NEAR EAST UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

SYNTHETIC APERTURE RADAR

GRADUATION PROJECT
EE - 400

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ABSTRACT

Synthetic aperture radar (SAR) has become an important tool for remote sensing of the environment. However, until recently SAR systems, particularly airborne ones have been incapable of yielding focused undistorted imagery consistently. Before any meaningful image understanding can be attempted it is essential to define the imaging function under all operating conditions. Some imaging problems are totally predictable and can be corrected in principle. The most serious difficulties are associated with unknown variations in the aircraft dynamics. In this review we outline the physical principles underlying SAR imaging, including a self-consistent scheme for the production of near-perfect images based on motion compensation from inertial navigation systems and a data-dependent auto focus and phase-correction technique.

In (SAR) imaging, a plane or satellite carrying an antenna flies along a (usually straight) flight track. The antenna emits pulses of electromagnetic radiation; this radiation scatters off the terrain and is received back at the same antenna. These signals are used to produce an image of the terrain. The problem of producing a high-resolution image from SAR data is very similar to problems that arise in geophysics and tomography; techniques from seismology and X-ray tomography are now making their way into the SAR community. These statements are outlined in mathematical model for the SAR imaging problem and discuss some of the associated problems

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INTRODUCTION

(SAR), an active microwave instrument, producing high-resolution imaging of the Earth's surface in all weather. Environmental monitoring, earth-resource mapping, and military systems require broad-area imaging at high resolutions. Many times the imagery must be acquired in inclement weather or during night as well as day. SAR provides such a capability. SAR systems take advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high resolution imagery. SAR complements photographic and other optical imaging capabilities because of the minimum constraints on time-of-day and atmospheric conditions and because of the unique responses of terrain and cultural targets to radar frequencies.

SAR technology has provided terrain structural information to geologists for mineral exploration, oil spill boundaries on water to environmentalists, sea state and ice hazard maps to navigators, and reconnaissance and targeting information to military operations. There are many other applications or potential applications. Some of these, particularly civilian, have not yet been adequately explored because lower cost electronics are just beginning to make SAR technology economical for smaller scale uses.

Chapter 1 is an introductory chapter which introduces the main objective of the project, the main steps of the fabrication process and the organization of the report.

Chapter 2 presents the principles of SAR which contains overview of SAR, their main platforms, how SAR works, imaging concepts, imaging radar, radar transmits a pulse measures reflected echo (backscatter), building up a radar image using the motion of the platform, theory of SAR, constructing of SAR, a radar Image, imaging different types of surface with radar, distinguishes SAR from hi-res optical imagery, two main properties distinguish SAR from optical imagery, SAR images good for, the meaning of colour in a SAR image.

Chapter 3 investigates the SAR applications. Further, this also shows reconnaissance, surveillance, and targeting, treaty verification and nonproliferation, interferometry (3-D SAR), navigation and guidance, foliage and ground penetration, moving target indication, change detection, environmental monitoring, inverse SAR, military applications, another application of SAR.

Chapter 4 presents fundamentals of SAR. It introduces a survey of basic principles of radar, radar Backscatter, changes radar backscatter, real aperture radar (SLAR), "unfocused", SAR, SAR imaging geometry, SAR used for oceanographic purposes, the use of SAR over land, advances in SAR, bringing together the best of radio and optical sensing, greeting a larger antenna, SAR fundamental, operating modes, geometric resolutions, geometric distortions, signal characteristics, radar equation, practical work, the techniques of SAR, SAR raw data processing, SAR interferometer, a cross Track interferometer, interferometer processing techniques, interferometer products and error budget, differential and along track interferometry, key aspects of scan SAR, burst and polar metric interferometer.

Chapter 5 contains reconnaissance, surveillance, and targeting, treaty verification and nonproliferation, interferometry (3-D SAR), navigation and guidance, foliage and ground penetration, moving target indication, change detection, envi inverse SAR, ornamental monitoring, military applications, SAR used for oceanographic purposes, advances, radar application, air-traffic control, maritime navigation, military defense and attack, air defense, countermeasures, traffic safety, meteorology, scientific,

CHAPTER ONE

INTRODUCTION

1.1 History of Radar

The word "RADAR" is an acronym for Radio Detection and Ranging. As it was originally conceived, radio waves were used to detect the presence of a target and to determine its distance or range.

Radar and penicillin actually have something in common- they were both discovered by accident. Radar, which stands for radio detection and ranging, was developed for military purpose during World War 2. The British and US military used radar to locate ships and airplanes. However, annoying blips were consistently appearing on radar screen. It turned out; these annoying radar returns were raindrops.

Radar is an acronym that stands for Radio Detection and Ranging. It is an old technology that was developed in 1935 by Sir Robert A Watson-Watt (the inventor of stereo).

The underlying principal is very simple: objects distances (range) and velocities can be determined from analyzing the echoes that objects reflects. Put simply, electromagnetic waves can be transmitted at an object. The transmitted wave would then be reflected back off the object to the transmitter (or now receiver). The received signal can be analyzed to determine the distance and velocity of the object that reflected the wave. Modern radar transmits radio waves to create these echoes. This is because most objects reflect radio waves as much as they do light, since both are forms of electromagnetic radiation at different frequencies. By detecting reflected radio waves it is now possible to see objects not only in daytime, but at night, through fog, haze, clouds, etc.

1.1.1 Microwaves

Meanwhile in Germany, Hans Eric Hollmann had been working for some time in the field of microwaves, which were to later become the basis of almost all radar systems. In 1935 he published Physics and Technique of Ultra short Waves, which was then picked up by researchers around the world. At the time he had been most interested in their use for communications, but he and his partner Hans-Karl von Willisen had also worked on radar-like systems.

In the autumn of 1934 their company, GEMA, built the first commercial radar system for detecting ships. Operating in the 50 cm range it could detect ships up to 10 km away, similar in purpose to Huelsmeyer's earlier device. In the summer of 1935 pulse radar was developed with which they could spot the ship t8 km away, with an accuracy of up to 50 m, enough for gun-laying. The same system could also detect an aircraft at 500 m altitude at a distance of 28 km. The military implications were not lost this time around, and construction of land and sea-based versions took place as Freya and Seetakt.

1.1.2 World War II

At this point both the United Kingdom and Nazi Germany knew of each other's ongoing efforts in their arms race. Both nations were intensely interested in the other's developments in the field, and engaged in an active campaign of espionage and false leaks about their respective equipment. But it was only in Britain that the usefulness of the system became obvious, so while the German systems had the edge technologically (operating on much shorter wavelengths) only Britain started true mass deployment of both the radars and the control systems needed to support them.

Research had been initiated by Sir Henry Tizard's Aeronautical Research Committee in 1935 and, from 1940, was based at the Telecommunications Research Establishment (TRE).

1.1.3 Chain Home

Shortly before the outbreak of World War II several radar stations known as Chain Home (or CH) were constructed in the south of England. As one might expect from the first radar to be deployed, CH was a simple system. The broadcast side was formed from two 300' (100 m) tall steel towers strung with a series of cables between them. The output of a powerful 50 MHz radio of about 200 kW (up to 800 kW in later models) was fed into these cables, pulsed at about 50 times a second. A second set of 240' (73 m) tall wooden towers were used for reception, with a series of crossed antennas at various heights up to 215' (65 m). Most stations had more than one set of each antenna, tuned to operate at different frequencies.

The CH radar was read with an oscilloscope. When a pulse was sent out into the broadcast towers, the scope was triggered to start its beam moving horizontally across the screen very rapidly. The output from the receiver was amplified and fed into the vertical axis of the scope, so a return from an aircraft would deflect the beam upward. This formed a spike on the display, and the distance from the left side - measured with a small scale on the bottom of the screen - would give the distance to the target. By rotating the receiver antennas to make the display disappear, the operator could determine the direction (this is the reason for the cross shaped antennas), the size of the vertical displacement indicated something of the number of aircraft involved, and by comparing the strengths returned from the various antennas up the tower, the altitude could be determined.

CH proved highly effective during the Battle of Britain, and is often credited with allowing the RAF to defeat the much larger Luftwaffe forces. Whereas the Luftwaffe had to hunt all over to find the RAF fighters, the RAF knew exactly where the Luftwaffe bombers were, and could converge all of their fighters on them. The RDF stations only worked over the sea, and the positions of enemy aircraft over land had to be relayed by observers and aircraft.

Very early in the battle the Luftwaffe made a series of small raids on a few of the stations, but they were returned to operation in a few days. In the meantime the operators took to broadcasting radar-like signals from other systems in order to fool the Germans into believing that the systems were still operating. Eventually the Germans gave up trying to bomb them. The Luftwaffe apparently never understood the importance of radar to the RAF's efforts, or they would have assigned them a much higher priority -- it is clear they could have knocked them out continually if they wished.

In order to avoid the CH system the Luftwaffe adopted other tactics. One was to approach Britain at very low levels, below the sight line of the radar stations. This was countered to some degree with a series of shorter range stations built right on the coast, known as Chain Home Low (CHL). These radars had originally been intended to use for naval gun-laying and known as Coastal Defense (*CD*), but their narrow beams also meant they could sweep an area much closer to the ground without seeing the reflection of the ground (or water) itself. Unlike the larger CH systems, CHL had to have the broadcast antenna itself turned, as opposed to just the receiver. This was done manually on a pedal-crank system run by WAAFs until more reliable motorized movements were installed in 1941.

1.1.4 Later Adaptations

Similar systems were later adapted with a new display to produce the Ground Controlled Intercept stations starting in late 1941. In these systems the antenna was rotated mechanically, followed by the display on the operators console. That is, instead of a single line across the bottom of the display from left to right, the line was rotated around the screen at the same speed as the antenna was turning.

The result was a 2-D display of the air around the station with the operator in the middle, with all the aircraft appearing as dots in the proper location in space. These so-called Plan Position Indicators (*PPI*) dramatically simplified the amount of work needed to track a target on the operator's part. Such a system with a rotating, or sweeping, line is what most people continue to associate with a radar display.

Rather than avoid the radars, the Luftwaffe took to avoiding the fighters by flying at night and in bad weather. Although the RAF was aware of the location of the bombers, there was little they could do about them unless the fighter pilots could see the opposing planes. However, just this eventuallity had already been foreseen, and Watson-Watt (likely at the urging of Tizzard) had already started work on a miniaturized radar system suitable for aircraft, the so-called AI (airborne interception) set. Initial sets were available in 1941 and fitted to Bristol Blenheim aircraft, replaced quickly with the better performing Bristol Beaufighter, which quickly put an end to German night- and bad-weather bombing over England. Mosquito night intruders were fitted with AI Mk VIII and later derivatives which, along with a device called "Serrate" to allow them to track down German night fighters from their *Lichtenstein* B/C and SN2 radar emissions, as well as a device named "Perfectos" that tracked German IFF, allowed the Mosquito to find and destroy German night fighters. As a counter measure the German night fighters employed Naxos ZR radar detectors.

1.1.5 Magnetron

The next major development in the history of radar was the invention of the cavity magnetron by Randall and Boot of Birmingham University in early 1940. This was a small device which generated much more powerful microwaves than previous devices, which in turn allowed for the detection of much smaller objects and the use of much smaller antennas. The secrecy of the device was so high that it was decided in 1940 to move production to the USA, which resulted in the creation of the MIT Radiation Lab to develop the device further.

1.1.6 German Developments

German developments mirrored those in the United Kingdom, but it appears radar received a much lower priority until later in the war. The Freya radar was in fact much more sophisticated than its CH counterpart, and by operating in the 1.2 m wavelength (as opposed to ten times that for the CH) the Freya was able to be much smaller and yet offer better resolution. Yet by the start of the war only eight of these units were in operation, offering much less coverage.

However the Germans did not have an airborne system of any sort deployed until 1942, leaving them with the problem of having to get their fighters into that 300 m range solely with ground-based equipment. To fill this need another system known as W?g was deployed, starting in 1941.

1.1.7 Comparison

Compared to the British PPI systems, the German system was far more labour intensive. This problem was compounded by the lackadaisical approach to command staffing. It was several years before the Luftwaffe had a command and control system nearly as sophisticated as the one set up by Watt before the war, after seeing the confusion too much information caused during one test.

German airborne radar units followed a similar pattern. Early Lichtenstein BC units were not deployed until 1942, and as they operated on the 2 m wavelength they required large antennas. By this point in the war the British had become experts on jamming German radars, and when a BC-equipped Ju 88 night fighter landed in England one foggy night, it was only a few weeks before the system was rendered completely useless. By late 1943 the Luftwaffe was starting to deploy the greatly improved **SN-2**, but this required huge antennas that slowed the planes as much as 50 km/h. Jamming the SN-2 took longer, but was accomplished. A 9 cm wavelength system known as Berlin was eventually developed, but only in the very last months of the war.

1.1.8 Cold War

After World War II, the United States and Canada built a chain of radars in the Arctic, the Distant Early Warning Line, to warn of Soviet bomber attack. In the late 1950s the Ballistic Missile Early Warning System was added to warn of ICBM launches.

