STUDY AND ANALYSIS OF JAMMING OF SYNTHETIC APERTURE RADAR

A Dissertation submitted in partial fulfillment of the requirement for the award of degree of

MASTER OF ENGINEERING
IN
ELECTRONICS AND COMMUNICATION

Submitted by

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PATIALA – 147004, INDIA
JULY- 2016

DECLARATION

I Ravneet Kaur, hereby, declare that the work presented in the thesis entitled "Study and Analysis of Jamming of Synthetic Aperture Radar" submitted by me in the partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication submitted at Electronics and Communication Department, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Hem Dutt Joshi, Assistant Professor, Electronics and Communication Engineering Department. The matter presented in this thesis has not been submitted in any other University/Institute for the award of any other degree.

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This is to certify that the above statement made by the student is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I would like to express sincerest gratitude to my esteemed mentor **Dr. Hem Dutt Joshi,** Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala, for his consistent devotion and invaluable guidance throughout the completion of the dissertation. It has been a matter of privilege to get the opportunity to learn great insights of in-depth knowledge under his mentorship.

I shall be failing in my duties if I do not express my deep sense of gratitude towards **Dr. Ashutosh Singh**, Assistant Professor, Thapar University, Patiala, who have been a constant source of inspiration for me throughout this work, and for providing me with adequate infrastructure in carrying the work.

I would like to thank **Dr. Sanjay Sharma**, Professor and Head, Electronics and Communication Engineering Department, Thapar University, for his earnest efforts to inspire the students to perform efficiently to meet the research objectives.

I express gratitude to **Dr. Amit Kumar Kohli,** Associate Professor and P.G. Coordinator, Electronics and Communication Engineering Department, Thapar University for inspired motivation to give the best of the potential at each step.

I sincerely thank the authors from the research community whose work has been greatly inspirational and has been duly quoted as reference in this report.

I heartily thank my parents and Almighty for their consistent blessings and support. At last but not the least I would like to thank all those who have provided their help in a direct or indirect manner to achieve this goal.

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ABSTRACT

Synthetic Aperture Radar (SAR) has been gaining huge popularity because surveying can be done at any time and under any weather conditions using SAR. The ability of SAR to process complex information leads to good resolution images, good contrast observance and precise measurements of the topographical attributes when captured using an airplane or some space station.

It finds immense popularity in the fields of agriculture, determining oceanic currents, monitoring disasters like forest fires, volcanic eruptions and oil spills. Its main application is in the field of military for surveillance, tactical assessment, etc. To protect our own army, important targets or objects it becomes important to jam radar of the enemies. Jamming radar is gaining huge attention over the years.

Jamming SAR is more difficult than the conventional radars because of its high processing gain. There are several methods available for jamming SAR, the two main methods are: active jamming, passive jamming. Active jamming involves adding up some false radiations in the true backscattered radiations. Passive jamming doesn't involve changing the electromagnetic radiations; it mainly involves blocking the incident radiations.

Fractional Fourier Transform is the generalized form of Fourier Transform. Any field where Fourier Transform is applicable can be replaced by Fractional Fourier Transform. In this dissertation, jamming signal is generated using Fourier Transform and by using Fractional Fourier Transform. The two signals simulated are compared and the results are observed.

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LIST OF ACRONYMS

Name	Meaning
RADAR	Radio Detection and Ranging
SAR	Synthetic Aperture Radar
RDA	Range Doppler Algorithm
IRDA	Inverse Range Doppler Algorithm
OFDM	Orthogonal Frequency Division Multiplexing
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
FRFT	Fractional Fourier Transform
IFRFT	Inverse Fractional Fourier Transform
BFHM – SAR	Bistatic Forward- Looking High-Speed Maneuvering-Platform Synthetic Aperture Radar
PSS	Phase Switched Screen
FDTSA	Frequency Domain Three Stage Algorithm
RCMC	Range Cell Migration Correction
CSA	Chirp Scaling Algorithm
GMTI	Ground Moving Target Indication
ωKA	Omega- K Algorithm

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The word RADAR is an acronym used for Radio Detection and Ranging. Synthetic Aperture Radar (SAR) is an imaging radars system that generates very high resolution images of a scene or target by using radar motion to synthesize the antenna aperture. The term radar came into existence during the Second World War, when radars were extensively used. That was the aura when tremendous achievements were made both theoretically and practically for radar technology [1]. The signals emitted by radar communicate with ground by reflection, scattering, refraction or absorption.

