwide climate change (including the prediction of major climate change) can be surveyed [7]. The intensity of backscattered waves is reduced because of the decrease in marine roughness caused by an oil spill on the surface of a sea. Due to this, SAR is the best effective method to survey oil pollution and natural oil spill film on the water and to detect marine oil and gas.

1.2.2.3 Forestry Research

SAR normally works in the microwave band with different frequencies. Backscattering and penetration of microwave signals differ for different geological surfaces and plants.

SAR can provide abundant vegetation and soil information; it also provides estimations of the vegetation height, forest stock volume, and forest biomass; it can identify forest types, forest disasters, forest density, forest age, and health status as well as monitor logging activities; moreover, it can estimate the biomass of forests in cloudy, rainy, and foggy tropical, subtropical, and high-latitude regions.

Soil moisture is an essential condition for plant growth. Therefore, the estimation of soil moisture is of great concern. SAR can also be used for soil moisture estimation and soil classification. The penetrating characteristics of SAR provide a certain penetration capacity for vegetation and soil, and radar's backscatter coefficient is very sensitive to soil moisture and soil type.

1.2.2.4 Deformation Monitoring

The differential SAR interference for monitoring the deformation has been widely used, for example, for high-rate dynamic monitoring of the stability of manmade buildings like dams, bridges, and tall towers and long-time monitoring and early warning of natural disasters like surface subsidence, landslides, avalanches, glacier displacement, and volcanic activity [8, 9]. Airborne, spaceborne, and ground-based SAR can be used for monitoring and early warning. Spaceborne SAR commonly employs repeat track interferometry to monitor the deformation of the ground surface. However, due to the long retracking time, it is difficult for spaceborne SAR to continuously monitor a fixed point in the deformed area. Double antenna interference in airborne SAR is commonly used for monitoring the deformation of the ground surface; however, the precision is not good enough for deformation. Ground-based SAR is commonly used to monitor the regional and continuous deformation of a fixed point. Ground-based SAR features good flexibility and feasibility, is contact free, and has high resolution and low cost.

1.3 Features of SAR

SAR is similar to other types of radar systems regarding the composition of the radar equipment. However, SAR has unique features in terms of the platform loading mode, radar system, and information processing.

1.3.1 Radar Loading Platforms

Many types of platforms, such as satellites, aircraft, and missiles, are used to load SAR. SAR is usually used to observe the two sides of the platform (except the satellite platform) to remotely map and image the ground (or sea). In working mode, the radar beam with the wave-propagation direction has a substantial component perpendicular to the flight-path direction and points to the sides of the platform.

In some operating modes, such as spotlight and squint modes, the radar beam deviates from the perpendicular direction of the flight path. To meet the requirements of multimodes, small SAR antennas are normally mounted on UAV and missile platforms, less than one square meter in size. Large SAR antennas, which are often mounted under the sides of an aircraft or underneath the belly to minimize the influence of the belly on the antenna radiation performance and to enlarge the ground observation angle, have dimensions of less than tens of square meters in size. Most satellite platforms will prefer large SAR, in which antenna size varies from tens to dozens of square meters. The radar antenna is folded during transmission and is unfolded when operating in orbit.

The basic function of all kinds of platforms is to provide a necessary resource to ensure the normal operation of radar and to transfer the processed results of the radar back to the ground. The five elements of the radar platform commonly referred to are the geometric size, weight, power consumption, motion parameters, and data communication rate.

1.3.2 Radar System

The movement of the SAR platform is used to create a virtually large aperture antenna to obtain a high azimuth resolution, while the azimuth resolution of conventional radar (especially ground-based radar) is the physical aperture. Their mechanism difference is mainly caused by the difference of the radar system. Conventional radar transmits a series of pulses, which then are bounced back by the target, and the target can be detected by signal processing. However, SAR needs to transmit and receive pulses many times until an expected aperture signal is collected to perform the signal processing to obtain a full SAR image. In the meantime, the SAR subsystems have their own characters.

For antennas, the instantaneous bandwidth of conventional radar and SAR are different due to their different range resolutions. Conventional radar normally has to work with a hopping frequency within a broader band range to improve the electronic countermeasure capability; therefore, demands for conventional radar and SAR on the antenna bandwidth are identical. For conventional radar, to reduce the interference power entering into the receiver in the side lobe region, the antenna side lobe is required to be less than −30 dB. For airborne early warning detection radar, to reduce the influence of strong ground clutter on the performance of the detecting target, the antenna side lobe is required to be less than −35 dB. For SAR, though a relatively high antenna side lobe has an effect on the ambiguity of the images and the detection ability on the moving target, the antenna side lobe is normally controlled to be around −20 dB. Generally, it is preferable to further lower the antenna side lobe.