1.1.9 Modern Radar

Radar found many applications in civilian and military life and became more sophisticated and specialized for each application. The use of radar in air traffic control grew quickly during the Cold War, especially with the jump in air traffic that occurred in the 1960s. Today almost all commercial and private aircraft have transponders. Transponders send out radar signals encoded with information about an aircraft and its flight that other aircraft and air traffic controllers can use. American traffic engineer John Barker discovered in 1947 that moving automobiles would reflect radar waves, which could be analyzed to determine the car's speed. Police began using traffic radar in the 1950s, and the accuracy of traffic radar has increased markedly since the 1980s.

Doppler radar came into use in the 1960s and was first dedicated to weather forecasting in the 1970s. In the 1990s the United States had a nationwide network of more than 130 Doppler radar stations to help meteorologists track weather patterns.

Earth-observing satellites such as those in the SEASAT program began to use radar to measure the topography of the earth in the late 1970s. The Magellan spacecraft mapped most of the surface of the planet Venus in the 1990s. The Cassini spacecraft, scheduled to reach Saturn in 2004, carries radar instruments for studying the surface of Saturn's moon Titan.

As radar continues to improve, so does the technology for evading radar. Stealth aircraft feature radar-absorbing coatings and deceptive shapes to reduce the possibility of radar detection. The Lockheed F-117A, first flown in 1981, and the Northrop B-2, first flown in

1989, are two of the latest additions to the U.S. stealth aircraft fleet. In the area of civilian radar avoidance, companies are introducing increasingly sophisticated radar detectors, designed to warn motorists of police using traffic radar.

1.1.10 Radar Gun

A radar gun is a small Doppler radar used to detect the speed of objects. A radar gun does not return position or power information. It relies on the Doppler effect applied to a radar beam to measure the speed of objects it is pointed at.

Radar guns may be hand-held or vehicle-mounted. Common uses include traffic speed law enforcement, and measuring the speed of balls in sports.

Synthetic Aperture Radar (SAR) is used to acquire high-resolution large-scale images of earth surface. The advantages of a SAR device are operations in all weather condition during the day and night circles of an orbit in order to complement the existing optical sensors. At present SAR becomes an important tool of active microwave remote sensors for environment monitoring and resource survey, military application in the world.

Since the end of 70's, institute of Electronics, Chinese Academy of Sciences (IECAS) started to study on imaging radar technology for radar system design and signal processing methods as the main unit in China. As technological progresses are rapidly extended, SAR systems both airborne and space borne platforms form the major subjects in IECAS, not only to demonstrate its technological feasibility, but also to develop SAR engineering projects and exploit some of the new generation's SAR technology. Technical researchers have developed hardware and software dealing with data processing of high data rate.

The applied researches on a variety of fields are widely extended such as Institute of Remote Sensing Application and users etc. Work on cartography, crop monitoring, disaster detection and monitoring, desertification assessment and new geographical information systems are increasingly involved.

Synthetic aperture radar (SAR) uses match filters to process the chirp signal to produce an accurate, high resolution images. A presence of moving targets, however, induces unwanted phase variations, resulting image degradations due to range migration. In addition, smeared and ill-positioned images with respect to the stationary background are caused as well. Hence, an estimate of the moving target relation to the antenna is necessary in order to improve the SAR images. On the other hand, these estimates allow us to determine the moving targets velocity. The later is the purpose of this paper. There are many works on how to estimate the phase coefficients. Based on the fact that the moving target and stationary background induce different Doppler spectra, the method requires the use of a high pulse repetition frequency (prf) and performs poorly as the moving targets have a small range velocity components. Soumekh et a described the relation of the phase coefficients and the center frequency of Doppler spectrum based on the short time Fourier transform (STFT). But as is well known, in STFT the resolution was limited either in time or in frequency domain, and it suffers from smearing and side-lobe leakage. Some methods use regression on the unwrapping signal phase to estimate the polynomial phase coefficients of a constant amplitude signal, which requires to use a phase unwrapping algorithm prior to coefficient estimation. The algorithms is based on accumulate the phase difference, but it can be fooled by spare, rapidly changing phase values, and phase unwrapping errors cause inaccurate coefficient estimates. Another method by maximum likelihood estimation, it performs well at low SNR, but its cost is high computational complexity.

An estimation algorithm based on sub-aperture interferometric scheme and phase shift measurement to estimate the Doppler coefficients is proposed in this paper. This paper also addresses the relation of target speed with the phase shift. Basically, the phase of the observed sequence is model as a polynomial embedded in white noise, which implies that, first, select an appropriate sub-aperture size and then segment recorded data to a finite number of subsets with the same size. Second, we can estimate the Doppler parameters from the phase shift.

Synthetic aperture radar (SAR) has been used to produce Photograph-like images of terrain features. Conventional SAR systems provide a two-dimensional map of the radar reflectivity of the Illuminated scene. While complex data are collected and processed to Produce the SAR image, one of the final steps in its production is to reduce a complex image (containing both magnitude and phase Information) to a purely magnitude image, with the phase information being discarded.

Radar interferometry, on the other hand, depends on phase Information. Through interferometry, range information can be resolved to less than a wavelength. However, interferometry brings with it range ambiguities that limit its usefulness.

Together, SAR and interferometry provide additional information to that of a conventional SAR. Depending on the implementation, interferometric SAR, or In SAR, can survey height information of the illuminated scene, measure the radial velocity of moving scatterers, track subtle terrain motions, or detect slight changes in scene content. The synthetic aperture radar (SAR) is discussed here because of its similarities with conventional linear array antennas. SAR permits the attainment of the high resolution associated with arrays by using the motion of the vehicle to generate the antenna aperture sequentially rather than simultaneously as conventional arrays. As an example of SAR. The eight elements in the figure will now represents point in space where the platform is located when the radar radiates energy as it travels from point seven to point zero. At each point along the path, data is gathered from the echoes received, and this information is stored. Upon collecting the data at position zero, all stored data from positions one through seven are combined with the data from position zero and processed as the data would be from an eight-element linear array with simultaneous inputs from all elements. The effect will be similar to a linear-array antenna whose length is the distance traveled during the transmission of the eight pulses.

1.2 Characteristics of Re-radiation

In order for a radar system to determine range, azimuth, elevation, or velocity data, it must transmit and receive electromagnetic radiation. This electromagnetic radiation is referred to as radio frequency (RF) radiation. RF transmissions have specific characteristics that determine the capabilities and limitations of a radar system to provide these target discriminates, based on an analysis of the characteristics of the target return. The frequency of transmitted RF energy affects the ability of a radar system to analyze target return, based on time, to determine target range. RF frequency also affects the ability of the transmitting antenna to focus RF energy into a narrow beam to provide azimuth and elevation information. The wavelength and frequency of the transmitted RF energy impact the propagation of the radar signal through the atmosphere. The polarization of the RF signal affects the amount of clutter the radar must contend with. The ability of a radar system to use the Doppler effect in analyzing the radar return impacts the velocity discrimination capability of the radar. These characteristics of RF radiation will be discussed

1.2.1 Radar Signal Characteristics

Every radar produces a radio frequency (RF) signal with specific characteristics that differentiate it from all other signals and define its capabilities and limitations. Pulse width (pulse duration), pulse recurrence time (pulse recurrence interval), pulse recurrence frequency, and power are all radar signal characteristics determined by the radar transmitter. Listening time, rest time, and recovery time are radar receiver characteristics. An understanding of the terms used to describe these characteristics is critical to understanding radar operation.

1.3 Radar System Components

The individual components of radar determine the capabilities and limitations of a particular radar system. The characteristics of these components also determine the countermeasures that will be effective against a specific radar system. It will discuss the components of basic pulse radar, continuous wave (CW) radar, a pulse Doppler radar, and monopulse radar.

1.4 Radar Principles

The primary purpose of radar systems is to determine the range, azimuth, elevation, or velocity of a target. The ability of a radar system to determine and resolve these important target parameters depends on the characteristics of the transmitted radar signal. This chapter explains the relationship of radar frequency (RF), pulse recurrence frequency (PRF), pulse width (PW), and beam width to target detection and resolution.

1.5 Radar Scans

The method radar antennas employ to sample the environment is a critical design feature of the radar system. This method is often called the radar scan. The scan type selected for a particular radar system often decides the employment of that radar in an integrated air defense system (IADS). The process the radar antenna uses to search airspace for targets is called scanning or sweeping. It will discuss circular, unidirectional, bidirectional, Helical, Raster, Palmer, and conical scans, and track-while-scan (TWS) radar systems.

1.6 How radar works

Radar relies on sending and receiving electromagnetic radiation, usually in the form of radio waves (see Radio) or microwaves. Electromagnetic radiation is energy that moves in waves at or near the speed of light. The characteristics of electromagnetic waves depend on their wavelength. Gamma rays and X rays have very short wavelengths. Visible light is a tiny slices of the electromagnetic spectrum with wavelengths longer than X rays, but shorter than microwaves. Radar systems use long-wavelength electromagnetic radiation in the microwave and radio ranges. Because of their long wavelengths, radio waves and microwaves tend to reflect better than shorter wavelength radiation, which tends to scatter or be absorbed before it gets to the target. Radio waves at the long-wavelength end of the spectrum will even reflect off of the atmosphere's ionosphere, a layer of electrically-charged particles in the earth's atmosphere.

A radar system starts by sending out electromagnetic radiation, called the signal. The signal bounces off objects in its path. When the radiation bounces back, part of the signal returns to the radar system; this echo is called the return. The radar system detects the

Return and, depending on the sophistication of the system, simply reports the detection or analyzes the signal for more information. Even though radio waves and microwaves reflect better than electromagnetic waves of other lengths, only a tiny portion—about a billionth of a billionth—of the radar signal gets reflected back. Therefore, a radar system must be able to transmit high amounts of energy in the signal and to detect tiny amounts of energy in the return.

A radar system is composed of four basic components: a transmitter, an antenna, a receiver, and a display. The transmitter produces the electrical signals in the correct form for the type of radar system. The antenna sends these signals out as electromagnetic radiation. The antenna also collects incoming return signals and passes them to the receiver, which analyzes the return and passes it to a display. The display enables human operators see the data.

All radar systems perform the same basic tasks, but the way systems carry out their tasks has some effect on the system's parts. A type of radar called pulse radar sends out bursts of radar at regular intervals. Pulse radar requires a method of timing the bursts from its transmitter, so this part is more complicated than the transmitter in other radar systems. Another type of radar called continuous-wave radar sends out a continuous signal. Continuous-wave radar gets much of its information about the target from subtle changes in the return, or the echo of the signal. The receiver in continuous-wave radar is therefore more complicated than in other systems.

1.7 Types of Radar

All radar systems send out electromagnetic radiation in radio or microwave frequencies and use echoes of that radiation to detect objects, but different systems use different methods of emitting and receiving radiation. Pulse radar sends out short bursts of radiation. Continuous wave radar sends out a constant signal. Synthetic aperture radar and phased-array radar have special ways of positioning and pointing the antennas that improve resolution and accuracy. Secondary radar detects radar signals that targets send out, instead of detecting echoes of radiation.

1.7.1 Simple Pulse Radar

Simple pulse radar is the simplest type of radar. In this system, the transmitter sends out short pulses of radio frequency energy. Between pulses, the radar receiver detects echoes of radiation that objects reflect. Most pulse radar antennas rotate to scan a wide area. Simple pulse radar requires precise timing circuits in the duplexer to prevent the transmitter from transmitting while the receiver is acquiring a signal from the antenna, and to keep the receiver from trying to read a signal from the antenna while the transmitter is operating. Pulse radar is good at locating an object, but it is not very accurate at measuring an object's speed.

1.7.2 Continuous Wave Radar

Continuous-wave (CW) radar systems transmit a constant radar signal. The transmission is continuous, so, except in systems with very low power, the receiver cannot use the same antenna as the transmitter because the radar emissions would interfere with the echoes that the receiver detects. CW systems can distinguish between stationary clutter and moving targets by analyzing the Doppler shift of the signals, without having to use the precise timing circuits that separates the signal from the return in pulse radar. Continuous wave radar systems are excellent at measuring the speed and direction of an object, but they are not as accurate as pulse radar at measuring an object's position. Some systems combine pulse and CW radar to achieve both good range and velocity resolution. Such systems are called Pulse-Doppler radar systems.

1.7.3 Synthetic Aperture Radar

Synthetic aperture radar (SAR) tracks targets on the ground from the air. The name comes from the fact that the system uses the movement of the airplane or satellite carrying it to make the antenna seem much larger than it actually is. The ability of radar to distinguish between two closely spaced objects depends on the width of the beam that the antenna sends out. The narrower the beam is, the better its resolution. Getting a narrow beam requires a big antenna. A SAR system is limited to a relatively small antenna with a wide beam because it must fit on an aircraft or satellite. SAR systems are called synthetic aperture, however, because the antenna appears to be bigger than it really is. This is because the moving aircraft or satellite allows the SAR system to repeatedly take measurements from different positions. The receiver processes these signals to make it seem as though they came from a large stationary antenna instead of a small moving one. Synthetic aperture radar resolution can be high enough to pick out individual objects as small as automobiles.