Radar detects and locates objects in range and angle by transmitting electromagnetic waves. These waves are scattered by objects in space and some of these are reflected back towards the radar, these reflections are read and analyzed by the radar. This reflected signal can be processed to show many properties of the original object that the wave reflected off. Thus the location of the object (distance and angular position) as well as its velocity can be obtained by analyzing the reflected signal [1].

Synthetic Aperture Radar (SAR) is a coherent imaging technology. It records the amplitude as well as the phase of the signals reflected by the objects in space. Surveying can be done at any time and under any weather conditions using SAR and for this the key feature of long range propagation of signals emitted by radars is used. The ability of SAR to process complex information leads to good resolution images, good contrast observance and precise measurements of the topographical attributes when captured using an airplane or some space station [2].

SAR is a kind of radar that creates images of a target, like that of scenery – these images may be 2D or 3D interpretations of the target. It utilizes the movement of the antenna mounted on SAR over an object space to give better spatial resolution.

SAR is affixed over a moving platform like an airplane or space station, and this is a precocious form of side-looking airborne radar. The distance the SAR sensor covers around a target forms a large synthetic antenna aperture.

Radar can operate at any frequency, but due to propagation effects, target scattering characteristics, availability of components, antenna size, and angular resolution requirements the frequency of operation is limited [1-3].

The electromagnetic spectrum in the frequency range of 3 MHz to 300 GHz is convenient for radar operation; but maximum number of operational radars operates in the microwave frequency range.

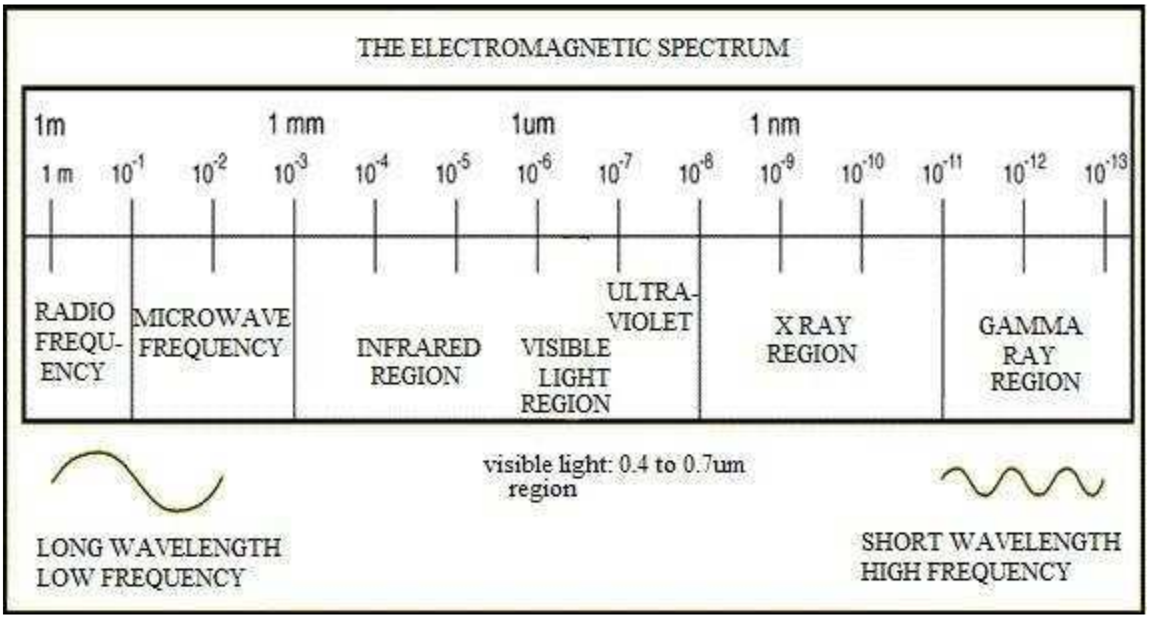

Figure 1.1 EM Spectrum [1]

1.2 EVOLUTION OF SAR

A good growth has been witnessed in the designs and applications of SAR since the 1950's. Carl Wiley observed a huge compatibility that persists between the azimuth coordinate of the reflecting target and Doppler shift of signal that was backscattered to the radar by that target.

