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AERONATICAL DEPARTMENT

DESIGN OF SYNTHETIC APERTURE RADAR SYSTEM

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR
THE REQUIREMENT OF B.S.C (honors) IN AERONATICAL**

by

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Abstract

The image obtained by conventional radar from target or territory involves information (range & azimuth) but this information could be unclear or disturbed due to clutter or atmospheric attenuation.

This problem can be solved by using synthetic aperture radar (SAR) according to its high resolution images.

Here we used SAR range-Doppler algorithm to be simulated in Matlab program.

After running simulation code in Matlab results have been found.

Acknowledgements

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We would like also to thank our teacher Abdullah Margany for encouraging us to continue and move forward, also we wouldn't forget to express our gratitude to Dr. Abduraheem Sa'ad , all our teachers and every one support and inspired us.

Dedication

We dedicate this work to our mothers, fathers, sisters, brothers, friends and special thank to our aunt Zainb kowa.

We vividly recall all those late evenings spent in researching and encourage with our other colleagues discussing ideas to overcome various software problems we faced during the course of this project.

We would like to thank all of them for such wonderful time.

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Table of Contents

1	Chapter one: Introduction	11
1.1	Introduction	11
1.2	Aims and objectives	11
1.2.1	Aims	11
1.2.2	Objectives	11
1.3	Problem statement	11
1.4	Motivation	12
1.5	Contribution	12
1.6	Proposed solution	12
1.7	Methodology	12
2	Chapter two: Background	13
2.1	Conventional Radar	13
2.1.1	A brief history of radar	13
2.1.2	Theory of operation.....	13
2.1.3	Block diagram of simple radar.....	14
2.2	Improved radar	15
2.2.1	Radar equation	18
2.3	Synthetic Aperture Radar	21
2.3.1	A SHORT HISTORY	21
2.3.2	Applications of SAR.....	22
1.	Targeting, Reconnaissance, and Surveillance	22
2.	On the Land	22
3.	Navigation, Guidance, and Moving Target Indication	22
2.3.3	SAR principle.....	23

2.3.4	Synthetic aperture radar equation	24
2.3.5	aperture mean.....	25
2.3.6	synthetic aperture mean	25
2.3.7	Moving Targets in SAR	26
2.4	Related Projects.....	27
2.4.1	Raw Signal Simulation	27
2.4.2	LANGUAGE & FPGA.....	28
2.4.3	DSP & FPGA.....	28
2.4.4	2D &3D SAR images.....	29
2.4.5	FM/CWTECHNOLOGY	30
3	Chapter three: Design of SAR and it's algorithm.....	31
3.1	The proposed configuration	31
3.1.1	1.The coherent oscillator.....	31
3.1.2	2.Antenna	31
3.1.3	3.SAR Signal Generation.....	32
3.1.4	4.Coherent Demodulation:.....	33
3.2	SAR processing	34
3.3	Digital SAR Processor	36
3.4	Range Doppler Algorithm.....	37
3.5	SAR algorithm.....	38
4	Chapter four: Results and Conclusions.....	40
4.1	Simulation Results:	40
4.2	Results:.....	Error! Bookmark not defined.
5	Chapter five: Conclusion and Recommendations.....	45

5.1 Conclusion.....	45
Recommendations.....	46

LIST OF FIGURES

FIGURE 2.1-1	
BLOCK DIAGRAM OF SIMPLE RADAR	14
FIGURE 2.2-1	
BLOCK DIAGRAM OF IMPROVED RADAR	15
FIGURE 2.3-1	
BASIC PRINCIPLE OF SYNTHETIC APERTURE RADAR.....	24
FIGURE 3.1-1	
BLOCK DIAGRAM OF SYNTHETIC APERTURE RADAR	31
FIGURE 3.1-2	
SIGNAL GENERATION	32
FIGURE 3.1-3	
COHERENT DEMODULATION	33
FIGURE 3.2-1	
BLOCK DIAGRAM OF SAR PROCESSING.....	35
FIGURE 3.3-1	
STEPS OF SAR PROCESSOR BLOCK DIAGRAM	36
FIGURE 3.4-1	
RANGE DOPPLER ALGORITHM BLOCK DIAGRAM.....	37
FIGURE 4.1-1	
ORIGINAL IMAGE	
IMAGE COURTESY OF MASSACHSETTS INSTITUTE OF TECHNOLOGY	40
FIGURE 4.1-2	
RAW DATA OF THE AERIAL IMAGE CHOSE.....	41
FIGURE 4.1-3	
DEBLURRING WITH OVERSIZED PSF.....	41
FIGURE 4.1-4	
DEBLURRING WITH UNDERSIZED PSF.....	42
FIGURE 4.1-5	
DEBLURRING WITH INITPSF	42
FIGURE 4.1-6	
BLURRED IMAGE	43

Table of Symbols

Symbol	Parameter Name
PT	Power transmitter
R	Distance between radar and target
GT	Gain of signal transmitted
σ	Radar cross _ section
Ae	Affective (aperture) area
P(den)	Power density
Pr	Power receiver
Λ	Wave length
Smin	Minimum detectable (receiver) signal
AT	Effective area of signal transmitted
Rmax	Maximum range
Er	Reflected field strength at radar
Ei	Strength of incident field at target
LSA	Synthetic aperture length
Θ_a	Aperture azimuth beamwidth
DAT	Along _Track antenna length
Δ_{at}	Earth target resolution element Along _ Track dimension
PRF	Pulse repletion frequency
Dur	Duration
Vp	Platform velocity
Fo	Carrier frequency
La	Antenna actual length
Xa	Minimum range distance
X0	Half target area width

الاية:

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Table of Abbreviations

A/D Convertor	Analogue To Digital Convertor
ATR	Automatic Target Recognition
CW	Continuous Wave
DSP	Digital Signal Processing
FPGA	Field Programmable Gate Array
FFT	Fast Fourier Transform
FM	Frequency Modulated
IFFT	Inverse Fast Fourier Transform
PSF	Point Speared Function
RADAR	Radio Detecting And Ranging
RDA	Range Doppler Algorithm
Rx	Receiver
SAR	Synthetic Aperture Radar
SLC	Signal look Complex
SL_SAR	Side Looking SAR
TR_SAR	Time Reversal SAR
Tx	Transmitter

Chapter one

Introduction

1.1 Introduction

Synthetic Aperture Radar (SAR) is an improved technology of image resolution, is a type of radar which is used for all-weather and all-time high resolution aerial and space based imaging of terrain. this project addresses Synthetic Aperture Radar Signal Processing with MATLAB Algorithms recent developments, providing its processing algorithms which offers dramatically improved image resolution over radar to accomplished the biggest challenges nowadays which is heresies understanding of the Earth environment.

1.2 Aims and objectives

1.2.1 Aims

Design system that can obtain clear image of terrain or a target with rejecting clutters and atmospheric attenuation with high accuracy.

1.2.2 Objectives

Design, Analysis, Modeling and Simulation of a Synthetic Aperture Radar image (SAR) System by using MATLAB program.

1.3 Problem statement

Acquire a clear image without atmospheric attenuation independent of time (day and night) and weather.

1.4 Motivation

Synthetic aperture radar has an extensive research area in the field of radar being used for imaging from air or from space; it has its applications in many important areas like defense, environmental monitoring and earth observations,

.

1.5 Contribution

Introducing image processing in the field of radar systems to make a dramatically clear image over conventional radar independent of time and weather.

1.6 Proposed solution

In this research carrying in mind the problem mentioned above an alternative way is proposed, which is synthetic aperture radar which is capable of carrying out aerial target detection during day or night, a SAR is proposed.

It mainly depends on image processing algorithms which is proposed and tested by MATLAB software.

1.7 Methodology

In this project analytic, theoretical, and soft ware (MATLAB) methods are applied.

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Chapter two

Background

2.1 Conventional Radar

2.1.1 A brief history of radar

The term RADAR is an acronym made up of the words:

Radio (Aim) Detecting and Ranging, The term “RADAR” was officially coined as an acronym by U.S. Navy Lieutenant Commander Samuel M. Tucker and F. R. Furth in November 1940. The acronym was by agreement adopted in 1943 by the Allied powers of World War II and thereafter received general international acceptance.

2.1.2 Theory of operation

It refers to electronic equipment that detects the presence of objects by using reflected electromagnetic energy. Under some conditions a radar system can measure the direction, height, distance, course and speed of these objects. The frequency of electromagnetic energy used for radar is unaffected by darkness and also penetrates fog and clouds. This permits radar systems to determine the position of airplanes, ships, or other obstacles that are invisible to the naked eye because of distance, darkness, or weather.

Conventional radar systems operate by measuring range to the target from the time it requires for the radar pulse to travel to and echo back from the target and direction to the target from how much of the signal was received compared *the direction of the antenna*.