Typically, an aircraft or satellite equipped with SAR flies past the target object. In inverse synthetic aperture radar, the target moves past the radar antenna. Inverse SAR can give results as good as normal SAR.

1.7.4 Phased-Array Radar

Most radar systems use a single large antenna that stays in one place, but can rotate on a base to change the direction of the radar beam. A phased-array radar antenna actually comprises many small separate antennas, each of which can be rotated. The system combines the signals gathered from all the small antennas. The receiver can change the way it combines the signals from the antennas to change the direction of the beam. A huge phased-array radar antenna can change its beam direction electronically many times faster than any mechanical radar system can.

1.7.5 Secondary Radar

A radar system that sends out radar signals and reads the echoes that bounce back is a primary radar system. Secondary radar systems read coded radar signals that the target emits in response to signals received, instead of signals that the target reflects. Air traffic control depends heavily on the use of secondary radar. Aircraft carry small radar transmitters called beacons or transponders. Receivers at the air traffic control tower search for signals from the transponders. The transponder signals not only tell controllers the location of the aircraft, but can also carry encoded information about the target. For example, the signal may contain a code that indicates whether the aircraft is an ally, or it may contain encoded information from the aircraft's altimeter (altitude indicator).

CHAPTER TWO
PRINCIPLES

2.1 Overview

Synthetic Aperture Radar, An active microwave instrument, producing high-resolution imagery of the Earth's surface in all weather. Environmental monitoring, earth-resource mapping, and military systems require broad-area imaging at high resolutions. Many times the imagery must be acquired in inclement weather or during night as well as day. Synthetic Aperture Radar (SAR) provides such a capability. SAR systems take advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high resolution imagery. Synthetic aperture radar complements photographic and other optical imaging capabilities because of the minimum constraints on time-of-day and atmospheric conditions and because of the unique responses of terrain and cultural targets to radar frequencies.

Synthetic aperture radar technology has provided terrain structural information to geologists for mineral exploration, oil spill boundaries on water to environmentalists, sea state and ice hazard maps to navigators, and reconnaissance and targeting information to military operations. There are many other applications or potential applications. Some of these, particularly civilian, have not yet been adequately explored because lower cost electronics are just beginning to make SAR technology economical for smaller scale uses.

Sandia has a long history in the development of the components and technologies applicable to Synthetic Aperture Radar 40 years in radar, antenna, and miniature electronics development; 30 years in microelectronics; and 25 years in precision navigation, guidance, and digital-signal processing. Over the last decade, we have applied these technologies to imaging radars to meet the needs of advanced weapon systems; verification and nonproliferation programs; and environmental applications. Sandia's expertise in electromagnetic, microwave electronics, high-speed signal processing, and high performance computing and navigation, guidance and control have established us as world leaders in real-time imaging, miniaturization, processing algorithms, and innovative applications for SAR..

2.2 The main Platforms

Several past, present, and future Earth Observation Satellites. Also the Shuttle Imaging Radar missions. See the table for a full list.

(1) ERS-1/ERS-2.
(2) JERS-1.
(3) Shuttle Imaging Radar SIR-C/X-SAR.
(4) Almaz.
(5) Radar Sat.

2.3 The work

A detailed description of the theory of operation of SAR is complex and beyond the scope of this document. Instead, this page is intended to give the reader an intuitive feel for how synthetic aperture radar works.

Consider an airborne SAR imaging perpendicular to the aircraft velocity as shown in the figure below. Typically, SARs produce a two-dimensional (2-D) image. One dimension in the image is called range (or cross track) and is a measure of the "line-of-sight" distance from the radar to the target. Range measurement and resolution are achieved in synthetic aperture radar in the same manner as most other radars: Range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target and, in the simplest SAR, range resolution is determined by the transmitted pulse width, i.e. narrow pulses yield fine range resolution

Figure 2.3 Synthetic Aperture Radar Imaging Concepts

2.4 Imaging Concept

The other dimension is called azimuth (or along track) and is perpendicular to range. It is the ability of SAR to produce relatively fine azimuth resolution that differentiates it from other radars. To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam. The sharpness of the beam defines the azimuth resolution. Similarly, optical systems, such as telescopes, require large apertures (mirrors or lenses which are analogous to the radar antenna) to obtain fine imaging resolution. Since SARs are much lower in frequency than optical systems, even moderate SAR resolutions require an antenna physically larger than can be practically carried by an airborne platform: antenna lengths several hundred meters long are often required. However, airborne radar could collect data while flying this distance and then process the data as if it came from a physically long antenna. The distance the aircraft flies in synthesizing the antenna is known as the synthetic aperture. A narrow synthetic beam width results from the relatively long synthetic aperture, which yields finer resolution than is possible from a smaller physical antenna.

Achieving fine azimuth resolution may also be described from a Doppler processing viewpoint. A target's position along the flight path determines the Doppler frequency of its echoes: Targets ahead of the aircraft produce a positive Doppler offset; targets behind the aircraft produce a negative offset. As the aircraft flies a distance (the synthetic aperture), echoes are resolved into a number of Doppler frequencies. The target's Doppler frequency determines its azimuth position.

While this section attempts to provide an intuitive understanding, SARs are not as simple as described above. Transmitting short pulses to provide range resolution is generally not practical. Typically, longer pulses with wide-bandwidth modulation are transmitted which complicates the range processing but decreases the peak power requirements on the transmitter. For even moderate azimuth resolutions, a target's range to each location on the synthetic aperture changes along the synthetic aperture. The energy reflected from the target must be "mathematically focused" to compensate for the range dependence across the aperture prior to image formation. Additionally, for fine-resolution systems, the range and azimuth processing are coupled (dependent on each other) which also greatly increases the computational processing. We will talk more about Synthetic Aperture Radar in Imaging radar.

2.5 Imaging Radar

Imaging radar works very like a flash camera in that it provides its own light to illuminate an area on the ground and take a snapshot picture, but at radio wavelengths. A flash camera sends out a pulse of light (the flash) and records on film the light that is reflected back at it through the camera lens. Instead of a camera lens and film, radar uses an antenna and digital computer tapes to record its images. In a radar image, one can see only the light that was reflected back towards the radar antenna.

Typical radar (Radio Detection and Ranging) measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarizations (waves polarized in a single vertical or horizontal plane).

For an imaging radar system, about 1500 high-power pulses per second are transmitted toward the target or imaging area, with each pulse having a pulse duration (pulse width) of typically 10-50 microseconds (us). The pulse normally covers a small band of frequencies, centered on the frequency selected for the radar. Typical bandwidths for imaging radar are in the range 10 to 200 MHz. At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna. This backscatter returns to the radar as weaker radar echo and is received by the antenna in a specific polarization (horizontal or vertical, not necessarily the same as the transmitted pulse). These echoes are converted to digital data and passed to a data recorder for later processing and display as an image. Given that the radar pulse travels at the speed of light, it is relatively straightforward to use the measured time for the roundtrip of a particular pulse to calculate the distance or range to the reflecting object. The chosen pulse bandwidth determines the resolution in the range (cross-track) direction. Higher bandwidth means finer resolution in this dimension.

2.6 Radar Transmits A pulse Measures Reflected Echo (Backscatter)

In the case of imaging radar, the radar moves along a flight path and the area illuminated by the radar, or footprint, is moved along the surface in a swath, building the image as it does so.

2.7 Building up A radar Image using the motion of the platform

The length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension. Synthetic Aperture Radar (SAR) refers to a technique used to synthesize a very long antenna by combining signals (echoes) received by the radar as it moves along its flight track. Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of a camera, this would be the shutter opening; for radar it is the antenna. A synthetic aperture is constructed by moving a real aperture or antenna through a series of positions along the flight track.

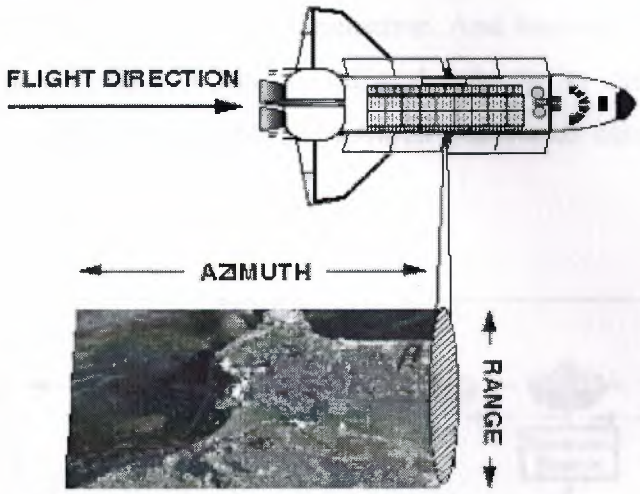


Figure 2.2 Building up a radar image using the motion of the platform

2.8 The Theory of SAR

2.8.1 Constructing a Synthetic Aperture

As the radar moves, a pulse is transmitted at each position; the return echoes pass through the receiver and are recorded in an 'echo store.' Because the radar is moving relative to the ground, the returned echoes are Doppler-shifted (negatively as the radar approaches a target; positively as it moves away). Comparing the Doppler-shifted frequencies to a reference frequency allows many returned signals to be "focused" on a single point, effectively increasing the length of the antenna that is imaging that particular point. This focusing operation, commonly known as SAR processing, is now done digitally on fast computer systems. The trick in SAR processing is to correctly match the variation in Doppler frequency for each point in the image: this requires very precise knowledge of the relative motion between the platform and the imaged objects (which is the cause of the Doppler variation in the first place).

Synthetic aperture radar is now a mature technique used to generate radar images in which fine detail can be resolved. SARs provide unique capabilities as an imaging tool. Because they provide their own illumination (the radar pulses), they can image at any time of day or night, regardless of sun illumination. And because the radar wavelengths are much longer than those of visible or infrared light, SARs can also "see" through cloudy and dusty conditions that visible and infrared instruments cannot.

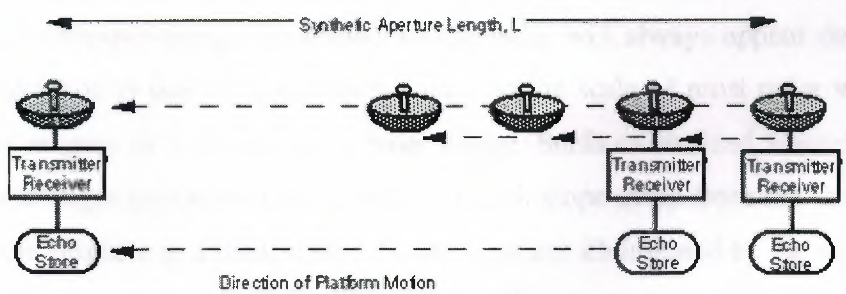


Figure 2.3 Constructing a Synthetic Aperture

2.8.2 A radar Image

Radar images are composed of many dots, or picture elements. Each pixel (picture element) in the radar image represents the radar backscatter for that area on the ground: darker areas in the image represent low backscatter, brighter areas represent high backscatter. Bright features mean that a large fraction of the radar energy was reflected back to the radar, while dark features imply that very little energy was reflected. Backscatter for a target area at a particular wavelength will vary for a variety of conditions: size of the scatterers in the target area, moisture content of the target area, polarization of the pulses, and observation angles. Backscatter will also differ when different wavelengths are used.

Scientists measure backscatter, also known as radar cross section, in units of area (such as square meters). The backscatter is often related to the size of an object, with objects approximately the size of the wavelength (or larger) appearing bright (i.e. rough) and objects smaller than the wavelength appearing dark (i.e. smooth). Radar scientists typically use a measure of backscatter called normalized radar cross section, which is independent of the image resolution or pixel size. Normalized radar cross section (sigma0.) is measured in decibels (dB). Typical values of sigma0. For natural surfaces range from +5dB (very bright) to -40dB (very dark).

A useful rule-of-thumb in analyzing radar images is that the higher or brighter the backscatter on the image, the rougher the surface being imaged. Flat surfaces that reflect little or no microwave energy back towards the radar will always appear dark in radar images. Vegetation is usually moderately rough on the scale of most radar wavelengths and appears as grey or light grey in a radar image. Surfaces inclined towards the radar will have a stronger backscatter than surfaces which slope away from the radar and will tend to appear brighter in a radar image. Some areas not illuminated by the radar, like the back slope of mountains, are in shadow, and will appear dark. When city streets or buildings are lined up in such a way that the incoming radar pulses are able to bounce off the streets and then bounce again off the buildings (called a double- bounce) and directly back towards the radar they appear very bright (white) in radar images. Roads and freeways are flat surfaces so appear dark. Buildings which do not line up so that the radar pulses are reflected straight back will appear light grey, like very rough surfaces.