It was concluded that analysis in frequency domain of the backscattered signals may lead to better azimuth resolution as compared to what is allowed by the azimuth width of the beam itself that supervised the functioning of the real aperture radar (RAR) structures of that time [2]. The radar group at Arizona built the first ever airborne SAR system, flown aboard a DC 3 in 1953.

SEASAT was the first SAR satellite launched. It functioned very well within the last days of June to the starting days of October, till a huge short circuit was faced within its power system. After the launch of SEASAT, Shuttle Imaging Radar A (SIR A) was launched in 1981, followed by Shuttle Imaging Radar B (SIR B) in 1984.

SIR A as well as SIR B radars were alterations about the SEASAT radar, functioning in L band and HH (horizontal transmit, horizontal receiver) polarization. SIR B had the additional ability to operate at different incident angles [3].

Except Soviet 1870 SAR, space shuttle based SEASAT derivatives were only launched in the 1980s. In 1990s considerable augmentation of SAR missions was witnessed by the launch of five satellites of SAR which were earth oriented, and also evolving interplanetary use to map Venus, for this Magellan SAR is used [3].

Many more satellites like ALMAZ, Japanese Earth Resources Satellite (JERS 1), European Remote Sensing (ERS 1), ERS 2 and RADARSAT 1 were also launched, these systems operated at single polarization and single frequency.

SIR C/XSAR, one of the most advanced SAR systems, was launched in April and October 1994. It was a collective mission comprising of NASA, German Space Agency, and Italian Space Agency [4]. This structure was capable of operating at the same time at many frequencies namely L, C, and X.

In 2002 ESA's ENVISAT, namely ERS 1, ERS 2, were launched. ERS, ENVISAT's ASAR (Advanced SAR) radar functions in C band, also it had an additional ability of gathering information in combination of four polar metric aggregations.

Recently several new SAR satellites were launched. The first commercially available radar satellite Terra SARX was launched in June 2007. It offered 1 m resolution imagery products. Constellation of small Satellites for Mediterranean basin Observation (Cosmo –Sky Med) is an Italian X band SAR, its first satellite was launched in June 2007 [2].

COSMO Sky Med provides earth observation with full global coverage, all weather, higher resolution, higher accuracy, day/night acquisition capability, superior image quality [3].

1.3 WORKING PRINCIPLE OF SAR

A synthetic aperture is obtained by moving a real aperture (or antenna) over a sequence of varying locations in the direction of the flight. SAR determines the intensity and round-trip time of the microwave signals radiated by radar and reflected by a faraway target.

The signal pulses transmitted operate in the range from 1 cm to 1 m, i.e., microwave wavelengths, which correspond to the frequency range of 300 MHz to 30 GHz [2]. The pulses are polarized in a single horizontal or vertical plane. SAR operates by transmitting high power pulses per second towards the object area; each and every pulse has pulse duration of about 20 to 50 microseconds [4].

On the surface of earth, the energy contained in the pulse gets dispersed in all directions and a fraction of it is reflected back towards the SAR. This back reflection to the SAR returns as a weak echo. The echo is received by the antenna either in horizontal or in vertical polarization; this may be different from that of the pulse that was transmitted [2]. These echoes are then transformed to data in digital form which is then sent to a data recorder for post processing and are then displayed as an image.

As the radar moves with respect to ground, the echoes get Doppler shifted. When radar moves towards an object a negative Doppler shift is witnessed and as it moves away, a positive Doppler shift is witnessed.

The echoes are focused to a single point by matching the Doppler shifted frequencies with a frequency taken as reference, therefore considerably enlarging the length of an antenna that is used for imaging a particular point target [3]. This process is generally termed as SAR processing and now days it is achieved digitally by using computer systems.

In imaging radar, the radar moves in the direction of flight track, footprint, or region irradiated by the radar, moves along the surface in a swath, making the image with its movement. The azimuth resolution along the direction of the track is determined by the length of the radar antenna. A finer resolution is witnessed in this dimension when longer antenna is used.