Conventional radar normally works at a narrow instantaneous bandwidth (usually 2.5~10 MHz), whereas SAR normally works at a broad instantaneous bandwidth (normally more than 400 MHz). Due to the signal bandwidth difference of the receiver, the dynamic range of the SAR receiver (the noise level of the receiver is taken as a benchmark) is 20~30 dB lower than that of a conventional radar receiver. However, given the target characteristics and pulse compression features, the transient behavior of the SAR receiver and conventional radar receiver are comparable.

Regarding waveform design, linear frequency modulation, nonlinear frequency modulation, phase encoding, and step frequency are used in signal waveforms of conventional radar. To obtain a high-range resolution, the bandwidth characteristics and the pulse compression effect of the system are specially emphasized in SAR, which normally employs a linear frequency modulated signal, or sometimes the stepped frequency pulse signal. To achieve a higher resolution at the centimeter level, waveform sub-band synthesis is a good choice. It can effectively reduce the difficulty of wideband waveform design.

For a frequency source, to improve the SNR of the radar system, especially the detection of a moving target in strong clutter, coherent processing is normally applied in conventional radars. Similarly, coherent processing is the foundation and prerequisite of SAR. Operation of high azimuth resolution results from coherent accumulation, closely related to the stability of the frequency source and coherent accumulation. In other words, the imaging resolution is closely linked with the stability of the frequency source. The frequency error caused by the random fluctuation has an effect on the phase characteristics of the echoes and thus deteriorates the azimuth resolution of SAR. The frequency error caused by the sine wave results in the appearance of paired echoes after pulse compression and has an impact on the imaging quality. In contrast with conventional radars, a long-time pulse accumulation is required for SAR system. In the meantime, the loading platform of SAR offers strong random characteristics, thus the frequency source of a SAR system focuses on frequency antivibration characteristics and long-time phase stability.

For signal processing, conventional radar and a SAR system both need to perform a range direction pulse compression. They differ greatly in azimuth. Azimuth accumulation of conventional radar is used to distinguish the target and the clutter in the frequency domain and to obtain a certain gain. Coherent accumulation of SAR is used to obtain a high-angle resolution along the range dimension. Furthermore, in a SAR system, different algorithm systems are used at different operation modes, such as SAR, ISAR, INSAR, GMTI, etc. For signal processing of a moving target, conventional radars and SAR are similar in starting pulse compression in the range direction, clutter suppression, and detection and information extraction of the moving target. The difference is that the SAR system usually adopts phase-parallel synthesis to obtain the angle high resolution, and the conventional radar coherent synthesis obtains the frequency resolution. In measuring the azimuth angle of the target, multibaseline interferometry is often used in SAR radar, while a narrow-beam characteristic or sum-difference beam method is used in conventional radar.

1.3.3 Information and Intelligence Processing

The basic operations of conventional radar (except the weather radar and other special radars) are almost similar to SAR. Conventional radar mainly measures the range, altitude, and azimuth information of the target and forms the target track. Stable target tracking is of great importance.

A 2D image is produced from the SAR signal processing. The image processing transforms the complex SAR image into usable intelligence. The targets can be quickly interpreted, detected, and identified from SAR images, with particular interest in the realization of small target detection and extraction in images with strong interference, strong scattering, and high-density electromagnetic signals.

Not only is the fusion of radar images obtained from different platforms included in fusion with other sensors but also the fusion of information obtained from passive detectors and other sensors, such as infrared, optical, and acoustic sensors.

1.4 New Technologies of SAR

More and more, applications show an urgent need for a wide swath, high resolution, high accuracy, real-time acquisition and processing, and timely update of SAR observation data. Some new technologies and methods that are appearing and will appear will give new vitality to the traditional SAR system. These new technologies and methods have been widely studied.

1.4.1 Digital Array Technology

Digital array technology (i.e. receiver/transmitter digital beam-forming [DBF] technology) provides such multidimensional information as spatial domain, time domain, and frequency domain, which can enhance the performance and simplify the structure of a radar system. Digital array technology has been successfully applied in target detection radar. If it is combined with SAR technology, it will significantly enhance the performance of the imaging system [10].