Modern radar can extract widely more information from a target's echo signal than its range. But the calculating of the range by measuring the delay time is one of its most important to functions.

2.1.3 Block diagram of simple radar

The elemental radar system consists of a transmitter unit, an antenna for emitting electromagnetic radiation and receiving the echo signal, an energy detecting receiver and a processor. The most basic form of radar is shown in Fig. (2.1-1) a portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. The antenna collects the returned energy in the backscatter direction and delivers it to the receiver. The distance to the receiver is determined by measuring the time taken for the electromagnetic signal to travel to the target and back.

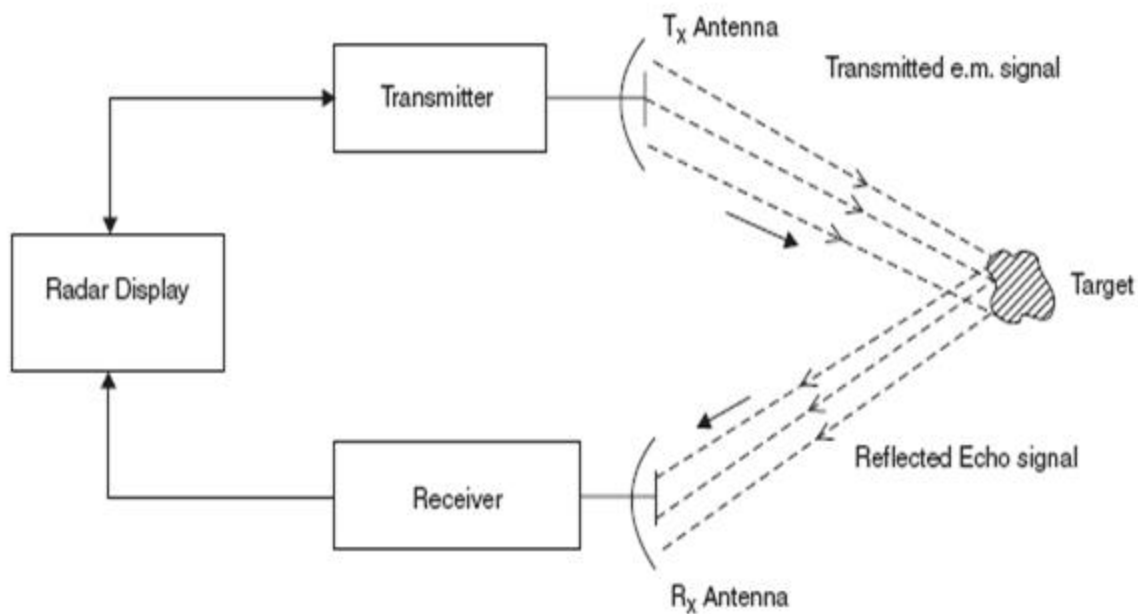


Figure 2.1-1
Block diagram of simple radar

2.2 Improved radar

Such radar where a single antenna is used for both transmitting and receiving is called monostatic radar which is usual form of radar.

A modified block diagram is shown in Fig. (2.2-1) which has another important block called the duplexer.

The duplexer is the device that allows a single antenna to serve both the transmitter and the receiver. On transmission it must protect the receiver from burnout or damage, and on reception it must channel the echo signal to the receiver, Duplexers, especially for high-power applications.

The functions of a duplexer are:

1. To isolate the transmitter and receiver during transmission and reception.
2. To protect the receiver from high power transmitter and
3. To help use a single transmitter/receiver antenna.

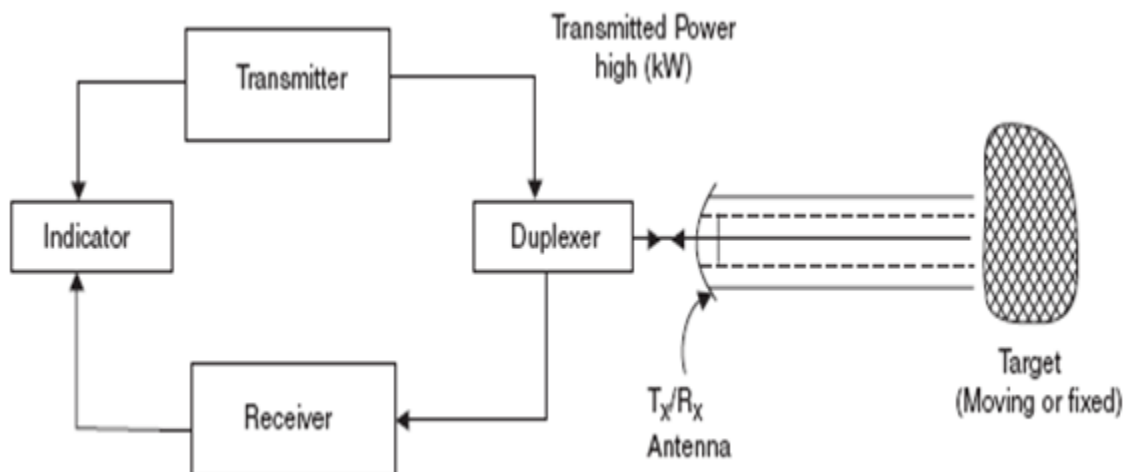


Figure 2.2-1
Block diagram of improved radar

2.3 RADAR ACCURACY

Radar accuracy is a measure of the ability of a radar system to determine the correct range, bearing, and, in some cases, height of an object. The degree of accuracy is primarily determined by the resolution of the radar system. Some additional factors affecting accuracy are pulse shape and atmospheric conditions.

2.4 TARGET RESOLUTION

The target resolution of radar is its ability to distinguish between targets that are very close together in either range or bearing. Weapons-control radar, which requires great precision, should be able to distinguish between targets that are only yards apart. Search radar is usually less precise and only distinguishes between targets that are hundreds of yards or even miles apart. Resolution is usually divided into two categories; RANGE RESOLUTION and BEARING RESOLUTION.

2.5 RANGE RESOLUTION

Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing but at different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator. Pulse width is the primary factor in range resolution. A well-designed radar system, with all other factors at

Maximum efficiency should be able to distinguish targets separated by one-half the pulse width time.

2.6 BEARING RESOLUTION

Bearing, or azimuth, resolution is the ability of a radar system to separate objects at the same range but at different bearings. The degree of bearing resolution depends on radar beam width

and the range of the **targets**. Range is a factor in bearing resolution because the radar beam spreads out as range increases.

2.7 AMBIGUOUS RETURNS

The radar timing system must be reset to zero each time a pulse is radiated. This is to ensure that the range detected is measured from time zero each time. The prt of the radar becomes important in maximum range determination because target return times that exceed the prt of the radar system appear at incorrect locations (ranges) on the radar screen. Returns that appear at these incorrect ranges are referred to as **AMBIGUOUS RETURNS** or **SECOND-SWEEP ECHOES**.

2.7.1 Radar equation

If the transmitter delivers PT watts power into an isotropic antenna (one which radiates power uniformly in all directions is used), then the power density (W/m^2) at a distance R from the radar is

$$P_t(\text{den}) = \frac{PT}{4\pi R^2} \quad \dots (2-1)$$

Here the $4\pi R^2$ represents the surface area of the sphere at distance R . Radars employ directional antennas to channel the radiated power PT in a particular direction. The gain GT of an antenna is the measure of the increased power radiated in the direction of the target, compared to the power that would have been radiated from an isotropic antenna. So power density from a directional antenna

$$P_t(\text{den}) = \frac{PTGT}{4\pi R^2} \quad \dots (2-2)$$

This energy is incident on the target and gets scattered in various directions. A part of the energy returns in the direction of the radar antennas. The target is usually described in terms of an equivalent cross-section σ such that if the total power contained in a section of the incident wave front having the area σ were radiated by an isotropic radiator located at the target the strength of the radio wave reaching the radar receiving antenna would be the same as the strength of the actual echo produced by target.

Area σ is then referred to as the effective echo area of the target.

Radar cross-section

The radar cross section of a target is the (fictional) area intercepting that amount of power which, when scattered equally in all directions, produces an echo at the radar equal to that from the target; or in other terms:

$$\sigma = \frac{\text{power reflected toward source/unit solid angle}}{\text{incident power density}/4\pi} = \lim_{R \rightarrow \infty} 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2 \quad \dots (2-$$

3)

Where:

R = distance between radar and target

E_r = reflected field strength at radar

E_i = strength of incident field at target

Hence the power density of the echo signal at the radar

$$Pr(\text{den}) = \frac{PTGT}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad \dots (2-4)$$

The receiving antenna effectively intercepts the power of the echo signal at the radar over a certain area called the effective area A_e .

Since the power density (watts/m²) is intercepted across an area A_e , the power delivered to the receiver is

$$Pr = \frac{PTGTA_e\sigma}{(4\pi R^2)^2} \quad \text{watts} \quad \dots (2-5)$$

Equation (3.4) is the free space radar equation.