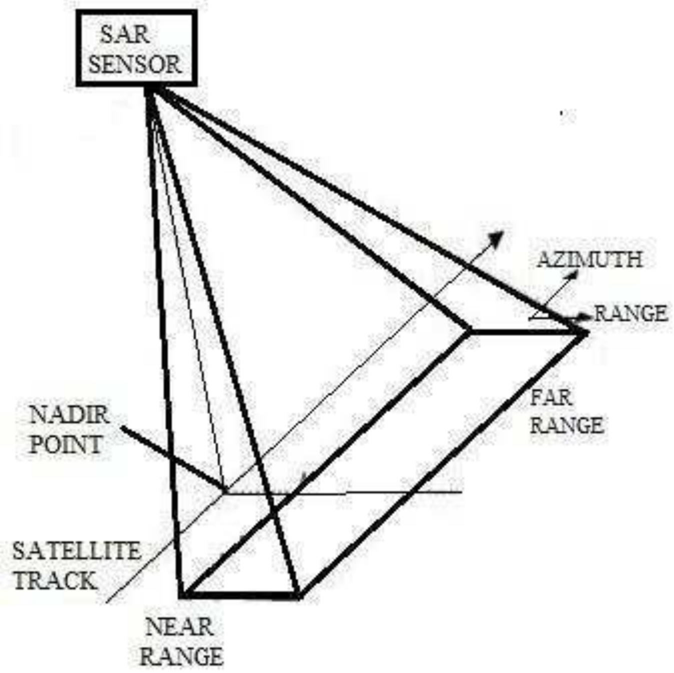

Figure 1.2 Basic Outlay of SAR [1]

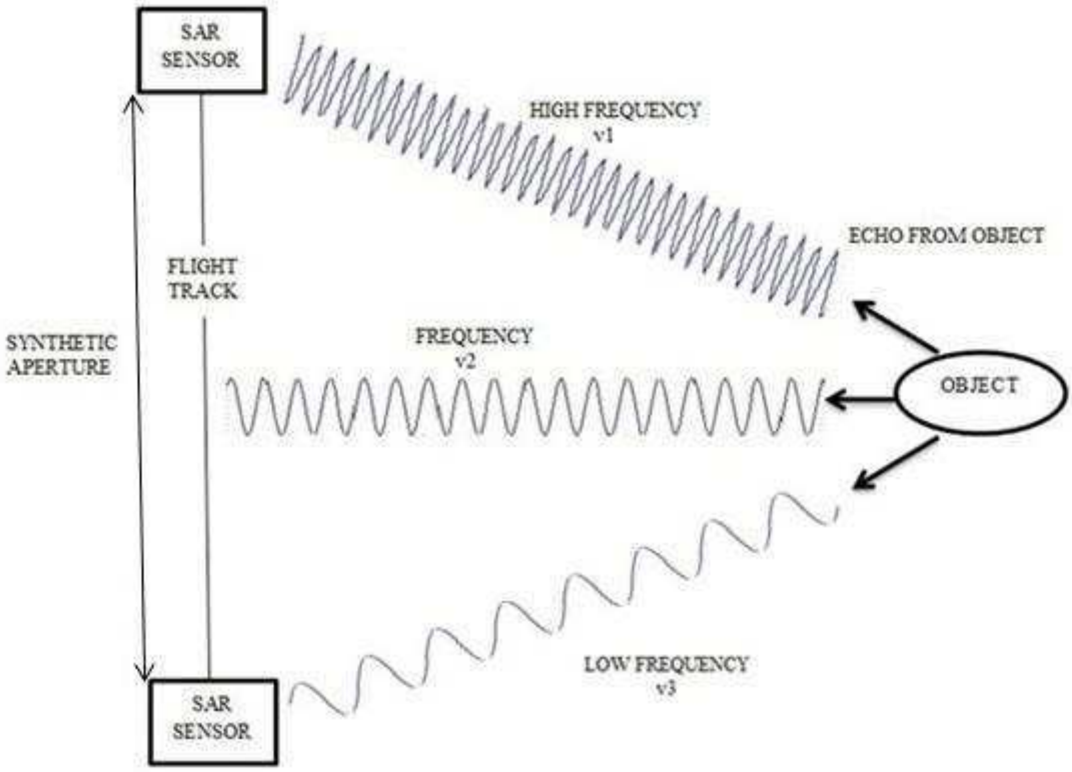

Figure 1.3 Principle of Synthetic Aperture Radar [2]