2.8.3 Imaging Different Types of Surface with Radar

Backscatter is also sensitive to the target's electrical properties, including water content. Wetter objects will appear bright, and drier targets will appear dark. The exception to this is a smooth body of water, which will act as a flat surface and reflect incoming pulses away from a target; these bodies will appear dark.

Backscatter will also vary depending on the use of different polarization. Some SARs can transmit pulses in either horizontal (H) or vertical (V) polarization and receive in either H or V, with the resultant combinations of HH (Horizontal transmit, Horizontal receive), VV, HV, or VH. Additionally, some SARs can measure the phase of the incoming pulse (one wavelength = 2pi in phase) and therefore measure the phase difference (in degrees) in the return of the HH and VV signals. This difference can be thought of as a difference in the roundtrip times of HH and VV signals and is frequently the result of structural characteristics of the scatterers. These SARs can also measure the correlation coefficient for the HH and VV returns, which can be considered as a measure of how alike (between 0/not alike and 1/alike) the HH and VV scatterers are.

Different observations angles also affect backscatter. Track angle will affect backscatter from very linear features: urban areas, fences, rows of crops, ocean waves, and fault lines. The angle of the radar wave at the Earth's surface (called the incidence angle) will also cause a variation in the backscatter: low incidence angles (perpendicular to the surface) will result in high backscatter; backscatter will decrease with increasing incidence angles.

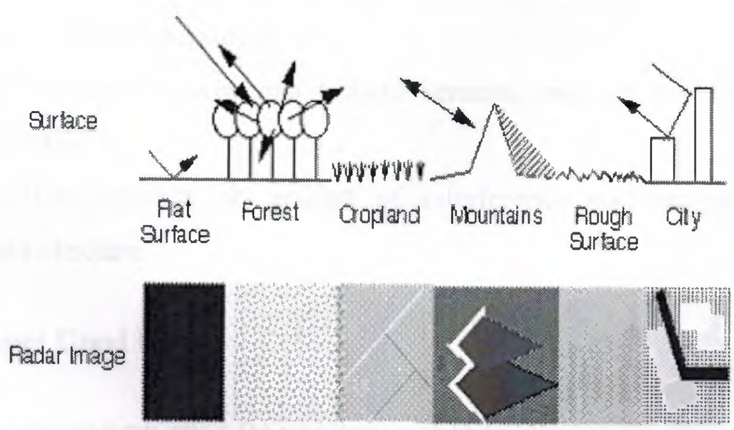


Figure 2.4 Imaging different types of surface with radar

2.9 Distinguishes from Hi-Rees Optical Imagery

2.9.1 Two Main Properties Distinguish from Optical Imagery:

The SAR is an active instrument. That is to say, it generates its own illumination of the scene to be viewed, in the manner of a camera with flash. The satellite's illumination is coherent: i.e. all the light in any flash is exactly in phase, in the manner of a laser, so it does not simply disperse over the distance between the satellite and the Earth's surface. A SAR instrument can measure both intensity and phase of the reflected light, resulting not only in a high sensitivity to texture, but also in some three-dimensional capabilities. Experiments with the technique of Interferometry (measuring phase differences in exactly aligned images of the same ground area) have shown that SAR can accurately model relief, and appears able also to detect small changes over time.
Some consequences of being an active instrument (and using coherent light) are:

(1) Works equally day or night Polarized - can be used to gain additional information (esp. when different polarizations are available on the same platform - as on the most recent Shuttle missions).
(2) Needs a lot more power than passive sensors, and can therefore only operate intermittently.
(3) Suffers from speckle, an artifact of interference patterns in coherent light, sensitive to texture.

2.9.2 SAR Images Good For

(1) Sensitive to texture: good for vegetation studies.
(2) Ocean waves, winds, currents.
(3) Seismic Activity.
(4) Moisture content.

2.10 The meaning of Colour in a SAR Image

Of course, all SAR image color is false color: the notion of true color is meaningless in the context of invisible microwave radiation.

Most SAR images are monochrome. However, multiple images of the same scene taken at different times may be superimposed, to generate false-colour multitemporal images. Colour in these images signifies changes in the scene, which may arise due to a whole host of factors, such as moisture content or crop growth on land, or wind and wave conditions at sea. SAR is particularly well-suited to this technique, due to the absence of cloud cover.

The shuttle SAR's images are the nearest to 'natural' colour, in the sense that they are viewing three different wavelengths, which can be mapped to RGB for pseudo-naturalistic display purposes (essentially the same as false colour in optical/IR imagery).

CHAPTER THREE

FUNDAMENTALS

3.1 Basic Principles of Radar

(1) Radio Detection and Ranging

(2) Wavelength (1cm–1m), pulse length (10_s),

Transmit power (1kW).

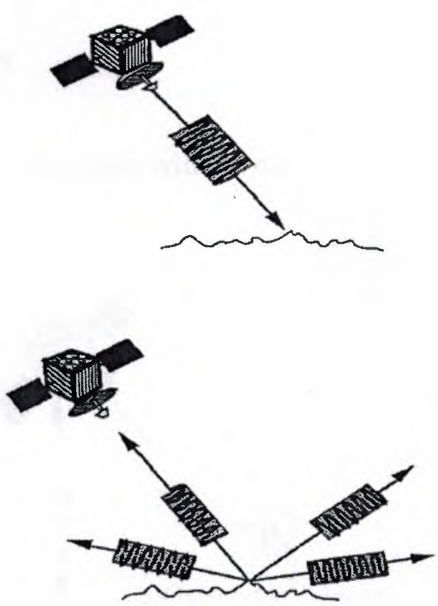


Figure3.1 Radar transmits a pulse Measures reflected echo (backscatter)

3.2 Radar Backscatter

Also known as Radar Cross Section (RCS) Measured in square meters [m2].
For looking at the Earth, radar scientists often use a measure called normalized radar cross-section,

3 .2.1 Changes Radar Backscatter

(1) Polarization, frequency, time of observation,
Observation angle (track- and incidence angle)
(2) Radar images are sensitive to changes in
Structure and water content:
(3) Changes in ocean wave direction
(4) Crop growth
(5) Harvesting
(6) Deforestation
(7) Urban growth
(8) Dry versus wet vegetation
(9) Dry versus wet soil
(10) Surfaces inclined towards the radar will have a
Stronger backscatter

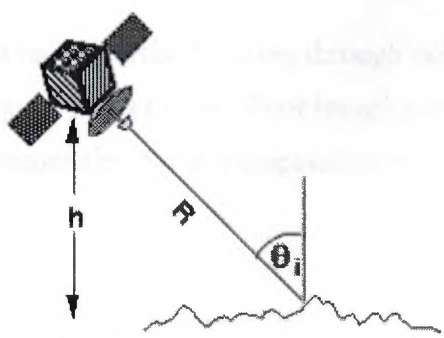
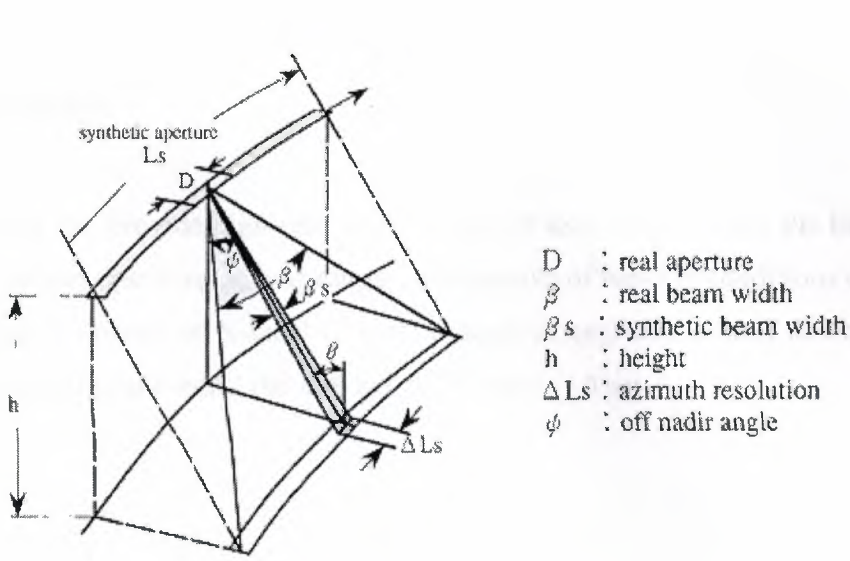


Figure 3.2 Radar backscatter is a function of incidence angle, (theta)i

3.3 Real Aperture Radar (SLAR)

Also known as SLAR (Side-Looking Aperture Radar), Narrow beam, hence large antenna, Usually high frequency, Resolution degrades linearly with range, No use of phase information, Minimal signal processing required, Spatial resolution in azimuth depends on the Azimuth beam width.



Figur3.3 Relations between Real Aperture and Synthetic Aperture Radar

3.4Unfocused

Requires coherent radar, Partial focusing through coherent summation, Azimuth resolution degrades with square root of range, Poor image quality, but sometimes used for quick look image at high frequencies, Small computation requirements.

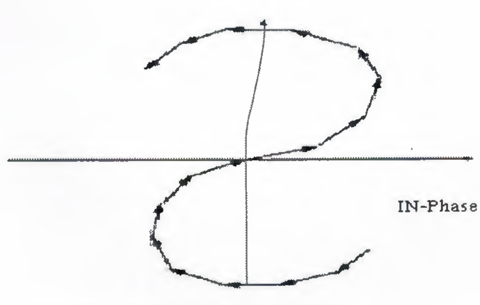


Figure 3.4 Phasor sum for unfocused

3.5 The phase

SAR can provide high-resolution images of extensive areas of the Earth's surface from a platform operating at long ranges, irrespective of weather conditions or darkness. Most systems operate at X-band (3 cm), C-band (6 cm) and L-band (24 cm), Also get systems operating at P-band (68 cm) and VHF-band (_ 3 m).

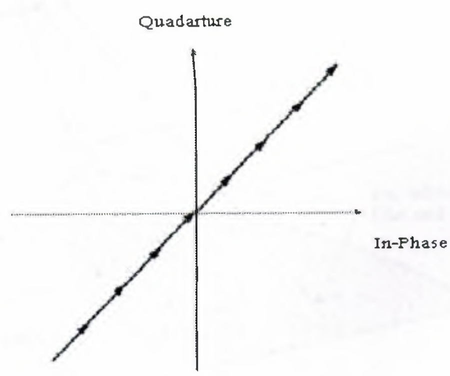


Figure 3.5 Phasor sum for focused

3.6 Imaging Geometry

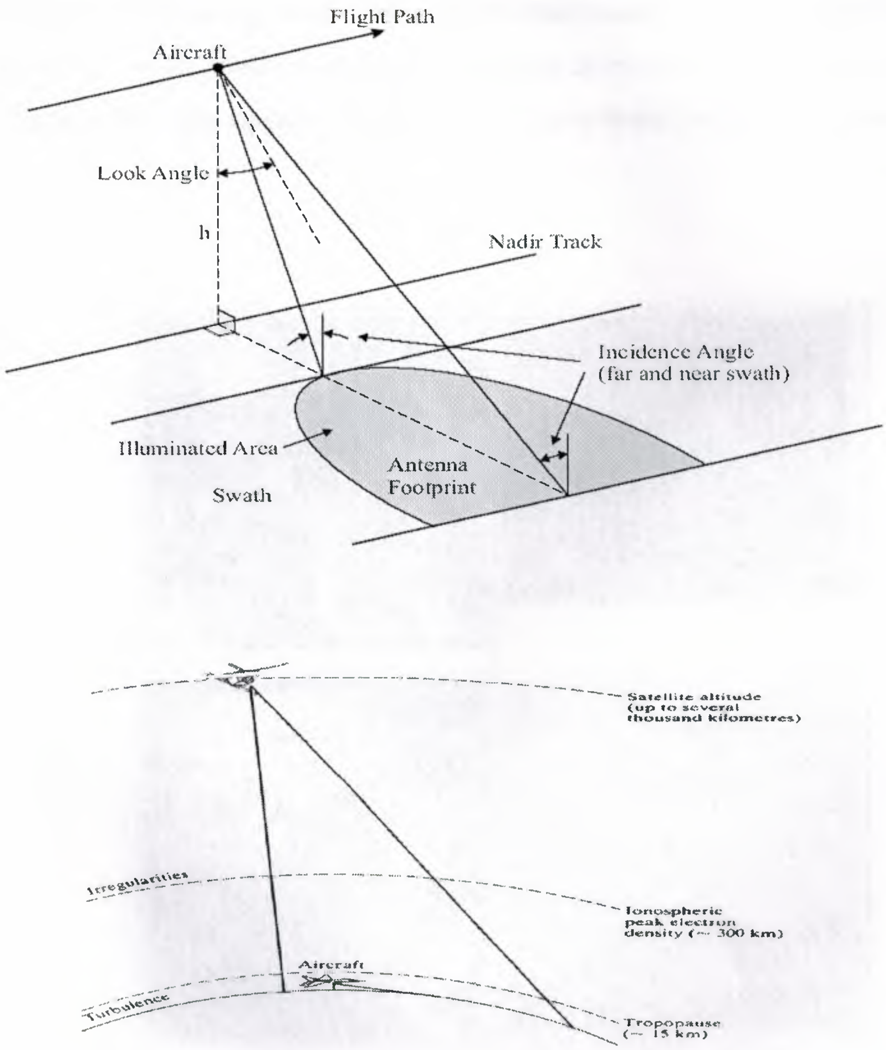


Figure 3.6 A comparison of the propagation paths of Airborne and satellite-borne SARs.