Now the maximum range R_{max} is the distance beyond which the target cannot be detected due to insufficient received power Pr . The minimum power which the receiver can detect is called the minimum detectable signal S_{min} .

Setting $Pr = S_{\text{min}}$ and rearranging the above equation gives

$$S_{\text{min}} = \frac{PTGTA_e\sigma}{(4\pi)^2 R_{\text{max}}^4} \quad \dots (2-6)$$

Or

$$R_{\max} = \sqrt[4]{\frac{PTGT Ae \sigma}{(4\pi)^2 S_{\min}}} \quad \dots (2-7)$$

Now G_T depends on the type of antenna system used. For a circular parabolic, as used in microwave radar

$$GT = \frac{8}{3} \cdot \frac{\pi AT}{\lambda^2} \quad \dots (2-8)$$

For dipole radiator, the gain gets increased by 50%. Hence effective

$$GT = \frac{3}{2} \cdot \frac{8}{3} \cdot \frac{\pi AT}{\lambda^2} = \frac{4\pi AT}{\lambda^2} \quad \dots (2-9)$$

Hence the circular parabolic antenna with dipole radiator, Eq. (12.6) giving the free space radar range equation becomes,

$$R_{\max} = \sqrt[4]{\frac{PT Ae AT \sigma}{4\pi \lambda^2 S_{\min}}} \quad \dots (2-10)$$

Generally the same antenna is used for reception and transmission, so that

$$G_T = G_R = G$$

Where G is given by

$$G = \frac{4\pi A}{\lambda^2} \quad \dots (2-11)$$

Where

$$AT = Ae = A$$

The equation (2-10) may be written as,

$$R_{\max} = \sqrt[4]{\frac{PT \sigma A^2}{4\pi S_{\min} \lambda^2}} \quad \dots (2-12)$$

Or

$$R_{\max} = \sqrt[4]{\frac{PT G^2 \sigma \lambda^2}{(4\pi)^3 S_{\min}}} \quad \dots (2-13)$$

2.8 Synthetic Aperture Radar

SAR is a type of radar which is used for all-weather and all-time high resolution aerial and space based imaging of terrain. The term all-weather means that an image can be acquired in any weather conditions like clouds, fog or precipitation etc. and the term all _time means that an image can be acquired during day as well as night.

These systems are coherent radars which generate high resolution images. Synthetic aperture means that the image which is produced it is the result of consecutive and coherent signals, which are transmitted and received in a little antenna which is moving along the orbit or flight route. To process the signal it will be used the magnitude and the phase of the signal received.

2.8.1 A SHORT HISTORY

The history of SAR and radar in general is important when study methods of SAR imaging. Radar was initially developed in World War II for tracking of ships and aircrafts. The radio frequency used had the advantage of being able to penetrate through heavy weather and darkness to locate targets when remote sensing with visible light would have failed. The Doppler shift of the pulse as it reflects off of the target also carries information on the speed of the target. Dennis Gabor, the engineer at British Thomson-Houston who invented holography in 1947, laid the groundwork for SAR with the principles of wave front reconstruction. Carl Wiley of Goodyear Aerospace discovered that post processing of the Doppler shift information provided the ability to obtain finer resolution in the direction of the travel of the beam. Using the Doppler shift post processing technique and wave front reconstruction theory, in 1951 Wiley developed the process known as SAR imaging by which two-dimensional images of targets and the earth's surface could be constructed using radar. It was not until the 1970s that military SAR technology was released to Matthew Schultz, the civilian community and radar imaging came into wide use to complement visual sensors. Radar imaging solutions allowed for increased capabilities when the optical Sensors were rendered useless due to poor sun exposure or weather conditions. Though early work with SAR imaging was done with aircraft, it was not until 1978 that the launch of the NASA's first earth orbiting satellite for remote sensing of the oceans, SEASAT that the use of radar for remote sensing became widespread practice. SEASAT used the L-Band frequency of 1.175 GHz at an altitude of 800 km, an angle of incidence of 23 degrees, and with a swath width of 100 km. It was able to obtain images with a resolution of 25m in the range and azimuth

directions where the azimuth is the direction parallel to the movement of the platform and the range is normal to the azimuth or perpendicular to the movement of the platform.

2.8.2 Applications of SAR

This section discusses a few of the applications for synthetic aperture radar. The applications increase rapidly as new technologies and innovative ideas are developed. While SAR is often used because of its all-weather, day-or-night imaging capability, it also finds application because it renders a different view of a "target," with synthetic aperture radar being at a much lower electromagnetic frequency than optical sensors. SAR has been shown to be very useful over a wide range of applications including:

1. Targeting, Reconnaissance, and Surveillance

Many applications for SAR are for targeting, reconnaissance, and surveillance. 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.

2. On the Land

The ability of SAR to penetrate cloud cover makes it particularly valuable in frequently cloudy areas such as the tropics. Image data serve to map and monitor the use of the land, and are of gaining importance for forestry and agriculture.

3. Navigation, Guidance, and Moving Target Indication

SAR provides the capability for all-weather, autonomous navigation and guidance. By forming SAR reflectivity images of the terrain and then by correlation of the SAR image with a stored reference (obtained from optical device 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. 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. New techniques have been developed 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. The potential of SAR in a diverse range of application led to the development of a number of airborne and space borne SAR systems.

2.8.3 SAR principle

SAR is radar system which synthesizes a large antenna to obtain a high azimuth resolution, it measures the range in the same way as the conventional pulsed radar does and measures azimuth perpendicular to the range. As the microwave frequency of the transmitted signals is low compared to optical systems, antenna length of several hundreds of meters would be needed to obtain the same resolution.

The principle can be described from several points of view:

- The radar specialist would describe it as Doppler processing.

The Doppler frequency is used to discriminate targets and to position them in azimuth.

- The antenna specialist would establish a link with a linear radiating array; Synthetic Aperture takes its name from this process because it is based on array antenna synthesis.
- The physics expert would note that in this kind of processing the receiver is matched to the signal received. The output from processing is the autocorrelation function of the input signal.

2.8.4 Synthetic aperture radar equation

$$\delta_{AT} = \frac{\lambda}{2L_{SA}} R = \frac{\lambda R}{\frac{2\lambda R}{D_{AT}}} = \frac{D_{AT}}{2} \quad \dots (2-1)$$

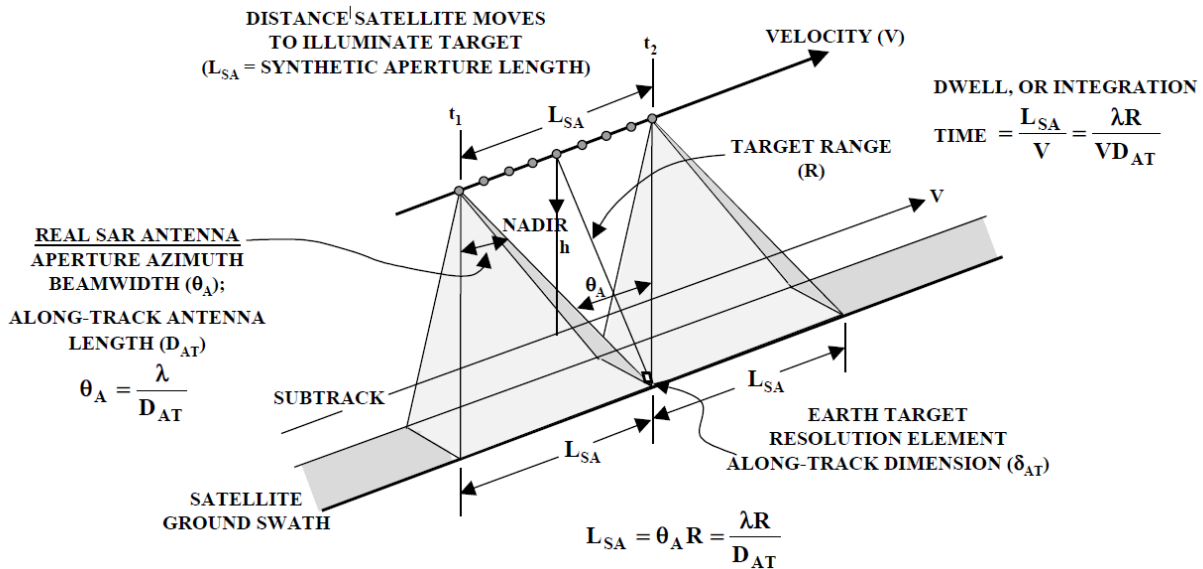


Figure 2.8-1
Basic principle of Synthetic Aperture Radar

A SAR system, as used in remote sensing, has two features which distinguish it from other radar systems:

- It makes a 2-dimensional image by having the radar platform move in a straight line during the data collection. The second dimension is given by measuring the time delay of the received radar pulse.
- It obtains high resolution in the motion direction by focusing or compressing the Doppler energy arising from the platform motion.