1.4 APPLICATIONS OF SAR

SAR has high altitude capability independent to that of the flight altitude. Its working is independent of weather conditions as well as day and night conditions. Some important areas for SAR application are as follows [2]:

- It can be used to determine speed of wind and oceanic currents in oceans.
- While monitoring glaciers it can be used to measure wetness of snow, snow water equivalent.
- In the field of agriculture, SAR has many uses like monitoring the moisture content in soil, surveying and classifying the crops.
- SAR finds application in terrain discrimination and subsurface imaging.
- It can be used in forestry for determining forest height, biomass, extent of deforestation, surveying any other kind of damages done to the forest like forest fire.
- It can be used for moving target indication (MTI).
- It can be used for surveying environment. Monitoring oil spills, floods, growth in urban areas.
- It can be used in military surveillance and tactical assessment.
- It can be also be used to monitor earth like volcano monitoring.

1.5 SAR IMAGE INTERPRETATION

SAR generates radar images with finer resolutions. Every pixel in the radar image represents the back reflected or echo signals from the region in the imaged scene. Backscatter is also referred as radar cross section and it is calculated in terms of square meters. The radar cross section is related to the size of the objects [2].

Objects of size equal to the wavelength appear bright and rough. Objects of size lesser than that of wavelength appear darker and smooth. Radar cross section is not dependent on the image resolution or pixel size and is used to measure backscatter [3].

Mostly the values for natural surfaces lie in the span of +5 dB, for very bright, to 40 dB, for very dark. Low backscatter in the image is represented by darker areas whereas high backscatter represents brighter areas. Brighter marks in an image signify that a considerable part of the radar energy was reflected back towards the radar, whereas darker marks signify that very less energy was reflected back. Backscatter for an area at a particular wavelength changes with a number of requirements like largeness of scatterers in the object region, moisture content of the area where the object exists, polarization of the pulses, and observation angles [4].

Back scatter differs when different wavelengths are used. Rougher ground surfaces appear as brighter and flatter surfaces that return back little or no microwave energy appear darker in images obtained using radar. Foliage is generally slightly rough on most of radar wavelengths and hence looks gray or light gray in a radar image.

Stronger backscatter is observed for surfaces that are inclined towards the radar and appear brighter in a radar image than those surfaces that are sloping away from the radar. Some areas such as the back slope of the mountains which lie in shadow and which cannot be illuminated by the radar always appear as dark in the radar image [3].

A double bounce phenomenon is observed when pulses radiated by radar, bounce from the roads and then bounce again from the buildings and are directed back towards the radar. This phenomenon is usually observed when buildings are lined up. Hence, such areas appear very bright in radar images [3]. Buildings which are not lined up appear gray in the image as in such cases the backscatter is returned straight away to the radar. Roads and freeways being flat appear as dark.

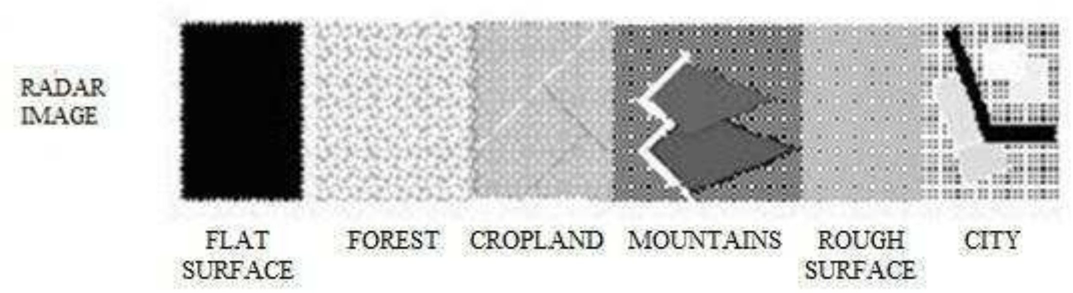

Figure 1.4 Images Obtained Using Radar for Various Surface Types [3]

Backscatter is sensitized to electrical properties of target and even to the water content. Bright implies damper targets whereas dark implies drier targets [4]. The only special case is a mirror like body of water that appears dark because this acts as a flat surface and reflects any pulse incident on it away from it. Backscatter also changes based on the use of the type of polarization.