Digital array technology can realize flexible allocation of radio-frequency (RF) signal power in the observation zone. Compared to multichannel technology with single transmitting and multireceiving, or the receiver DBF technology only in the range direction, it can realize a new adaptive SAR imaging mode so that the SAR system can be switched between different modes, including strip-map, spotlight, scanning, GMTI, and interference. It can also produce image results of different modes based on the same group of echo data, enabling the system to operate under multimode simultaneously. The improvement of the observation efficiency has a greater significance for a space-borne SAR system, which is restricted by the revisit period. It is not difficult to predict that the digital array technology is one important trend of future SAR.

Digital array technology can effectively alleviate the contradiction between high azimuth resolution and the wide swath of traditional satellite SAR, realizing high-resolution wide-swath imaging. It is mainly realized by azimuth digital array technology and range direction digital array technology as well as a combination of these two technologies to further improve the system performance. Azimuth digital array technology can greatly alleviate contradiction between minimum detectable speed and blind speed in conventional a SAR/moving target indication (MTI) system and can improve the performance of SAR/MTI. By using digital array technology, multimode and multimission operation can be realized simultaneously. In addition, the digital array technology provides simultaneous multibeam adaptive capability, which can resist many kinds of electronic jamming. When a disturbance signal is detected, the interference can be weakened in the signal processing stage by zero setting the antenna pattern in an appropriate suitable direction. The digital array technology can also vary the transmitted waveform during beam scanning, which lowers the probability of interception. Therefore, digital array SAR has stronger anti-interference ability and battlefield survivability.

Both the theory and technology of digital array SAR have evolved from receiving DBF SAR and transmitting DBF SAR to DBF multiple-input, multiple-output (MIMO) SAR, namely, the gradual integration of the digitalization technology, software, the transmitting and receiving system, and the distributed system architecture. The distributed SAR system based on digital array technology with respective transmitting and receiving cannot only complete missions that are difficult for a single platform but also can obtain more and more diversified target information. After integrating the transmitting and receiving system with the distributed system architecture, the radar system has more reliability and more flexibility and is suitable for many different applications, such as continuous monitoring, wide-swath, and high-resolution imaging.

Compared with a conventional SAR system, a digital array SAR system is simplified and has obvious performance and functional advantages. However, to make a full use of these advantages, there are still some technical issues to be resolved, mainly including high-density integration of radar system and broadband data transmission and processing. As these problems are solved, the performance and function of digital array SAR systems will be improved.

1.4.2 MIMO Technology

MIMO radar is capable of obtaining equivalent observation channels whose number is far more than the actual number of the antennas, through simultaneous multiple antennas transmitting and receiving. For target detection, parameter estimation, and radar imaging, it is better than those of the traditional radar system. It has been widely researched by experts and scholars in the field of radar. The combination of MIMO technology and SAR provides a new way to solve the conflict between high resolution and wide swath and the problem of detecting slow moving targets, which commonly exists in conventional SAR.

There are four primary characteristics in the concept of MIMO-SAR: (1) Multiple transmitting/receiving antennas are distributed on the motion platform; (2) the transmitting antennas simultaneously transmit multiple waveforms independently, and the waveforms can be mutually orthogonal or uncorrelated; (3) the receiving antennas simultaneously receive the echoes of the swath independently, and the echoes of each transmitted signal can be separated by a group of filters; and (4) the performance of SAR system is improved by joint processing the echo data of multiple observation channels during signal processing.

According to the classification of MIMO radar, MIMO-SAR can be divided into two categories, common platform MIMO-SAR and distributed MIMO-SAR. For common platform MIMO-SAR, all transmitting and receiving antennas are installed on one platform, while for distributed MIMO-SAR, the transmit and receive antennas are placed on different platforms, and they are connected by network, except for bistatic SAR.

After years of development, much progress has been made in the theory and application of MIMO radar. But there are few for MIMO-SAR. A complete theoretical system is seldom seen as far as system concept, theoretical model, imaging strategy and method, performance evaluation, and so on. Many critical technologies have yet to be further addressed and improved, such as orthogonal waveform optimization, array configuration optimization, integrated imaging processing, etc. The special transceiver mode of MIMO-SAR and its diverse waveforms make the existing SAR imaging algorithm difficult to apply directly. Therefore, it is important to explore the imaging processing method and imaging method that are suitable for MIMO-SAR.