2.8.5 Aperture mean

Many people associate the word aperture with photography, where the term represents the diameter of the lens' opening.

The camera's aperture then determines the area through which light is collected. Similarly, a radar antenna's length partially specifies the area through which it collects radar signals. The antenna's length is therefore also called its aperture.

2.8.6 synthetic aperture mean

In general the larger the antenna, the more unique information you can obtain about a particular viewed object. With more information, you can create a better image of that object (improved resolution). It's prohibitively expensive to place very large radar antennas in space, however, so researchers found another way to obtain fine resolution: they use the spacecraft's motion and advanced signal processing techniques to simulate a larger antenna.

A SAR antenna transmits radar pulses very rapidly. In fact, the SAR is generally able to transmit several hundred pulses while its parent spacecraft passes over a particular object. Many backscattered radar responses are therefore obtained for that object. After intensive signal processing, all of those responses can be manipulated such that the resulting image looks like the data were obtained from a big, stationary antenna. The synthetic aperture in this case, therefore, is the distance travelled by the spacecraft while the radar antenna collected information about the object.

A SAR system operated from an aircraft illustrates the 2-dimensional nature of the SAR imaging mechanism.

One dimension is the aircraft flight direction, which is called **azimuth**. The other dimension is given by the radar beam, which is approximately perpendicular to the flight direction. This second dimension is called **range**, as it is proportional to the range R from the sensor to the reflectors on the ground.

2.8.7 Moving Targets in SAR

Ideally, the SAR processor focuses the targets using the phase history. SAR processors usually assume that the scattering points within the SAR scene are stationary during the time of data collection. Each point within the scene is then characterized by a unique phase history, and the SAR processor exploits this uniqueness to place the point within the scene. Depending on the particulars of the motion (direction, speed), the uncompensated phase may result in a wide range of phenomena, from a simple shift in position of the target (constant direction and speed during the measurement) to a smearing making the target impossible to see (changing of direction or speed during the measurement). This phenomenon could be seen in radar maps of maritime scenes, that the ships are depicted beside its own bow wave. Moving targets in SAR images can be analyzed and focused using time-frequency techniques. This makes it possible to differentiate moving targets from stationary background (Clutter) and to relocate the moving targets shift in position.

2.9 Related Projects

2.9.1 Raw Signal Simulation

This project studied a tool for SAR system design, mission planning, processing algorithm testing, and inversion algorithm design. It explores a SAR raw signal simulation. The raw signal simulation is the simulated received signal before any processing with exception of the down-converter. The simulation plays a significant role in studies concerning noise and clutter rejection and contributes toward optimizing SAR system parameters.

To simulate SAR raw data, a Chirp Scaling (CS) method is used. This method first stretches the input surface reflectivity of the target in the azimuth and range direction respectively. Then it derives the raw data by inverse equalizing the signal based on CS principle.

This method avoids the time-domain integral operation and improves the computational efficiency.

He has gotten from simulation results that the chirp scaling (CS) principle method can get precise result compare to time domain simulation. His results showed the phase error could not be more than 60 degree in range direction and 40 degree in azimuth direction. This method avoids the time domain integral and because it processes in frequency domain, it has great computational efficiency. To verify the efficiency, simulation of extended scenes has run with the surface reflectivity and system parameters. The simulation took about 2.14 seconds to simulate 600x932 pixel raw data on Intel® Core™2 Dual CPU with 2.2GHz frequency.

In addition, this method can generate simulated raw data based on any target reflectivity matrixes without using inverse SAR image algorithm. Its accomplished at (Shoalehvar, June 2012) from (Faculty of the California Polytechnic State University San Luis Obispo, California)

2.9.2 SAR Sensor

This project discussed the study of SAR sensor on board small satellite, in its the use of short wave length which offers the possibility of small SAR with high quality of image has found that it can be achieved through implemented of transmitter with high duty cycle. By Prilando Rizki Akbar, Josaphat Tetuko Sri Sumantyo & Hirobami Saito from (THE INSTITUTE OF

ELECTRONICS INFORMATION AND COMMUNICATION ENGINEERS) in (2012-10) their project about (DESIGN OF SYNTHETIC APERATURE RADAR ONBOARD SMALL SATELLITE)

2.9.3 LANGUAGE & FPGA

This thesis specifically deals with such image generation algorithm being implemented by Alaska SAR Facility through software in C language . This work offers an FPGA (field programmable gate array) based prototype solution using FLASH language and Block Diagram Editor. Both these tools are developed as a part of the ACS project at the University of Kansas, sponsored by DARPA. His thesis also demonstrates the ease and flexibility of design using FLASH and BDE. His result showed that this current implementation is a good prototype design demonstrating the feasibility of an FPGA based SAR signal processor. By Hemang Parekh from (Maharaja Sayajirao University of Baroda, Vadodara, India) in (1998) his project about (Design, Implementation and Performance Evaluation of Synthetic Aperture Radar Signal Processing on FPGA),

2.9.4 DSP & FPGA

This project aimed at the System-Level Design, Modeling and Simulation of a Synthetic Aperture Radar System and the Implementation of the signal processor for SAR using a TI C6416 DSP, they had resulted that In many complex systems, the initial choice of a processing engine and its associated design methodology can have a profound impact on the system reliability. This choice will also have a large affect on the effort required to maintain the system throughout its life cycle. One fundamental architecture issue is the type of DSP platform. Digital signal processing functions are commonly implemented on two types of programmable platform: digital signal processors (DSP) and (FPGA). In generally come to be expected that all software (DSP code is considered a type of software) will contain some bugs and that the best one can do is to minimize them.

By Misbah Ahmad Mussawar, Farrukh Rashid, Furqan Ahmed and Usman Tahir Mir from (Department of Telecommunication Engineering National University of Computer and Emerging Sciences) about (Analysis and Design of a Synthetic Aperture Radar System) in (2007-2008)

2.9.5 2D & 3D SAR images

This thesis further develops a method from ongoing thesis projects with the goal of generating images using (SAR) simulations coded in MATLAB.

Through the simultaneous processing of the radar reflections over the movement of the antenna via the range Doppler algorithm (RDA), the superior resolution of a theoretical wider antenna, termed synthetic aperture, is obtained. The long term goal of this ongoing project is to develop a simulation in which realistic SAR images can be generated and used for SAR Automatic Target Recognition (ATR). Current and past Master's theses on ATR were restricted to a small data set of Man-portable Surveillance and Target Acquisition Radar (MSTAR) images as most SAR images for military ATR are not released for public use. Also, with an in-house SAR image generation scheme the parameters of noise, target orientation, the elevation angle or look angle to the antenna from the target and other parameters can be directly controlled and modified to best serve ATR purposes or other applications such as three-dimensional SAR holography. By Matthew Schultz from (the Faculty of the California Polytechnic State University, San Luis Obispo) project about (Synthetic Aperture Radar Imaging Simulated in MATLAB) in (2009-June) By Matthew Schultz from (the Faculty of the California Polytechnic State University, San Luis Obispo) project about (Synthetic Aperture Radar Imaging Simulated in MATLAB) in (2009-June) IMAGING IN MULTIPATH

This project discussed that Conventional spotlight (SAR) assumes a single reflection of transmitted waveforms from targets. Multiple reflections of targets due to surrounding scatterers appear as ghosting artifacts in conventional

SAR images, which obscures true target image and leads to poor resolution. They developed image formation techniques using time reversal, Time Reversal SAR (TR-SAR), to remove ghosting artifacts and achieve high resolution.

The TR-SAR algorithm is tested using phase history data collected by a rail-mounted SAR sensor operated by Raytheon. They described and demonstrated time reversal algorithms for spotlight SAR under stretch processing in a rich

Scattering multipath environment. The rail-SAR data collected at the Raytheon test site show the benefits of TR-SAR that include improved resolution and reduced side lobes and ghost artifacts.

By Yuanwei Jin, Jose M.F. Moura, and Nicholas O'Donoghue from (Carnegie Mellon University Pittsburgh, PA 15213) in (2008) their thesis under the title of (Time Reversal Synthetic Aperture Radar Imaging in Multipath),

2.9.6 FM/CW TECHNOLOGY

His work demonstrated a (SAR) capable of generating high quality images using frequency modulated, continuous wave (FM/CW) technology and its advantages over conventional SAR systems. His mathematical analysis examined the range and azimuth compression of a single target and showed that FM/CW based SAR produces compressed images. A 10 GHz prototype is developed using innovative coplanar techniques and a simple FM/CW signal generator.

The performance of the system matches the expected performance based upon the analysis. The experimental and mathematical models support the conclusion that FM/CW based SAR is capable of creating well-compressed imagery in both range and azimuth.