3.7 Bringing Together the best of Radio and Optical Sensing

Radar has been a cornerstone of military hardware since WWI. The concept is simple: microwave radiation is transmitted and an antenna measures the reflected energy. Unlike optical remote sensing, microwaves ignore bad weather and could care less about whether it's day or night; however, these systems hide as much as they reveal. Unlike the camera in the sky, the radar operator knows something is there, but can't tell what it is.

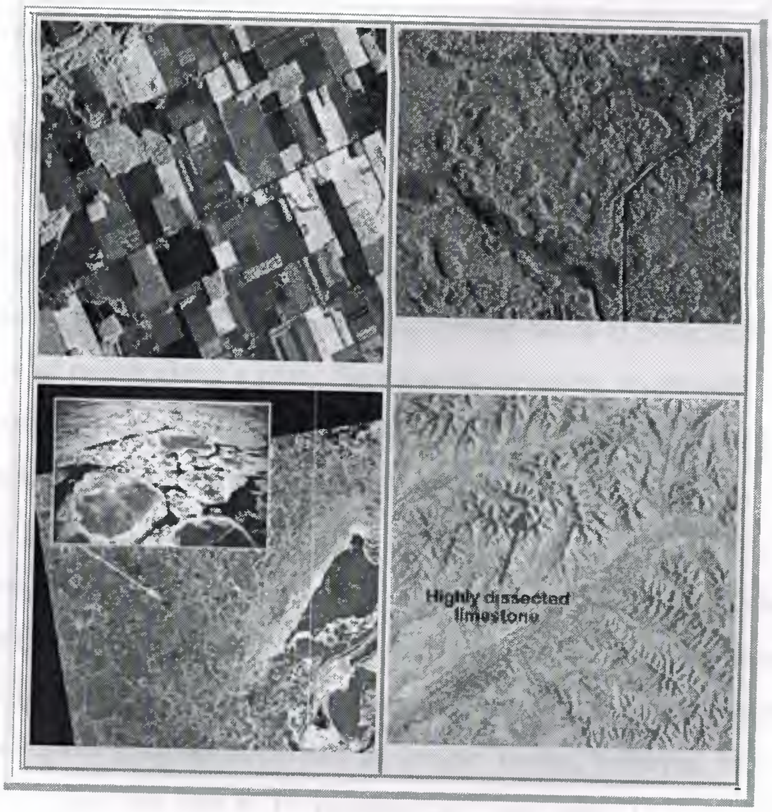


Figure 3.7 The Canada Centre for Remote Sensing (CCRS) is working to develop operational applications for Synthetic Aperture Radar (SAR), such as crop monitoring

(top left), species differentiation for forestry (top right), ice and navigation mapping (bottom left) and prospective areas for mining operations (bottom right).

Just as an optical microscopist has difficulty resolving an object that is smaller than the wavelength of illuminating light, radar is inhibited by the size of the emitting antenna. Add to that the fact that microwave radiation is somewhere around 100,000 times longer than optical wavelengths, and it quickly becomes apparent that radar can resolve the proverbial "side of a barn," but that's about it.

Since the 1950s, scientists have worked on the problem of how to give radar the ability to resolve images with optical precision while remaining immune to environmental conditions. The answer was not so straightforward. Reducing the transmitted wavelength increased the system's resolution, but reduced its ability to penetrate clouds, fog, and even foliage. The answer lay along a different path called Synthetic Aperture Radar (SAR).

3.8 Creating a larger Antenna

SAR is similar to using an antenna array without the array. A single antenna, generally on a space- or flying platform, sends out a wide beam of polarized microwave radiation at a series of points along a path. Because the radiation is coherent and always in phase upon transmission, the backscatter at each point is collected and then combined with the other data-sets to create high resolution images.

According to Dave Munson of the University of Illinois at Champaign-Urbana, SAR shares some characteristics with optical remote sensing in that the resulting image is a 2D Fourier transform. In fact, early process techniques used optical Fourier transforms to translate the return signals from the SAR into an image. Today, however, improvements in digital technology allow the data to be automatically converted to images that make sense to the human eye.

Early techniques developed by researchers at Goodyear Aerospace kept the radar antenna at one attitude in relationship to the ground and "strip mapped" the land below, usually for military surveillance or battle planning. Newer techniques, such as "spotlight" mode SAR, direct the antenna to a single spot over and over again as the antenna passes high above. By carefully measuring the changes in reflected and polarized light -- and by increasing the frequency from a few gigahertz to several hundred or even a thousand

3.9 Another Fundamental

Real and synthetic aperture radar systems. Short history of SAR. Operating and planned SAR sensors and missions.

3.9.1 Operating Modes:

Strip map, spotlight, scan SAR, burst. Interferometric configurations.

3.9.2 Geometric Resolutions:

Range resolution. Pulse compression operation. Synthetic aperture concept. Azimuth resolution, Doppler interpretation. Slant altitude resolution.

3.9.3 Geometric Distortions:

Slant and ground range. Foreshortening, layover and shadow effects. Basic principles of SAR image geocoding.

3.9.4 Signal Characteristics:

Radar cross section and backscattering coefficient. Image reflectivity. Statistics (speckle effect). Radiometric resolution. Sampling criteria (grating lobes). Azimuth and range ambiguities. Radar polarimetry.

3.10 The Techniques

3.10.1 Raw Data Processing

Strip map SAR raw signal characteristics: Point target response. System transfer function and squint effects. Strip map SAR raw data processing. Available algorithms (range-Doppler, chirp scaling, two dimensional, etc.). Motion compensation. Point target characteristics. Speckle noise filtering. Quality assessment and enhancement. Estimation procedures for optimizing data processing. Auto focus approaches, clutter lock techniques. Azimuth central frequency estimation procedures. Key aspects of spotlight scan SAR and burst raw data processing: Raw data characteristics. Comparison with the strip map mode. Processing techniques (decamping and SPECAN techniques, etc.)

3.11 Interferometry

3.11.1 Across Track Tnterferometry

Single and dual pass configurations. Interferometric signal characteristics.

3.11.2 Interferometric Processing Techniques

Image registration. Phase unwrapping techniques. Delocalization and geocoding operations.

3.11.3 Interferometric Products and Error Budget

Interferometric signal statistics. Phase and coherence, decor relation effects. Height error budget.

3.11.4 Differential and Along Track Interferometry

Earth surface deformation detection and monitoring. Sea and ocean current measurements.

3.11.5 Key Aspects of Scan SAR, Burst and Polar Metric Interferometry

SRTM scan SAR interferometry case study. Polar metric interferometry applications.

CHAPTER FOUR
APPLICATIONS

4.1 Reconnaissance, Surveillance, and Targeting

Many applications for synthetic aperture radar are for reconnaissance, surveillance, and targeting. These applications are driven by the military's need for all-weather, day-and-night imaging sensors. SAR can provide sufficiently high resolution to distinguish terrain features and to recognize and identify selected man made targets.

4.2 Treaty Verification and Nonproliferation

The ability to monitor other nations for treaty compliance and for the nonproliferation of nuclear, chemical, and biological weapons is increasingly critical. Often, monitoring is possible only at specific times, when over flights are allowed, or it is necessary to maintain a monitoring capability in inclement weather or at night, to ensure an adversary is not using these conditions to hide an activity. SAR provides the all-weather capability and complements information available from other airborne sensors, such as optical or thermal-infrared sensors.

4.3 Interferometry (3-D SAR)

Interferometer synthetic aperture radar (IFSAR) data can be acquired using two antennas on one aircraft or by flying two slightly offset passes of an aircraft with a single antenna. Interferometric SAR can be used to generate very accurate surface profile maps of the terrain.

4.4 Navigation and Guidance

Synthetic aperture radar provides the capability for all-weather, autonomous navigation and guidance. By forming SAR reflectivity images of the terrain and then "correlating" the SAR image with a stored reference (obtained from optical photography or a previous SAR image), a navigation update can be obtained. Position accuracies of less than a SAR resolution cell can be obtained. SAR may also be used to guidance applications by pointing or "squinting" the antenna beam in the direction of motion of the airborne platform. In this manner, the SAR may image a target and guide a monition with high precision.

4.5 Foliage and Ground Penetration

Synthetic aperture radars offer the capability for penetrating materials which are optically opaque, and thus not visible by optical or IR techniques. Low-frequency SARs may be used under certain conditions to penetrate foliage and even soil. This provides the capability for imaging targets normally hidden by trees, brush, and other ground cover. To obtain adequate foliage and soil penetration, SARs must operate at relatively low frequencies (10's of MHz to 1 GHz).

Recent studies have shown that SAR may provide a limited capability for imaging selected underground targets, such as utility lines, arms caches, bunkers, mines, etc. Depth of penetration varies with soil conditions (moisture content, conductivity, etc.) and target size, but individual measurements have shown the capability for detecting 55-gallon drums and power lines at depths of several meters. In dry sand, penetration depths of 10's of meters are possible.

4.6 Moving Target Indication

The motion of a ground-based moving target such as a car, truck, or military vehicle, causes the radar signature of the moving target to shift outside of the normal ground return of a radar image. Sandia has developed techniques to automatically detect ground-based moving targets and to extract other target information such as location, speed, size, and Radar Cross Section (RCS) from these target signatures.

4.7 Change Detection

A technique known as coherent change detection offers the capability for detecting changes between imaging passes. To detect whether or not a change has occurred, two images are taken of the same scene, but at different times. These images are then geometrically registered so that the same target pixels in each image align. After the images are registered, they are cross correlated pixel by pixel. Where a change has not occurred between the imaging passes, the pixels remain correlated, whereas if a change has occurred, the pixels are uncorrelated. Of course, targets that are not fixed or rigid, such as trees blowing in the wind, will naturally decor relate and show as having "changed." While this technique is useful for detecting change, it does not measure direction or the magnitude of change.

4.8 Environmental Monitoring

Synthetic aperture radar is used for a wide variety of environmental applications, such as monitoring crop characteristics, deforestation, ice flows, and oil spills. Oil spills can often be detected in SAR imagery because the oil changes the backscatter characteristics of the ocean. Radar backscatter from the ocean results primarily from capillary waves through what is known as Bragg scattering (constructive interference from the capillary waves being close to the same wavelength as the SAR). The presence of oil dampens the capillary waves, thereby decreasing the radar backscatter. Thus, oil slicks appear dark in SAR images relative to oil-free areas.

4.9 Inverse Synthetic Aperture Radar

Synthetic aperture radar (SAR) techniques rely on motion of the radar system relative to the target. For SAR, the motion is assumed to be produced by a moving radar system against a stationary target. A stationary radar system can also make use of SAR techniques provided the target is moving in relation to the radar. This variation is known as inverse synthetic aperture radar (ISAR). Inverse synthetic aperture radar is popularly employed against ships bobbing in three dimensions on the ocean's surface or against aircraft as they fly across the sky.

4.10 Military Applications

The military continues to develop new applications for SAR. In addition to using SAR to increase the optical resolution of astronomical images -- such as the moon's surface -- Munson's laboratory is exploring new areas as well: inverse SAR and identifying moving targets.

Inverse SAR is a completely new field where an antenna passively listens for reflected radiometric energy. Munson and his students at the University of Illinois are exploring ways to use television and radio signals that are always present to image objects on the ground -- specifically military targets.

Moving targets create different problems for typical SAR sensing. Because SAR data is collected over time, if the object moves during the collection period then combining the data into a picture can prove nearly impossible. According to Charles "Jack" Jackowatz of Sandia National Laboratory (Albuquerque, NM), interferometric SAR (IFSAR) techniques can alleviate this blurring by placing several antennas along a single platform, each looking down at a slightly different angle. Because the signals are in phase with one another, SAR can better detect the position of moving objects by looking at the phase differences in the return signals.

Another type of interferometric technique involves vertical IFSAR instead of horizontal. Used for high-precision terrain mapping, this method simply places one antenna farther away from the object in vertical space. According to Jackowatz, "You form an interference map as you would with laser interferometry in a nondestructive testing lab to look at the surface defects on a part."