Some SAR systems have the ability to radiate pulses in anyway using horizontal (H) polarization or vertical (V) polarization and receive in anyway H or V, with the probable union of HH (Horizontal transmit, Horizontal receive), VV, HV, or VH. Few SAR systems estimate the phase of the incident signal and hence calculate the phase difference in the return of the HH and VV signals [4].

This difference in the round trip times of HH and VV signals is due to the physical features of the scatterers. The correlation coefficient may be measured using these SAR systems.

Backscatter is also affected by different observations angles, track angle. Track angle affects it like: metropolitan regions, railings, ocean waves, and geological fault, rows of crops. The incidence angle has a huge impact on the backscatter.

Lower the incidence angle higher is the backscatter, i.e. with increasing angle of incidence the backscatter decreases.

1.6 SAR IMAGE FORMATION

SAR image can be formed by using any of the available algorithms. The most popular ones are the Range Doppler Algorithm; the Chirp Scaling Algorithm; Omega K Algorithm [4].

- RANGE DOPPLER ALGORITHM (RDA) [4,5,6]

  The RDA was developed for processing SEASAT SAR data. This algorithm was utilized to form the first digitally processed image using SAR [4]. Block processing efficiency is achieved using operations in frequency domain in range and azimuth directions. This algorithm utilizes the approximate separability of processing in the above mentioned two directions. Range cell migration correction (RCMC) is used amidst the two one-dimensional operations. This algorithm still stands the most widely used algorithm because of its efficiency, accuracy and simplicity. One of the key features of this algorithm an interpolator being used in the range Doppler domain for implementing RCMC [6]. Its two major disadvantages are: it experiences high computational load when a long kernel is used to achieve better precision; secondly, in case of higher squint angle its accuracy stands restricted. This concept of RDA is discussed later in detail in upcoming chapters.

- CHIRP SCALING ALGORITHM (CSA) [4]

  The CSA was introduced specially to remove the need for an interpolator required for RCMC [4]. It is based on a scaling principle, according to which a frequency modulation is applied to a chirp-encoded signal in order to achieve a shift or scaling of the signal. By making use of this chirp scaling principle, the required range-variant RCMC shift can be realized using phase multipliers instead of a time-domain interpolator.

- OMEGA-K ALGORITHM (ωKA) [4]

  When the squint angle is large or if the aperture is wide the RDA and CSA reject some of the higher order phase terms in their processing, leading to not accurately compensated range azimuth coupling [4]. The ωKA is capable of processing data received over wide azimuth apertures and also handles the range dependence of the range azimuth coupling correctly. This is due to the fact that the data is refined completely in the 2-D frequency domain, where the approximations that were used in the CSA and RDA are not needed. However, there are certain approximations made in the ωKA, which curbs its ability to handle large range swaths.

1.7 JAMMING

Applications involving SAR are gaining huge interest, especially military applications. So, at the same time it becomes important to hide our important martial targets and our army from enemy. So it becomes important to jam SAR. Jamming SAR is more difficult than jamming radar because SAR possess high processing gain.

Jamming is basically the emission of radio frequency signals done purposely so as to disturb the functioning of the SAR by dousing its receiver with some noise or some other false data [7].

Jamming a SAR is classified basically into active jamming and passive jamming [7].

- Active jamming comprises of false information or barrage jamming and deception jamming.
- Passive jamming makes use of strong reflection angle reflection instrument, foil strip screen, and many more things to hinder the target defining properties, and so, generates some other point which also has very good reflection.

1.7.1 ACTIVE JAMMING

Active jamming comprises of barrage jamming and deception jamming. Barrage jamming performs hindering, targeting and jamming random pulses, while deception jamming performs transmitting, reacting and dispersing jamming [8].

1.7.2 NOISE JAMMING

It is an efficient method for jamming, which implies adding limited noise to the original signal; this reduces radar resolution very efficiently, and also results in no imaging radar. Noise jamming can be achieved by radio frequency noise, noise amplitude modulation, noise frequency modulation and noise phase modulation jamming [9].

Point target can be jammed using independent noise, with increase in power of noise the point target can be disturbed [7].

1.7.3 JAMMING USING SHIFT IN FREQUENCY

Pulse compression radar has many advantages, such as less capturing chances, higher resolution; detecting long distances, strong anti-jamming power, and many more. In pulse compression signal, delay in time and shift in frequency have strong coupling property, so this property and shift frequency can be used to perform jamming of pulse compression radar [7]. The time of compressed matched output signal main peak will either lead or lag, when there is Doppler frequency shift in pulse compression signal.