By Ryan L. Smith from (the faculty of Brigham Young University) in (December 2002) under the title of (MICRO SYNTHETIC APERTURE RADAR USING FM/CW TECHNOLOGY).

Chapter three

Design of SAR and it's algorithm

3.1 The proposed configuration

The proposed system block diagram is shown below, which is composed of:

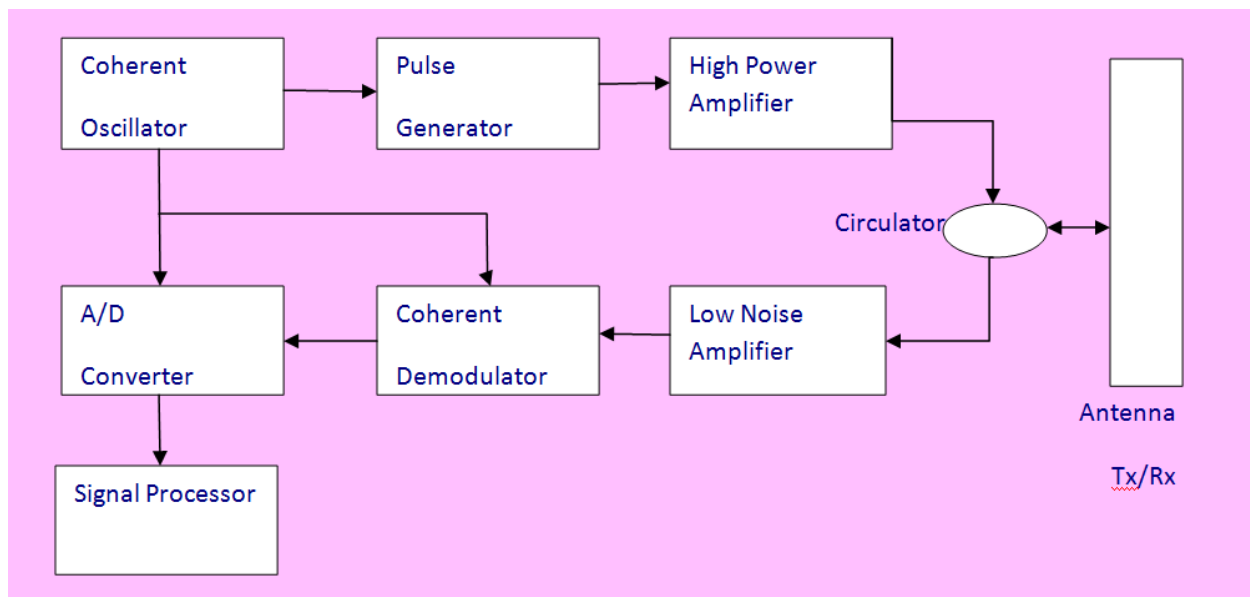


Figure 3.1-1
Block diagram of Synthetic Aperture Radar

3.1.1 1.The coherent oscillator

(Coho) is a very stable clock which provides timing for the signal generation, transmission time, sampling window, demodulation and A/D converter

3.1.2 2.Antenna

An antenna couples electromagnetic waves (signals) propagating in free space to and from a transmission line.

Frequency dependent, Directional, Polarization dependent.

For SAR applications the axis that defines the wave's electric field orientation with respect to the antenna defines the wave polarization. The general case is elliptical polarized waves.

An antenna focuses the radiated waves into a beam in three dimensions.

- For efficiency the radiating aperture > 1 wavelength.
- Large radiating areas (apertures) can make tight beams
- The gain of an antenna is determined by:
 - Electrical losses
 - beam area (solid angle)

3.1.3 3.SAR Signal Generation

Chirp: Bandwidth = 20 MHz

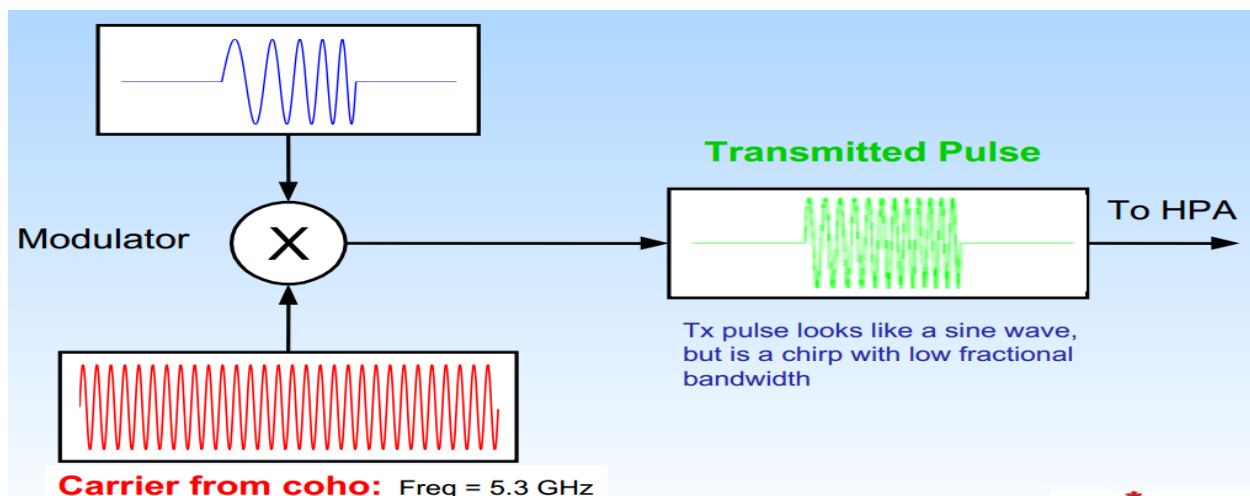


Figure 3.1-2
Signal generation

The first step in the SAR signal generation process is to generate a chirp signal with the desired bandwidth, the time of the beginning of the chirp is precisely controlled by a counter running off the coherent oscillator (coho).

The beginning of the pulses are separated by the pulse repetition interval.

The pulse is then multiplied by the radar carrier frequency so that the resulting signal has the desired centre frequency, The signal out of the multiplier is filtered so only the signal around the carrier frequency is kept. The signal remaining is then the pulse which is sent to the high power amplifier and transmitted.

3.1.4 4.Coherent Demodulation:

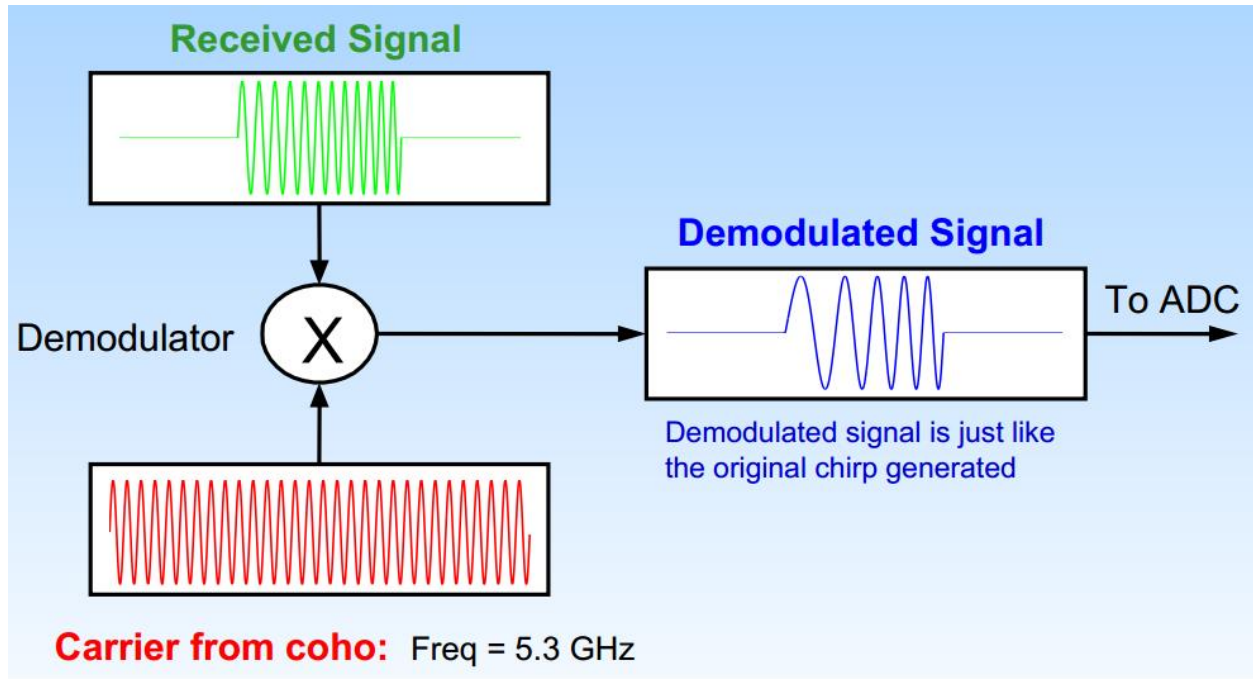


Figure 3.1-3
Coherent demodulation

The coherent demodulator is essentially the reverse of the up-converter in the signal generator. If the received signal is the same as the transmitted signal the demodulated signal is the baseband chirp originally generated.