Vertical IFSAR has produced terrain maps of open ground and tree canopies to within a few inches, with an order of magnitude better than the best stereoscopic optical techniques. This information is extremely useful for mission rehearsal, battle planning, and even for developing high-precision terrain models for guided munitions. Jackowatz's lab has even demonstrated multipass interferometric techniques where a single antenna makes several passes to develop the data for later interferometric interpretation. While this works fine for open ground, he said, tree canopies or any kind of moving areas do not produce good images because of temporary decor relation.

Other groups are actively working on applications that specifically deal with trees. Munson said that, by going to a lower frequency (500 MHz), boosting the bandwidth, and increasing the number of angles from which an antenna images the object, SAR can actually see through tree canopies to detect targets hiding underneath. "This is a very exciting and active area of military research," Munson said. However, he added that the technique is limited by the large number of angles needed to resolve a particular object.
Trees are also at the heart of a growing number of applications that have nothing to do with munitions or battle plans. In the 1980s, Europe and Canada began to build the first SAR satellites for commercial applications, expanding the way the world looks for natural resources.

4.11 Another Applications

(1) Review of SAR products: Surface model generation. Terrain model generation. Orthorectified image generation. Polar metric and coherence channels.

Topographic mapping

(2) Biomass estimation

(3) Thematic mapping: Polarimetry, Multifrequency operation. Change detection.

(4) City modeling

(5) Traffic monitoring

(6) Sea applications: Sea Bathymetry. Oil pollution and ship detection. Surface current measurement.

(7) Hazards and disaster monitoring

4.12 SAR Used For Oceanographic Purposes:

SAR is sensitive to the shorter wavelengths (Bragg scatter mechanism), The slope at different parts of a large wave may alter the backscatter from ripple waves.

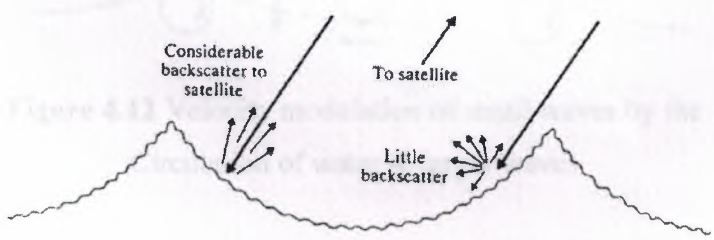


Figure 4.12 Tilt modulation of the backscattered signal

The short ripple waves observed by the SAR are modulated by a hydrodynamic interaction with the longer waves.

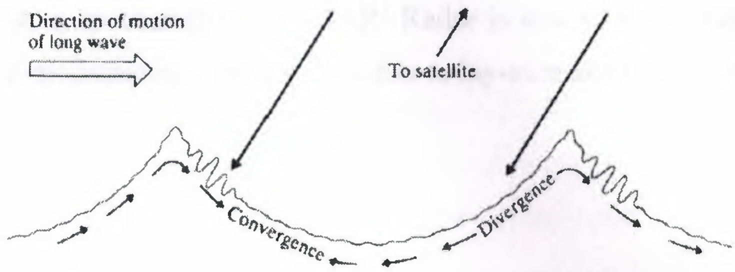


Figure 4.12 Long-wave modulation of Bragg waves by Hydrodynamic interaction

The velocity perturbations of the Bragg ripple waves imposed by the orbital motion of the water in large waves may cause the SAR image to go in and out of focus, thus revealing the presence of the larger wave.

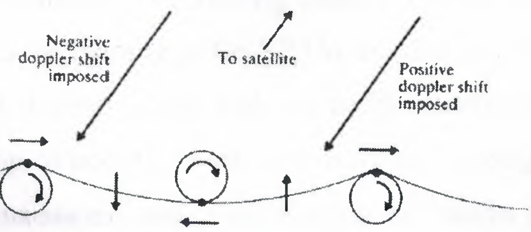


Figure 4.12 Velocity modulation of small waves by the Circulation of water in larger waves

4.13 The use of SAR over Land:

Monitoring vegetation, such as agricultural Crops (requires multi-frequency and/or multipolarization Systems), Applications in forestry Used in ice mapping imaging planets from orbiting spacecraft Inverse SAR! Radar is stationary but target is Moving, Operating SAR in mountainous regions gives rise to lay-over and shadowing.

4.14 Advances

Synthetic aperture radar (SAR) is probably the discipline inside the radar world which is currently undergoing the most rapid development and innovation. After the invention of SAR in the early 1950s in the USA (Wiley, Sherwin et al.), it took a long time for the supporting technologies (RF components, antennas, digital technology, computer power) to reach a status that made SAR the mature imaging tool we have today. Synthetic aperture radar offers a number of valuable features pertaining to earth observation which cannot be achieved with optical sensors: day and night operation, penetration of weather, dust and obscurants, geometric Resolution independent of range, polar metric detection and classification, three-dimensional imaging by interferometric techniques, and Doppler discrimination of moving targets. Typical applications include the generation of digital elevation maps (e.g. the SRTM mission in 2000), observation of volcanic activities and flood disasters, land and sea traffic monitoring, observation of vegetation growth, monitoring of ocean currents and traveling icebergs, detection of oil spills on the ocean, reconnaissance and classification of military targets, damage assessment in military conflicts etc. In view of the rapid development of SAR, it was felt in the early 1990s that a conference devoted to SAR techniques and technology should be established. In 1996 the European Conference on Synthetic Aperture Radar (EUSAR) was launched and this has taken place every two years since then. Areas of current interest are space based SAR, polarimetry, interferometry, PolIn SAR (a combination of polarimetry and interferometry), ultrahigh resolution SAR, and bi- and multistatic SAR configurations.

Shortly before EUSAR 2002, the ENVISAT earth observation satellite which includes a SAR instrument was launched.

This Special Issue on SAR contains 14 papers which were presented in brief form at EUSAR 2002 in Cologne, Germany. These papers were selected out of a total of more than 200 EUSAR 2002 papers. The criterion for the selection was to cover as much as possible of the whole range of SAR techniques and applications while keeping a certain balance in participating nations. As a result, this collection of 14 papers gives a very good picture of the state-of-the-art in SAR techniques, technology and applications, and may serve even non-SAR experts as an overview of the present capabilities of SAR and the perspectives for the future.

The paper by Krieger et al. deals with concepts of multistatic parasitic satellite configurations. Such configurations use an existing satellite for illumination and let a number of receiver satellites accompany the transmitter on different orbits. As transmitters existing SAR satellites such as PALSAR, Terra SAR-X and ASAR on board ENVISAT have been assumed. Examples are the Cartwheel, the Cross-Track Pendulum, and the Crape. These configurations are compared with respect to their capability of generating digital elevation maps. In the session on 'Innovative concepts' W. Keydel gave perspectives of a future 'Global Reconnaissance and Remote Sensing System', involving a transmitter satellite, several receiver satellites, GPS, airborne sensors, parasitic transmitters and ground stations. Keydel's view is a global system for automated earth monitoring.

R. Zahn reports on advances in space-based radar technology. The paper focuses on active front-end technology as well as on advances in SAR signal processing. Three papers on polarimetry were selected. W. M. Boerner gives a broad overview of existing techniques and activities in polarimetry, interferometry and PolIn SAR, including space-based SAR configurations and applications to environmental monitoring. A large number of invited collaborators contributed to this paper.

The paper by S. R. Cloude and K. T. Papathanassiou deals with a new inversion algorithm for polar metric SAR interferometry, a technique which can for instance be used to monitor the growth of vegetation. D. Schuler et al. report on measurements on ocean internal waves and ocean current fronts by evaluating the polarization orientation angle in polarimetry SAR data. Phase unwrapping has been an issue in interferometric SAR for long time. In the area of interferometric SAR, A. Monti Guarnieri's approach to phase unwrapping exploits some a priori knowledge on the topography of the imaged scene to improve the quality of the interferometric phase.

In the field of image generation a paper on an extension of the chirp scaling algorithm by E. Gimeno-Nieves et al. was selected. It deals with an improvement of the well known chirp scaling algorithm by including higher order terms of the Taylor expansion of the phase history. In the paper by D. Lloyd and I. D. Long staff, an ultra-wideband SAR for mine detection is described. The large bandwidth is required to achieve a resolution in the order of magnitude of the size of a mine. J. Ender and A. Brenner report on the first flight trial with the newly developed ultra-high resolution airborne SAR, PAMIR, which has proven to achieve a resolution of less than 10 cm_10 cm.

Notice that this paper goes far beyond the original EUSAR 2002 contribution.

The analysis of vibrating targets by time–frequency analysis of airborne SAR data is subject of the paper by T. Sparr and B. Krane. In the area calibration the contribution by J. Dall deals with an automated calibration procedure which can be applied to single and multi-path interferometric SAR as well. L. B. Neronskiy et al. present a model for the signal replica of a space borne SAR. A first assessment of the SAR experiments within the ENVISAT mission is reported by A. Monti Guarnieri et al.

We hope the reader will appreciate this choice of contributions on SAR. I am grateful to J. Ender and A. Brenner, as well as the large number of reviewers, for their assistance in completing this Special Issue and I would also like to thank the IEE for the excellent cooperation. In particular, I appreciate the IEE's interest in connections with EUSAR.

4.15 Radar Applications

Many industries depend on radar to carry out their work. Civilian aircraft and maritime industries use radar to avoid collisions and to keep track of aircraft and ship positions. Military craft also use radar for collision avoidance, as well as for tracking military targets. Radar is important to meteorologists, who use it to track weather patterns. Radar also has many other scientific applications.

4.15.1 Air-Traffic Control

Radar is a vital tool in avoiding midair aircraft collisions. The international air traffic control system uses both primary and secondary radar. A network of long-range radar systems called Air Route Surveillance Radar (ARSR) tracks aircraft as they fly between airports. Airports use medium-range radar systems called Airport Surveillance Radar to track aircraft more accurately while they are near the airport.

4.15.2 Maritime Navigation

Radar also helps ships navigate through dangerous waters and avoid collisions. Unlike air-traffic radar, with its centralized networks that monitor many craft, maritime radar depends almost entirely on radar systems installed on individual vessels. These radar systems search the surface of the water for landmasses; navigation aids, such as lighthouses and channel markers; and other vessels. For a ship's navigator, echoes from landmasses and other stationary objects are just as important as those from moving objects. Consequently, marine radar systems do not include clutter removal circuits. Instead, ship-based radar depends on high-resolution distance and direction measurements to differentiate between land, ships, and unwanted signals. Marine radar systems have become available at such low cost that many pleasure craft are equipped with them, especially in regions where fog is common.

4.15.3 Military Defense and Attack

Historically, the military has played the leading role in the use and development of radar. The detection and interception of opposing military aircraft in air defense has been the predominant military use of radar. The military also uses airborne radar to scan large battlefields for the presence of enemy forces and equipment and to pick out precise targets for bombs and missiles.

4.15.3.1 Air Defense

A typical surface-based air defense system relies upon several radar systems. First, a lower frequency radar with a high-powered transmitter and a large antenna searches the airspace for all aircraft, both friend and foe. A secondary radar system reads the transponder signals sent by each aircraft to distinguish between allies and enemies. After enemy aircraft are detected, operators track them more precisely by using high-frequency waves from special fire control radar systems. The air defense system may attempt to shoot down threatening aircraft with gunfire or missiles, and radar sometimes guides both gunfire and missiles (see Guided Missiles).

Longer-range air defense systems use missiles with internal guidance. These systems track a target using data from a radar system on the missile. Such missile-borne radar systems are called seekers. The seeker uses radar signals from the missile or radar signals from a transmitter on the ground to determine the position of the target relative to the missile, then passes the information to the missile's guidance system.

The military uses surface-to-air systems for defense against ballistic missiles as well as aircraft (see Defense Systems). During the Cold War both the United States and the Union of Soviet Socialist Republics (USSR) did a great deal of research into defense against intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs). The United States and the USSR signed the Anti-Ballistic Missile (ABM) treaty in 1972. This treaty limited each of the superpowers to a single, limited capability system. The U.S. system consisted of a low-frequency (UHF) phased-array radar around the perimeter of the country, another phased-array radar to track incoming missiles more accurately, and several very high speed missiles to intercept the incoming ballistic missiles. The second radar guided the interceptor missiles.

Airborne air defense systems incorporate the same functions as ground-based air defense, but special aircraft carry the large area search radar systems. This is necessary because it is difficult for high-performance fighter aircraft to carry both large radar systems and weapons.

Modern warfare uses air-to-ground radar to detect targets on the ground and to monitor the movement of troops. Advanced Doppler techniques and synthetic aperture radar have greatly increased the accuracy and usefulness of air-to-ground radar since their introduction in the 1960s and 1970s. Military forces around the world use air-to-ground radar for weapon aiming and for battlefield surveillance. The United States used the Joint Surveillance and Tracking Radar System (JSTARS) in the Persian Gulf War (1991), demonstrating modern radar's ability to provide information about enemy troop concentrations and movements during the day or night, regardless of weather conditions.