Current research on MIMO-SAR imaging technology remains in the initial stage of theoretical exploration, but its potential advantages have been widely noted by researchers. It is expected that MIMO-SAR will play an important role in SAR and GMTI applications, UAV multibase SAR imaging applications, sensing radar imaging applications, radar communication integration applications, and so on.

1.4.3 Microwave Photonic Technology

Microwave photonic technology is an emerging technology accompanied by the development of semiconductor lasers, integrated optics, optical fiber waveguides, and microwave monolithic integrated circuits. It is the combination of microwave and photon technology. It has potential applications in microwave signal generation, transmission, processing, and so on. To overcome the inadequacies in conventional SAR systems, researchers began to explore the application of microwave photonic technology in SAR. The microwave photonic technology in SAR applications will become a new frontier.

The microwave signal is modulated onto the optical carrier, and the long-distance transmission of the microwave signal by using the optical fiber has been applied in communication. The advantages of optical fiber have been used in the radar research field. Designers introduced microwave optoelectronic technology in phased array systems, such as optical fiber being used as the transmission line of radar data and signal, the true optical delay line being used to form optical beam, and so on. Metal waveguide or coaxial cable is usually used as the microwave signal transmission line, and an electronic phase shifter is used to form and control the antenna beams in conventional radar systems. They are not only bulky, heavy, and easily disturbed but also very expensive. To realize beam forming and control, eliminate the phenomenon of crowding on the back of the array through metal waveguides and coaxial cable, which can greatly reduce the system size and weight. Optical fiber instead of coaxial cable is used as the transmission medium, and real-time delay is used to replace an electronic phase shifter.

The optical phased array technology comes from the combination of microwave photonic technology and phased array technology. In an optical phased array, the RF signal is modulated on an optical carrier and is transmitted to the antenna units through different optical paths. Beam forming and control in the optical domain will produce many anticipated effects. It is well known that optical domain is nondispersive, and the propagation time will not change with respect to the frequency in a very wide microwave frequency band. The optical device is a kind of nonconductive transmission medium, and the light in the optical device offers good anti-interference capability. At the same time, the crosstalk to the connector is almost zero. These remarkable advantages cannot be realized by microwave devices. In addition, optical devices are not sensitive to interference and are durable, which makes them especially suitable for airborne and spaceborne SAR applications.

The application of microwave photonics technology in SAR has evolved from realizing remote control by using an optical link to control amplitude and phase of the antenna array elements. One of important research directions is to distribute the RF signal of the antenna unit by using the optical system. At present, most research focuses on realizing the true time-delay line of the large instantaneous bandwidth by microwave optoelectronic technology. The delay line is characterized by small size, light weight, low cost, and wide bandwidth. More attention will be paid to the improvement of performance and environmental adaptability of optical delay line in the future.

1.4.4 Miniaturization

A conventional SAR system is bulky, has high energy consumption, is expensive, and can only be deployed in large platforms, such as unmanned or manned aircraft, satellites, and missiles, which dramatically limits the large-scale implementation of SAR. The shape and mission requirements of modern aircraft are becoming more and more diverse. It is beneficial for SAR to be installed on a smaller and lighter platform, which requires its miniaturization.

Generally, two forms are adopted in the miniature SAR systems: the pulse system and the continuous-wave system. The pulse SAR system is complex, bulky, and heavy. New technology, devices, and materials are needed to achieve the miniaturization, and the system structure need to be optimized. With the development of light antenna and signal processing technology, it is possible to miniaturize SAR. The continuous-wave SAR system is a combination of frequency modulated continuous-wave and SAR technologies. It combines advantages of continuous-wave radar and SAR – small size, low cost, low power consumption, and high resolution – which is an important trend of miniature SAR. These miniature SAR systems are particularly suitable for small UAVs that fly at low heights.

The miniaturization of SAR system has many advantages. In addition to small size, light weight, high technical content, short development cycle, and low manufacturing cost, miniaturization can serve as a test bed for new technology. Therefore, the development and application prospects are very broad. In addition, micro-miniaturization of SAR systems is also one of the important techniques to realize deep-space microwave detection.

At present, the research on miniature SAR (such as the size of kilograms) is still in the stage of verification and is far from being developed and used in large scale. With the development of high-speed digital signal processing technology, motion measurement technology, and various new SAR imaging algorithms, SAR miniaturization is bound to flourish.

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