3.2 SAR processing

Range Processing: The received signal from each pulse is correlated with the linear FM pulse replica. This procedure is repeated for each pulse for which the target was effectively in view of the radar.

The signal after range compression is in fact the Doppler signal received from the point target as the radar moves by. This is called Doppler compression or azimuth compression.

The waveform is a function of various factors like orbit location, velocity of the spacecraft and most importantly it is dependent on the range of the target. Therefore, for point target at different range, we have different waveforms. So though the basic compression is of the correlate type

This correlate can be implemented as a matched filter, if the Parameters Doppler frequency, F_d and rate of change of Doppler frequency, F_r are independent of radar location over a period till the point target is visible to the radar.

However, in practical cases, these change leading to range migration effect, and so a correction of range migration becomes essential in case of a SAR where the spacecraft is also moving along the observation section of its path, this delay error is inevitable. This problem is called Range Migration. In order to generate Doppler shift, the range shift has to be larger than the wavelength λ and in order to remain in the same range bin, range change has to be smaller than range resolution

Azimuth Compression: After Range Migration correction, the image is now straightened out. Now the echo from a point target is scattered along the pixels along the single range bin. Thus, it seems that, an identical matched filtering as carried out in Range Compression would suffice the need. Since matched filtering in time domain is just a multiplication with a complex conjugate, the azimuth reference function generated in the time domain needs to be Fourier transformed.

This azimuth reference function in the frequency domain is then weighed using an azimuth weighing function to suppress sidelobes and normalize the look energies for a multilook image. Now the azimuth scaling of the range migration corrected data is performed with the conjugate

of the FFT of the azimuth reference function. The inverse Fourier transform will bring back the image to time domain.

Thus, all the above analysis shows that FFT forms a core of the algorithm, and an excellent implementation of FFT is essential to the performance of SAR processor.

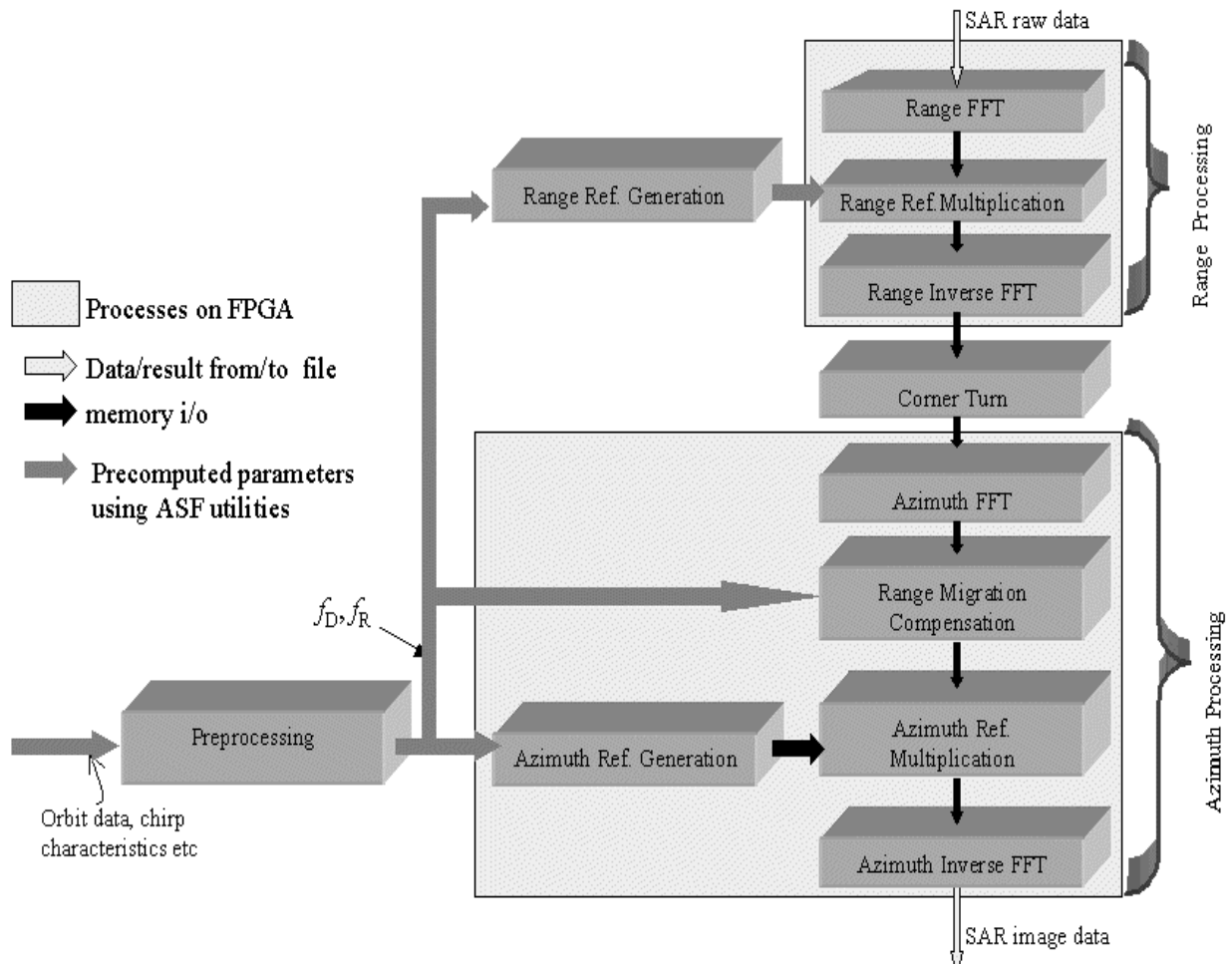


Figure 3.2-1
Block diagram of SAR processing

3.3 Digital SAR Processor

The complete procedure to get the SLC in figure (3.3-1); it contains all the steps which must be done in the MATLAB code to obtain the expected image