4.15.3.2 Countermeasures

The military uses several techniques to attempt to avoid detection by enemy radar. One common technique is jamming—that is, sending deceptive signals to the enemy's radar system. During World War II (1939-1945), flyers under attack jammed enemy radar by dropping large clouds of chaff—small pieces of aluminum foil or some other material that reflects radar well. "False" returns from the chaff hid the aircraft's exact location from the enemy's air defense radar. Modern jamming uses sophisticated electronic systems that analyze enemy radar, then send out false radar echoes that mask the actual target echoes or deceive the radar about a target's location.

Stealth technology is a collection of methods that reduce the radar echoes from aircraft and other radar targets (see Stealth Aircraft). Special paint can absorb radar signals and sharp angles in the aircraft design can reflect radar signals in deceiving directions. Improvements in jamming and stealth technology force the continual development of high-power transmitters, antennas good at detecting weak signals, and very sensitive receivers, as well as techniques for improved clutter rejection.

4.15.4 Traffic Safety

Since the 1950s, police have used radar to detect motorists who are exceeding the speed limit. Older police radar "guns" use Doppler technology to determine the target vehicle's speed. Such systems were simple, but they sometimes produced false results. The radar beam of such systems was relatively wide, which meant that stray radar signals could be detected by motorists with radar detectors. Newer police radar systems, developed in the 1980s and 1990s, use laser light to form a narrow, highly selective radar beam. The narrow beam helps insure that the radar returns signals from a single, selected car and reduces the chance of false results. Instead of relying on the Doppler effect to measure speed, these systems use pulse radar to measure the distance to the car many times, then calculate the speed by dividing the change in distance by the change in time. Laser radar is also more reliable than normal radar for the detection of speeding motorists because its narrow beam is more difficult to detect by motorists with radar detectors.

4.15.5 Meteorology

Meteorologists use radar to learn about the weather. Networks of radar systems installed across many countries throughout the world detect and display areas of rain, snow, and other precipitation. Weather radar systems use Doppler radar to determine the speed of the wind within the storm. The radar signals bounce off of water droplets or ice crystals in the atmosphere. Gaseous water vapor does not reflect radar waves as well as the liquid droplets of water or solid ice crystals, so radar returns from rain or snow are stronger than that from clouds. Dust in the atmosphere also reflects radar, but the returns are only significant when the concentration of dust is much higher than usual. The Terminal Doppler Weather Radar can detect small, localized, but hazardous wind conditions, especially if precipitation or a large amount of dust accompanies the storm. Many airports use this advanced radar to make landing safer.

4.15.6 Scientific

Scientists use radar in several space-related applications. The Spacetrack system is a cooperative effort of the United States, Canada, and the United Kingdom. It uses data from several large surveillance and tracking radar systems (including the Ballistic Missile Early Warning System) to detect and track all objects in orbit around the earth. This helps scientists and engineers keep an eye on space junk—abandoned satellites, discarded pieces of rockets, and other unused fragments of spacecraft that could pose a threat to operating spacecraft. Other special-purpose radar systems track specific satellites that emit a beacon signal. One of the most important of these systems is the Global Positioning System (GPS), operated by the U.S. Department of Defense. GPS provides highly accurate navigational data for the U.S. military and for anyone who owns a GPS receiver.

During space flights, radar gives precise measurements of the distances between the spacecraft and other objects. In the U.S. Surveyor missions to the moon in the 1960s, radar measured the altitude of the probe above the moon's surface to help the probe control its descent. In the Apollo missions, which landed astronauts on the moon during the 1960s and 1970s, radar measured the altitude of the Lunar Module, the part of the Apollo spacecraft that carried two astronauts from orbit around the moon down to the moon's surface, above the surface of the moon. Apollo also used radar to measure the distance between the Lunar Module and the Command and Service Module, the part of the spacecraft that remained in orbit around the moon.

Astronomers have used ground-based radar to observe the moon, some of the larger asteroids in our solar system, and a few of the planets and their moons. Radar observations provide information about the orbit and surface features of the object.

The U.S. Magellan space probe mapped the surface of the planet Venus with radar from 1990 to 1994. Magellan's radar was able to penetrate the dense cloud layer of the Venusian atmosphere and provide images of much better quality than radar measurements from Earth.

Many nations have used satellite-based radar to map portions of the earth's surface. Radar can show conditions on the surface of the earth and can help determine the location of various resources such as oil, water for irrigation, and mineral deposits. In 1995 the Canadian Space Agency launched a satellite called RADARsat to provide radar imagery to commercial, government, and scientific users.

CHAPTER FIVE
AIRBORNE

5.1 AirSAR-Instrument-On-Aircraft

5.1.1 Basic Operation

In a typical SAR application, a single radar antenna will be attached to the side of an aircraft. A single pulse from the antenna will be rather broad (several degrees) because diffraction requires a large antenna to produce a narrow beam. The pulse will also be broad in the vertical direction; often it will illuminate the terrain from directly beneath the aircraft out to the horizon. However, if the terrain is approximately flat, the time at which echoes return allows points at different distances from the flight track to be distinguished. Distinguishing points along the track of the aircraft is difficult with a small antenna. However, if the amplitude and phase of the signal returning from a given piece of ground are recorded, and if the aircraft emits a series of pulses as it travels, then the results from these pulses can be combined. Effectively, the series of observations can be combined just as if they had all been made simultaneously from a very large antenna; this process creates a synthetic aperture much larger than the length of the antenna (and in fact much longer than the aircraft itself).

Combining the series of observations is done using Fast Fourier Transform techniques; it requires significant computational resources, and is normally done at a ground station after the observation is complete. The result is a map of radar reflectivity (including both amplitude and phase) on the ground. The phase information is, in the simplest applications, discarded. The amplitude information, however, contains information about ground cover, in much the same way that a black-and-white picture does. Interpretation is not simple, but a large body of experimental results has been accumulated by flying test flights over known terrain.

The basic design of a synthetic aperture radar system can be enhanced in various ways to collect more information. Most of these methods use the same basic principle of combining many pulses to form a synthetic aperture, but they may involve additional antennas or significant additional processing.

5.1.2 Polarimetry

Radar waves have a polarization. Different materials reflect radar waves with different intensities, but anisotropic materials such as grass often reflect different polarizations with different intensities. Some materials will also convert one polarization into another. By emitting a mixture of polarizations and using receiving antennas with a specific polarization, several different images can be collected from the same series of pulses. Frequently three such images are used as the three color channels in a synthesized image. This is what has been done in the picture above. Interpretation of the resulting colors requires significant testing of known materials.

5.1.3 Interferometry

Rather than discarding the phase information, information can be extracted from it. If two observations of the same terrain from very similar positions are available, a great deal of interesting information can be extracted. This technique is called interferometric SAR or InSAR.

If the two samples are obtained simultaneously (perhaps by placing two antennas on the same aircraft, some distance apart), then any phase difference will contain information about the angle from which the radar echo returned. Combining this with the distance information, one can determine the position in three dimensions of the image pixel. In other words, one can extract terrain altitude as well as radar reflectivity, producing a digital elevation model with a single airplane pass. One aircraft application at the Canada Center for Remote Sensing produced digital elevation maps with a resolution of 5 m and altitude errors also on the order of 5 m.

If the two samples are separated in time, perhaps from two different flights over the same terrain, then there are two possible sources of phase shift. The first is terrain altitude, as discussed above. The second is terrain motion: if the terrain has shifted between observations, it will return a different phase. The amount of shift required to cause a significant phase difference is on the order of the wavelength used. This means that if the terrain shifts by centimeters, it can be seen in the resulting image (A digital elevation map must be available in order to separate the two kinds of phase difference; a third pass may be necessary in order to produce one).

This second method offers a powerful tool in geology and geography. Glacier flow can be mapped with two passes. Maps showing the land deformation after a minor earthquake or after a volcanic eruption (showing the shrinkage of the whole volcano by several centimeters) have been published.

5.2 Ultra-Wideband SAR

Normal radar emits pulses with a very narrow range of frequencies. This places a lower limit on the pulse length (and therefore the resolution in the distance direction) but greatly simplifies the electronics. Interpretation of the results is also eased by the fact that the material response must be known only in a narrow range of frequencies.

Ultra-wideband radar emits very short pulses consisting of a very wide range of frequencies, from zero up to the radar's normal operating frequency. Such pulses allow high distance resolution but much of the information is concentrated in relatively low frequencies (with long wavelengths). Thus such systems require very large receiving apertures to obtain correspondingly high resolution along the track. This can be achieved with synthetic aperture techniques.

The fact that the information is captured in low frequencies means that the most relevant material properties are those at lower frequencies than for most radar systems. In particular, such radar can penetrate some distance into foliage and soil.

5.3 Doppler Beam Sharpening

A commonly used technique for SAR systems is called Doppler Beam Sharpening. Because the real aperture of the RADAR antenna is so small (compared to the wavelength in use), the RADAR energy spreads over a wide area (usually many degrees wide in a direction ortho-normal (right angle) to the direction of the platform (aircraft). Doppler Beam Sharpening takes advantage of the motion of the platform in that targets ahead of the platform return a Doppler up-shifted signal (slightly higher in frequency) and targets behind the platform return a Doppler down-shifted signal (slightly lower in frequency). The amount of shift varies with the angle forward or backward from the ortho-normal direction. By knowing the speed of the platform, target signal return is placed in a specific angle "bin" that changes over time. Signals are integrated over time and thus the RADAR "beam" is synthetically reduced to a much smaller aperture - or more accurately (and based on the ability to distinguish smaller Doppler shifts) the system can have hundreds of very "tight" beams concurrently. This technique dramatically improves angular resolution; however, it is far more difficult to take advantage of this technique for range resolution.

5.4 Chirped (Pulse Compressed) Radars

A common technique for many RADAR systems (sometimes found in SAR systems) is to "chirp" the signal. In a "chirped" radar, the pulse is allowed to be much longer (which usually hinders range resolution - but increases the probability of detection because more energy is returned), but this longer pulse is also allowed to have a frequency shift during the pulse (hence the chirp or frequency shift). When the "chirped" signal is returned, it is passed to a dispersive delay line (often a SAW device (Surface Acoustic Wave) that has the property of varying velocity of prorogation based on frequency. This technique "compresses" the pulse in time - thus having the effect of a much shorter pulse (improved range resolution) while having the benefit of longer pulse length (much more signal returned).

5.5 Data Collection

Highly accurate data can be collected by aircraft over flying the terrain in question. One such aircraft was flown by the Canada Center for Remote Sensing until about 1996 when it was decommissioned for cost reasons. Most land-surveying applications are now carried out by satellite observation. Satellites such as ERS-1, JERS-1, and RADARSAT-1 were launched explicitly to carry out this sort of observation. Their capabilities differ, particularly in their support for interferometer, but all have collected tremendous amounts of valuable data. The Space Shuttle has also carried synthetic aperture radar equipment, and the Magellan space probe mapped the surface of Venus over several years.

5.6 Triangulation Conditions

We all know that InSAR technique can extract the 3D terrain information, but, without GCPs, the absolute space positions of the ground objects are still unknown to us. So, different from InSAR technique, we studied the high-resolution airborne SAR images triangulation conditions, which can be summarized as the follows:

- Airborne SAR images stereo-pairs based triangulation models;
- 60% overlap degree between the adjacent flight paths;
- Independent model block adjustment to compute target 3D coordinates only supported by sparse GCPs available;
- GPS/INS data supported airborne SAR triangulation without GCPs;

5.7 Mathematic Models

5.7.1 Independent Model Unit Configuration

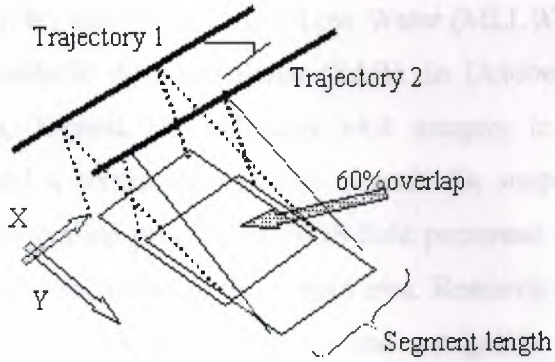


Figure 5.1 the independent model unit for airborne SAR imagery triangulation

To construct the independent model unit, we must pre-prepare the airborne SAR imagery. Firstly, we divide the imagery paths into many segments with some length, for example, the length of one synthetic aperture, and 20%~30% overlapping with adjacent segments in the same path. Then, take the flight direction as the X-axis, and range direction as Y. And, according to our flight course design, there is 60 percent overlap area between the two segments of independent model unit from adjacent imagery paths, so, the segments of the same overlap area in adjacent paths will construct the independent model unit for airborneSARimagerytriangulation.