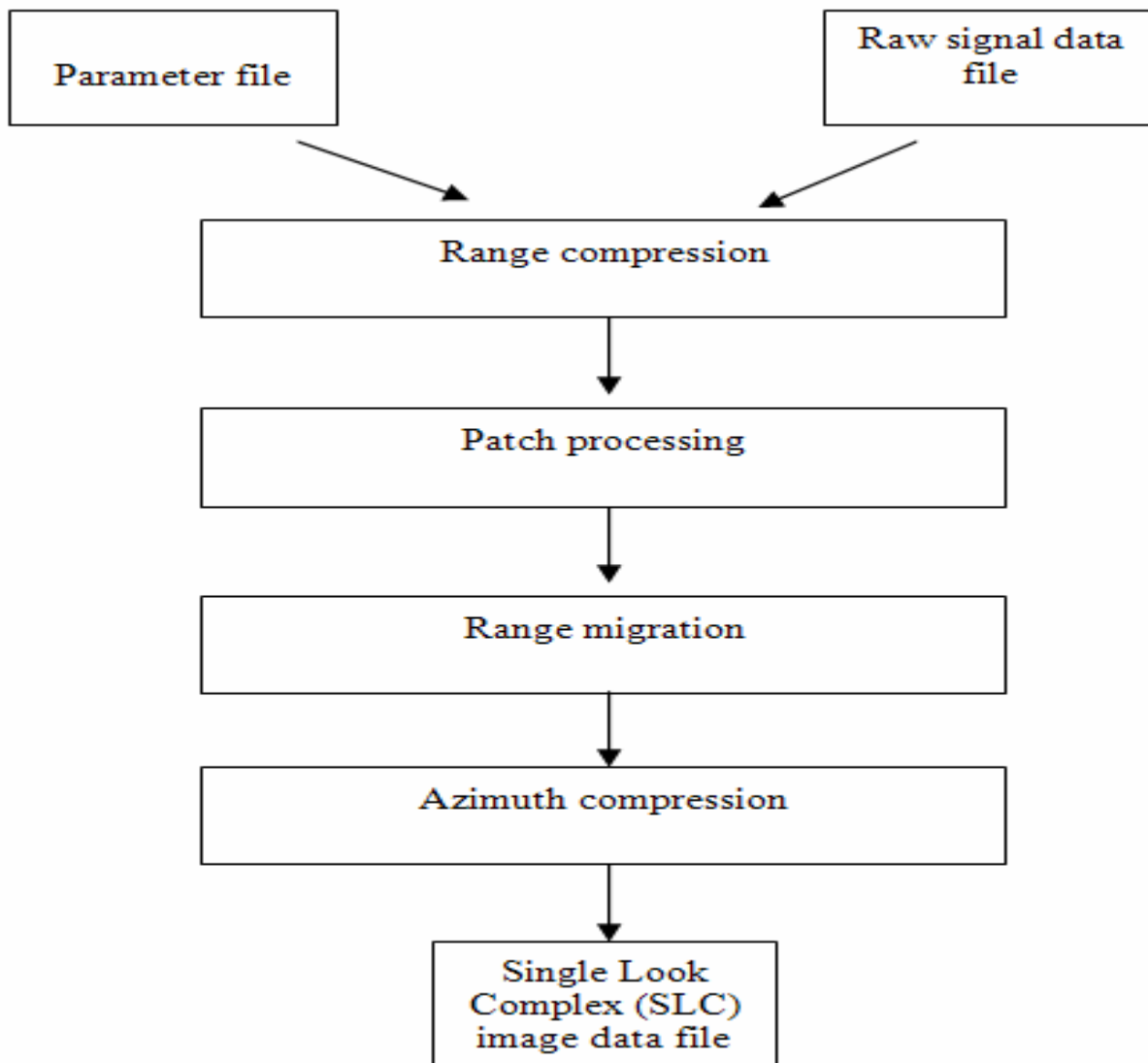


Figure 3.3-1
Steps of SAR processor block diagram

3.4 Range Doppler Algorithm

A block diagram of the RDA is shown in figure below. The raw signal space SAR

input is the two-dimensional signal. The two-dimensional signal is first analyzed as a series range time signals for each azimuth bin. Each range time signal undergoes matched filtering in the range frequency/azimuth time domain through range FFTs applied to the range time signals. After each signal is transformed back into the range time/azimuth time domain, the result is the range compressed signal as the matched filtering was performed in the range frequency domain. In order to obtain azimuth compression, azimuth matched filtering must be performed. The range compressed signal is then composed into a series of signals with respect to azimuth time at different range bins. Each azimuth signal is Fourier transformed via an azimuth FFT and RCMC is performed before azimuth matched filtering in the range-Doppler domain. After azimuth matched filtering of each signal and azimuth inverse fast Fourier transforms (IFFTs), the final target image is obtained. More in depth analysis of these processes and example RDA steps on a single point target in two-dimensional geometry SAR follows.

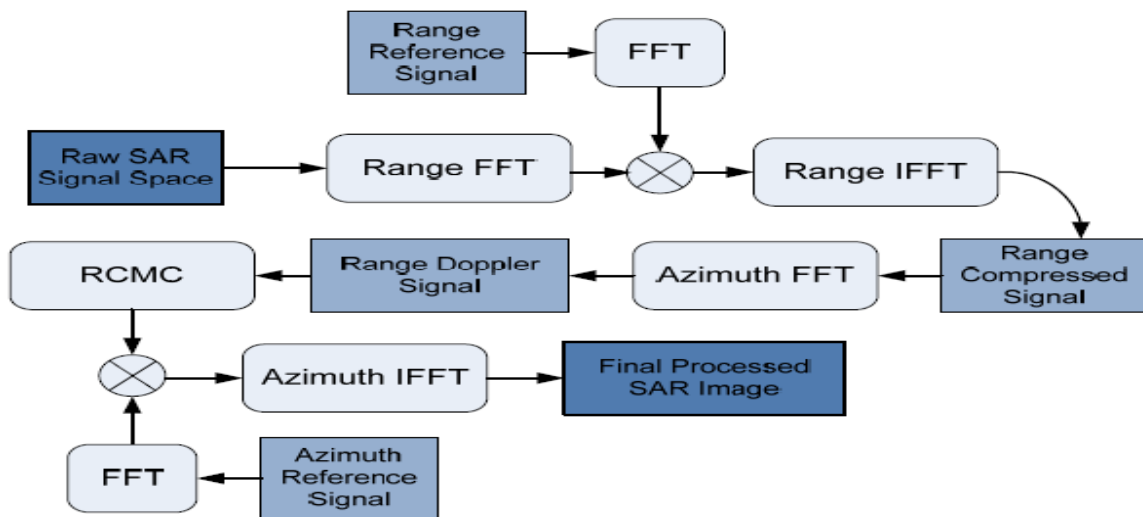


Figure 3.4-1
Range Doppler Algorithm block diagram

3.5 SAR algorithm

The proposed algorithm steps for the SAR is as below

Initialization

Step 1: Main SAR parameters

Pulse repetition frequency (PRF) = 300

Velocity of platform = 200

Carrier frequency = 4.5GHz

Antenna length = 2

Range distance to center of target area = 20000

Half target area width = 200

Chirp pulse duration = $0.25e^{-5}$

Baseband bandwidth = $100e^6$

Step 2: Noise

Setting a flag, to add noise to signal so noise = 0

Standard deviation of noise = 0.2.

Step 3: General variables

Propagation speed equal $3e^8$

Propagation frequency equal $1/c$

Wavelength equal c/f_0

Step 4: Range parameters

Range chirp rate = B_0 / T_p

Time domain sampling interval = $(1/(2*B_0))$

Start time of sampling = $(2*(X_c - X_0))/c$

End time of sampling = $(2*(X_c - X_0))/c + T_p$

Step 5: Azimuth parameters

Linear azimuth FM rate = $(2*v_p^2)/(\lambda*(X_c))$

Step 6: Measurement parameters

Number of time (range) samples = $2*\text{ceil}((0.5*(T_f - T_s))/dt)$,

Time array for data acquisition = $T_s + (0:r_{\text{bins}}-1)*dt$

Echoes signal array = $\text{zeros}(PRF*dur, r_{\text{bins}})$.

The code of SAR for image processing is written and shown in appendix A

Chapter four

Results and Discussion

4.1 Simulation Results

The code in appendix A is run in MATLAB and the results as:

An aerial image figure (4.1-1) is acquired from NASA program system which is shot at

Velocity of platform = 200 m/sec

Duration = 3 sec

Pulse Repetition Frequency = 300HZ.

(Which are the same parameters as proposed)



Figure 4.1-1
ORIGINAL IMAGE
image courtesy of Massachusetts Institute of Technology

The code in appendix A is applied to distort the image in figure (4.1-1) and acquired back the basic image.

Images are the steps of processing the raw data.

The raw data of the aerial image chose shown in figure(4.1-2)

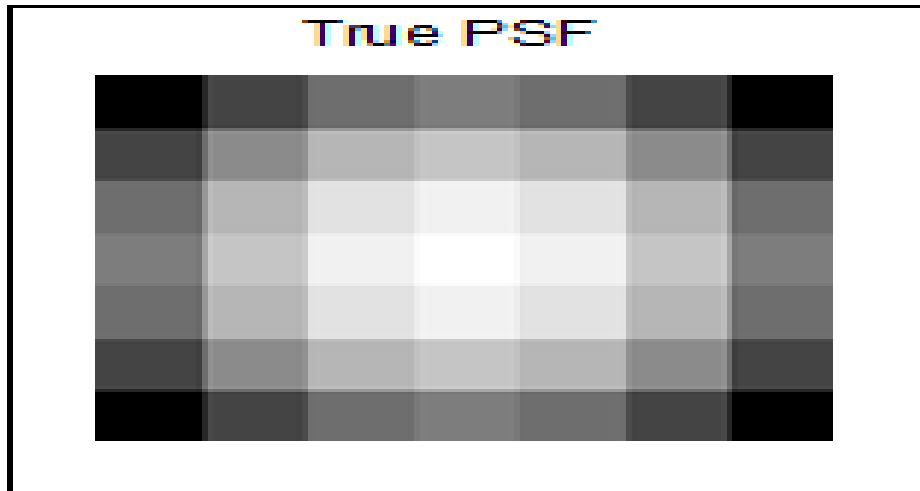


Figure 4.1-2
Raw Data of the aerial image chose



Figure 4.1-3
Deblurring with Oversized PSF



Figure 4.1-4
Deblurring with Undersized PSF



Figure 4.1-5
Deblurring with INITPSF



Figure 4.1-6
Blurred image

Finally the basic image figure (4.1-1) is acquired and using subprogram is used to recognize the basic image.

4.2 Discussion

The radar code is used using MATLAB and the results are found as the figures shown in simulation results.

.

Chapter five

Conclusion and Recommendations

5.1 Conclusion

The proposed SAR which is used for aerial detection is widely used and proved excellent results independent of weather attenuation and day-and-night target sensing problems and other infrared sensors.

Image processing is the core of SAR detection.

Algorithms proposed could be an initial step for complete image processing in the future.

Other applications of SAR are used nowadays such as side-looking Radars (SL-SAR).

5.2 Recommendations

We recommend a continuation in research on the project development, upgrade to process all types of image format and research in the area of hardware implementation for the proposed design of synthetic aperture radar.

APPENDICIES

Appendix A

```
I = imread('C:\Users\Public\Pictures\Sample
Pictures\images.jpg');
figure;imshow(I);title('Original Image');
text(size(I,2),size(I,1)+15, ...
'Image courtesy of Massachusetts Institute of
Technology', ...
'FontSize',7,'HorizontalAlignment','right');
PSF = fspecial('gaussian',7,10);
Blurred = imfilter(I,PSF,'symmetric','conv');
figure;imshow(Blurred);title('Blurred Image');
UNDERPSF = ones(size(PSF)-4);
[J1, P1] = deconvblind(Blurred,UNDERPSF);
figure;imshow(J1);title('Deblurring with Undersized
PSF');
OVERPSF = padarray(UNDERPSF,[4 4],'replicate','both');
[J2, P2] = deconvblind(Blurred,OVERPSF);
figure;imshow(J2);title('Deblurring with Oversized
PSF');
INITPSF = padarray(UNDERPSF,[2 2],'replicate','both');
[J3, P3] = deconvblind(Blurred,INITPSF);
figure;imshow(J3);title('Deblurring with INITPSF');
figure;
subplot(221);imshow(PSF,[],'InitialMagnification','fit'
);
title('True PSF');
subplot(222);imshow(P1,[],'InitialMagnification','fit')
;
title('Reconstructed Undersized PSF');
subplot(223);imshow(P2,[],'InitialMagnification','fit')
;
title('Reconstructed Oversized PSF');
subplot(224);imshow(P3,[],'InitialMagnification','fit')
;
```

```

title('Reconstructed true PSF');
WEIGHT = edge(I, 'sobel', .3);
se = strel('disk', 2);
[J, P] = deconvblind(Blurred, INITPSF, 30, [], WEIGHT);
P1 = 2;
P2 = 2;
FUN = @(PSF) padarray(PSF(P1+1:end-P1, P2+1:end-P2), [P1
P2]);
figure; imshow(J); title('Deblurred Image');
[JF, PF] =
deconvblind(Blurred, OVERPSF, 30, [], WEIGHT, FUN);
figure; imshow(JF); title('Deblurred Image');

```

Appendix B

SAR simulation

```

function Simulation2D()
clear
% INITIALIZATION
% Main SAR Parameters
PRF=300; % Pulse Repetition Frequency (Hz)
dur=3; % Time of Flight (sec), PRF*dur = received echoes
vp=200; % Velocity of platform
fo=4.5e9; % Carrier frequency (4.5GHz)
La=2; % Antenna length actual
Xc=20000; % Range distance to center of target area
X0=200; % Half Target Area Width (Target is located within [Xc-
X0, Xc+X0])
Tp=.25e-5; % Chirp Pulse Duration
B0=100e6; % Baseband bandwidth is plus/minus B0\
target_name='pole1'; %Name of Target Profile Image (GIF Grayscale
Image)
%Noise
noise=0; % Set this flag to add noise to signal
std_dev=.2; % Standard Deviation of Noise
% General Variables
cj=sqrt(-1);
c=3e8; % Propagation speed
ic=1/c; % Propagation frequency
lambda=c/fo; % Wavelength (60cm for fo = 4.5e9)
eta=linspace(0, dur, PRF*dur)'; % Slow Time Array
% Range Parameters
Kr=B0/Tp; % Range Chirp Rate
dt=1/(2*B0); % Time Domain Sampling Interval
Ts=(2*(Xc-X0))/c; % Start time of sampling

```

```

Tf=(2*(Xc+X0))/c+Tp; % End time of sampling
% Azimuth Parameters
Ka=(2*vp^2)./(lambda*(Xc)); % Linear Azimuth FM rate
% Measurement Parameters
rbins=2*ceil((.5*(Tf-Ts))/dt); % Number of time (Range) samples
t=Ts+(0:rbins-1)*dt; % Time array for data acquisition
s=zeros(PRF*dur,rbins); % Echoed signal array
% Target Initialization
target=imread(target_name,'gif'); %Select Input Target Profile
[M N]=size(target); ntarget=M*N;
tnum=1; xn=zeros(ntarget,1); yn=xn; Fn=xn; % Target Intialization
Variables
for m=1:M
for n=1:N
xn(tnum)=(n-N/2);
yn(tnum)=(M/2-m+1);
Fn(tnum)=double(target(m,n))/255;
tnum=tnum+1;
end
end
stretch=3;
xn=xn*stretch; yn=yn*stretch; %Stretch out Target Profile
% GENERATE ECHOES
for j=1:(PRF*dur);
for i=1:ntarget;
wa=sinc(La*(atan(vp*(eta(j)-dur/2+yn(i)/vp)/Xc))/lambda).^2;
R=sqrt((Xc+xn(i))^2+vp^2*((eta(j)-dur/2+yn(i)/vp)^2));
td=t-2*R/c;
if noise==1
s(j,:)=s(j,:)+std_dev*randn(size(s(j,:)))...
+Fn(i)*wa*exp(-cj*(4*pi*fo*ic*R)+cj*pi*Kr*...
(td.^2-td*Tp)).*(td >= 0 & td <= Tp);
else
s(j,:)=s(j,:)+Fn(i)*wa*exp(-cj*(4*pi*fo*ic*R)+cj*pi*Kr*...
(td.^2-td*Tp)).*(td >= 0 & td <= Tp);
end
% if noise==1
% s(j,:)=s(j,:)+std_dev*randn(size(s(j,:)))...
% +Fn(i)*wa*exp(-cj*(4*pi*fo*ic*R)+cj*pi*Kr*...
% (td.^2-td*Tp)).*(0.5*(1-
cos((2*pi()*td*rbins/Tp)/(rbins-1))).*(td >= 0 & td <= Tp);
% else
% s(j,:)=s(j,:)+Fn(i)*wa*exp(-
cj*(4*pi*fo*ic*R)+cj*pi*Kr*...
% (td.^2-td*Tp)).*(0.5*(1-
cos((2*pi()*td*rbins/Tp)/(rbins-1))).*(td >= 0 & td <= Tp);
% end
end
if mod(j,50)==0
display(j/9) % Echo Gen. Percent Complete
end
end
% RANGE DOPLER ALGORITHM (RDA)
% Range Reference Signal
td0=t-2*(Xc/c);

```

```

pha20=pi*Kr*((td0.^2)-td0*Tp);
s0=exp(cj*pha20).*(td0 >= 0 & td0 <= Tp);
% s0=exp(cj*pha20).*(0.5*(1-cos((2*pi()*td*rbins/Tp)/(rbins-1)))).*(td0
>= 0 & td0 <= Tp);
fs0=fty(s0); % Reference Signal in frequency domain
% Power equalization
amp_max=1/sqrt(2); % Maximum amplitude for equalization
afsb0=abs(fs0);
P_max=max(afsb0);
I=find(afsb0 >= amp_max*P_max);
fs0(I)=(amp_max*(P_max^2)*ones(1,length(I))./afsb0(I))...
.*exp(cj*angle(fs0(I)));
deltaR=(2*lambda^2*(Xc).*(Ka*(dur*0.5-eta)).^2)/(8*vp^2); % RCM
cells=round(deltaR/.56); % .56 meters/cell in range direction
rcm_max=9; %maximum range cell migration
fs=zeros(PRF*dur,rbins); fsm=fs; fsmb=fs; smb=fs; fsac=fs; sac=fs;
% Range Compression
for k=1:(PRF*dur);
fs(k,:)=fty(s(k,:)); % Range FFT
fsm(k,:)=fs(k,:).*conj(fs0); % Range Matched Filtering
smb(k,:)=ifty(fsm(k,:)); % Range IFFT
end;
% Azimuth Reference Signal
smb0=exp(cj*pi*Ka.*eta.*(2*eta*(PRF*dur/2+1)-eta));
fsmb0=ftx(smb0); % Azimuth Matched Filter Spectrum
for l=1:rbins;
fsmb(:,l)=ftx(smb(:,l)); % Azimuth FFT
end;
% Range Cell Migration Correction (RCMC)
fsmb2=fsmb;
for k=1:dur*PRF;
for m=1:rbins-rcm_max
fsmb2(k,m)=fsmb(k,m+cells(k));
end
end;
for l=1:rbins;
fsac(:,l)=iftx(fsmb2(:,l)); % Azimuth IFFT
end;
% Azimuth Compression
for l=1:rbins;
fsac(:,l)=fsmb2(:,l).*conj(fsmb0); % Azimuth Matched Filtering
sac(:,l)=iftx(fsac(:,l)); % Azimuth IFFT / Final Target Image
end;
% Plot Final Results
figure(1), imagesc(abs(sac))
xlabel('Range, samples'), ylabel('Azimuth, samples')

```

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