5.7.2 Triangulation Model Based on Independent Models

Under the condition of only sparse GCPs available around the mapping area, the vector model of independent models based airborne SAR triangulation see as Fig.2. To make the processing simple, we adopt the stereo-pairs from the adjacent flight paths to buildup the independent model unit. And, each object P in the independent model unit will have the unique relative model coordinates, which can be transform into the absolute ground coordinates (X', Y', Z') through sequent space transform matrix. A more detailed explanation is as follows

5.8 The Use of High Resolution Airborne (SAR) for Shoreline Mapping

As part of an effort to evaluate the potential of several new mapping technologies, the National Geodetic Survey (NGS) is attempting to conduct precision mapping of the Mean High Water (MHW) and Mean Lower Low Water (MLLW) shorelines using high resolution airborne Synthetic Aperture Radar (SAR). In October 1997, NGS acquired dual antenna, 1-meter, X-band, HH-polarized SAR imagery in a remote area of the Alaska shoreline aboard a contracted research aircraft. To support the analysis of the navigation and image formation procedures, NGS field personnel conducted an extensive GPS survey to place radar reflectors in the project area. Research personnel are presently engaged in processing the raw phase history and navigation data into images and interferometrically-derived digital elevation models (DEM). Preliminary results indicate that the quality of the data is excellent and that high resolution SAR has the potential to meet the demanding application of precise shoreline mensuration. This paper presents an overview of this project and shows selected results to date.

5.9 Airborne Reconnaissance - Low (ARL)

The Airborne Reconnaissance Low (ARL) is a multifunction, day/night, all weather reconnaissance intelligence asset developed and fielded by the Army in support of an urgent requirement for a low profile intelligence aircraft. ARL is a modified DHC-7 fixed wing aircraft with a core SIGINT and IMINT mission payload controlled and operated via onboard open architecture, multifunction workstations. The system developed from a Commander in Chief U.S. Southern Command (SOUTHCOM) requirement for a manned aviation platform that could provide an IMINT and SIGINT collection capability in SOUTHCOM. The design requirements submitted stated that Airborne Reconnaissance Low should support nation-building, counternarcotics, and promote-democracy missions (now classified as stability and support operations or operations other than war) in SOUTHCOM's area of responsibility.

The DeHavilland of Canada Dash-7, a four-engine, turboprop, commuter airplane was chosen as the platform for SIGINT and IMINT collection. The Dash-7 aircraft's ability to operate out of austere runways, its ability to carry the mission payload and its endurance led to the Dash-7's selection. It is an extensively modified aircraft that has a higher maximum gross weight and extended range capability added in the ARL conversions. ARL aircraft survivability equipment includes the AN/APR-39A(V1) radar warning receiver, the AN/AAR-47 infrared missile warning receiver, and the M-130 flare and chaff dispenser.

The ARL system has been developed to accommodate diverse mission requirements through the implementation of an open architecture, modular, reconfigurable mission sensors. The SIGINT subsystem has a HF/VHF/UHF intercept and direction finding (DF) capable Electronic Support Measures (ESM) system. The IMINT subsystem is equipped with infrared line scanner (IRLS), forward looking infrared (FLIR), and daylight imaging system (DIS). The core complement of sensors may be augmented with low-light level TV (LLTV), MTI cueing radar, Synthetic Aperture Radar (SAR), multi-spectral camera, acoustic range extension system, precision targeting subsystem, and remote configuration using a direct air-to-satellite data link.

Two separate systems, the ARL-IMINT (ARL-I) and the ARL-COMINT (ARL-C), designated the O-5A and EO-5B respectively, were initially developed to meet SOUTHCOM's requirements. The ARL-C has a high-frequency, very-high frequency (VHF), and ultrahigh frequency (UHF) direction-finding (DF) capability controlled by four onboard operator stations. Dissemination is through secure UHF (line-of-sight and SATCOM) or VHF-frequency modulation communications, or in the post-mission downloads of COMINT data. ARL-I has three separate imagery systems onboard: first-generation forward-looking infrared camera turret, a day-imaging system camera turret, and an infrared line scanner. The system can send RS-170 video imagery via downlink to commercial off-the-shelf systems, such as TACLINK II, which is a portable video receiver. Two onboard operators can record information on 8-millimeter videotape or transmit "live" to the ground forces commander.

The RC-7B, the ARL-M (Multifunction) includes upgrades to systems already installed on ARL-I and -C, and added MTI SAR capabilities. Planned SIGINT collection improvements include the Super hawk radio intercept and DF system. Four onboard operators manipulate IMINT, SIGINT, and MTI SAR data. ARL-M has growth potential to include systems like the Communications High-Accuracy Location System Exploitation (CHALS-X), a second-generation FLIR, the Radar Ground Display System, and improvements to the airframe.

Three interim capable ARL systems were fielded to the 470th MIBN(LI), Howard AFB, Panama to support SOUTHCOM requirements. These fielded systems are in two different configurations; two for performing signals intelligence (SIGINT) missions (ARL-C) and one for performing imagery intelligence (IMINT) missions (ARL-I). Two ARL-M, multiple mission (IMINT and SIGINT) capable systems, with the addition of an MJI/SAR have been fielded to Korea to perform the I and W mission of the retiring Mohawk (OV-ID). A third ARL-M was completed in FY97. In March 1998 Raytheon Systems Company announced the sale of two additional radar systems for the ARL-M program, bringing to five the total of Raytheon HISAR radars supporting the effort. All interim capable systems will be converted to the multiple mission capable ARL-M configuration.

The ARL-M program represents US domestic sales of the program known internationally as the Highly Integrated Surveillance and Reconnaissance System (HISAR). HISAR leverages military technology pioneered by Raytheon' Sensors and Electronic Systems Segment to provide all-weather, day or night synthetic aperture radar coverage from the same family of radars used on U-2 spy plane and the B-2 Bomber. The system is capable of both air-to-air and air-to-ground standoff imaging with six-meter resolution and a moving target indicator facility, making it a versatile and affordable multi-role surveillance platform. At the core of this multimission system are the SAR and the DB-110 long-range optical sensors derived from the same family of sensors used on the U-2 spy plane, as well as forward looking infrared, signals intelligence sensors, and a variety of radios, data links, and ground stations. Another variant of the HISAR package is in flight test for the US Department of Defense Advanced Research Projects Agency's Global Hawk High Altitude Endurance Unmanned Aerial Vehicle.

5.10 Modular Airborne Systems

EDO's Radar Programs Group is a supplier of world-class ground-based Moving Target Indicator (MTI) Radars and Airborne MTI and synthetic aperture radar (SAR) - Fixed Target Imaging - radars. Our radar products consist of a family of modular radars which rely on a fully mature complement of radar hardware and software modules which may be configured in airborne or ground-based configurations for Reconnaissance, Surveillance, Target Acquisition, Imaging and Electro-Optic Sensor Cueing. In addition, EDO's product line includes Missile Warning, Range Instrumentation, Air-Intercept, and Surface Surveillance Radars.

The radars represent state-of-the-art in performance for Moving Target Indicator (MTI), Air-Intercept and SAR Imagery for this size, weight, and power class. The radars operate in the Ku-frequency band, and are a fully coherent, pulsed Doppler design. Due to their modular design, their applications are extremely flexible, and the systems are readily integrated onto a variety of platforms ranging from Jeeps and HMMWV's to manned aircraft, external pod, UAV's and airships. Man-portable, battery powered, configurations are available.

The SARs are realized by the addition of a SAR Module to the Airborne MTI systems. The SAR systems provide both fine and coarse resolution imagery in strip and spotlight modes.

5.11 Radar for Mineral Exploration

Work has been undertaken through the Cooperative Research Centre for Landscape Evolution and Mineral Exploration, which successfully demonstrated the use of airborne radar techniques for mineral exploration.

Work has been undertaken through the Cooperative Research Centre for Landscape Evolution and Mineral Exploration, which successfully demonstrated the use of airborne radar techniques for mineral exploration.

The AIRSAR (AIRborne Synthetic Aperture Radar) system has particular application in arid or sand covered regions where the more common remote sensing systems are less successful. For example, the AIRSAR system, when used near the Telfer gold mine in WA, revealed significant new insights into the geological structure of the region.

5.12 The C/X-SAR System

The C/X-SAR system is an airborne synthetic aperture radar (SAR), developed by the Canada Centre for Remote Sensing. It is available for use by the remote sensing research and development community, resource managers, and the exploration, maritime, and mapping industries.

The C/X-SAR was used to support initial RADARSAT marketing through projects like GlobeSAR, with airborne imagery providing the basis for simulations of satellite SAR swath configurations, and as a facility for the optimization of future radar satellites.
The C/X-SAR can provide imagery of all classes of terrain, ocean, or ice scenes. The imagery can be compared easily with mapped information. It is possible to monitor natural resources (agriculture, forestry, geology), temporal variations (urban growth, sea ice and icebergs, ocean waves and currents, shipping and fishing), and disasters (oil spills, floods, fires).

Since the commissioning of the C- and X-band SARs, in 1986 and 1988, respectively, the C/X-SAR system has undergone several upgrades, including improvements in real-time processing, more flexible imaging geometries, navigation, motion compensation processing, and a data recording unit. The system is highly versatile when used in its basic configuration. In addition, the C-band radar now has two advanced research capabilities, providing interferometric and polarimetric modes.

The C/X-SAR is carried on a Convair 580 aircraft, a rugged and reliable turboprop, and it is complemented by the latest in navigation equipment and a suite of other sensors. This advanced system provides reliable, accurate products. The C/X-SAR has seen operational use worldwide, from polar ice caps to equatorial rain forests: in North and South America, Europe, the Middle and Far East, and Africa.

5.13 SAR Technical Specifications

5.13.1 C/X SAR Transmitter

	C-band	X-band
Frequency:	5.30 GHz	9.25 GHz
Wavelength:	5.66 cm	3.24 cm
Power:	16, 1 kW	6 kW
Polarization:	horizontal or vertical polarimetric	horizontal or vertical
Polarization Cross-Coupling:	<-40 dB	<-40 dB
Pulse Repetition Frequency:	2.32 or 2.57 Hz/m/s	2.32 or 2.57 Hz/m/s
Estimated Noise-Equivalent Backscatter Coefficient:	-40 dB	-30 dB
Chirp Length:	7 μs (high resolution mode), 8 μs (low resolution mode)	15 μs (high resolution mode), 30 μs (low resolution mode)
Chirp Coding:	Nonlinear FM (high resolution mode), Linear FM (low resolution mode)	Linear FM (high resolution mode), Linear FM (low resolution mode)

5.13.2C/X SAR Receiver

	C-band	X-band
STC Attenuator Range:	38 dB	38 dB
A/D Converter Dynamic Range:	30 dB	30 dB
Polarization:	Horizontal and vertical	horizontal and vertical
Noise Figure:	5.2 dB (high resolution mode), 3.7 dB (low resolution mode)	5.3 dB (high resolution mode), 5.2 dB (low resolution mode)
I, Q Bandwidth:	26.3 MHz (high resolution mode), 8.3 MHz (low resolution mode)	31.2 MHz (high resolution mode), 7.5 MHz (low resolution mode)
I,Q Sampling Frequency:	37.5 MHz (high resolution mode), 10.0 MHz (low resolution mode)	37.5 MHz (high resolution mode), 10.0 MHz (low resolution mode)

5.13.3 C/X SAR Antenna

	C-band	X-band
Azimuth Beam Width (-3dB):	3.03° (horizontal polarization), 3.30° (vertical polarization)	1.40° (horizontal polarization), 1.40° (vertical polarization)
Elevation Beam Width (-3dB):	28.0° (horizontal polarization), 25.0° (vertical polarization)	26.0° (horizontal polarization), 26.0° (vertical polarization)
Gain (one-way):	26.0 dB (horizontal polarization), 24.8 dB (vertical polarization)	28.0 dB (horizontal polarization), 28.5 dB (vertical polarization)
Cross-Polarization Coupling:	<-35 dB(horizontal polarization), <-35 dB (vertical polarization)	<-35 dB (horizontal polarization), <-35 dB (vertical polarization)

CONCLUSION

There are many improvements that we can make to our system in order to create better results. First of all, we need to increase the range of the detection, not having to limit our input signals as much to get accurate results. We need to adjust with the sampling rate that we use in order to be able to detect smaller velocities as well as more accurate ranges. We could optimize the algorithm for the peak locator in the velocity analysis to give more accurate results.

In the end, we managed to create a system that created signals to send out with radar, as well as simulate a returned signal for objects a specific distance away or moving at a certain velocity. We were able to detect the range for objects that were fairly close, and calculate the velocity for objects moving extremely fast.

By combining synthetic aperture radar and radar interferometry, many unique capabilities are presented through Interferometric SAR.

When configured with the two receiving antennas vertically separated, high-quality terrain elevation mapping is possible. When these receiving antennas are separated horizontally, precise surface motions may be mapped. When an InSAR product, an interferogram, is produced from complex SAR images collected on separate passes scene coherency can be measured.

Applications of this technology include ocean surface monitoring (surface current velocity mapping, wave spectra, and ocean-surface coherence-time measurement), topographic mapping, terrain-surface-displacement mapping, land classification, and ice-sheet-flow monitoring. Both airborne and space borne demonstrations of this technology are reported.

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