1.7.4 DECEPTION JAMMING

Deception jamming signal and actual echo signal resemble each other; this makes the required jamming power very small because deception signal achieves processing gain similar to that of radar echo. In order to achieve this similarity deception signal, actual echo signal parameters such as: carrier frequency of transmitter, modulation slope, bandwidth of pulse, pulse cycle time must be selected in accordance with SAR transmitting signal parameters, and carrier frequency shift must be small as compared to the Doppler shift-frequency [9].

Deception jamming method mainly consists of: transmitting, responding and scattering jamming [7].

In transmitting jamming received radar signal is amplified and transmitted at once. To get distributed objects in the image using this jamming, Doppler expansion is required, which is achieved by changing the phase of the jamming signal, by this actual target characteristics can be hidden effectively [7]. Responding jamming captures the received SAR signal, waits for some time and then transmits it. It alters the delay time and shifts the phase of the jamming signal; as a result, many false point objects appear in the image obtained by using SAR [7]. Scattering jamming forms jamming coherent pulse sequence after receiving radar linear frequency modulated pulse. This sequence is transmitted to the required covered object area; it gets mixed with the backscattered signal and these mixed signals are received by radar [7], leading to formation of a disturbed SAR image.

1.7.5 PASSIVE JAMMING

The normal performance of SAR system is not disturbed by passive jamming. To distort and reduce radar echo, passive jamming makes use of appliances, and natural conditions to hide actual object [9]. It reduces war efficiency by reducing the ability of SAR to form true target image.

This type of jamming can be achieved by using the below mentioned techniques:

1.7.5.1 STRIP SCREEN

When the radar beam covers an object, the main requirement is to form a foil strip screen that can be used to cover the actual target, thereby disturbing the normal functioning of SAR [7].

1.7.5.2 ABSORPTION MATERIAL

It is also known as radar camouflage material. Microwave absorption material is capable of reducing scattering of signal radiated by radar and object radar cross section area by absorbing considerable portion of the radar signal. This covers target light parts [7].

1.8 DISSERTATION ORGANIZATION

Chapter 1 gives an introduction to the basic concept of Synthetic Aperture Radar, its operating principle, image interpretation, jamming, and the various types of jamming SAR.

Chapter 2 is dedicated to the literature survey. Various research papers which are relevant to this thesis are discussed in this chapter.

Chapter 3 presents the system model. It describes the Range Doppler Algorithm. It also discusses the already available method for jamming SAR and also presents the results achieved using this method.

Chapter 4 presents the proposed model for jamming SAR and also present the results obtained using this method.

Chapter 5 compares the results obtained using the already available method and the proposed method.

Chapter 6 concludes this dissertation and offers suggestions for future work on this topic.

CHAPTER 2

LITERATURE SURVEY

Literature survey is an important part of project work; to begin with it is indeed important to analyze the research papers that have already been implemented by other analysts. The papers associated with this field are selected and studied. This literature review helps to provide a better perspective for this project.

To start with the research, it is important to understand the very basic algorithm used to form SAR images. The following paper was studied for this purpose.

Akliouat, H., et al. [6] proposed a paper that presents a contribution related to accomplishing SAR image formation using the IDL language. It is the most established way of SAR image reconstruction. The received signal is passed through various processes: range compression, range migration, and azimuth compression. These processes are performed in a frequency domain correlation. The output of this method is the data being converted back to its actual form and then written to an output file. This method first performs range compression in Fourier domain; the next step is to perform azimuth compression in Fourier domain. To summarize, the complete Range Doppler algorithm is described in this paper.

To understand the various technologies available for SAR jamming the following papers were studied.

Nan,L., et al. [7] proposed a paper that discusses various types of jamming SAR technologies, ranging from active to passive jamming. It also discusses the various subtypes of active as well as passive jamming. It also discusses the efficiency of all the jamming types described. The merits and demerits of the various types of jamming are also discussed in this paper.

Shenghua, Z., et al. [8] proposed a paper that analyses the possibilities of active methods of jamming SAR and their effectiveness. Because of the high processing gain for SAR, very high barrage power is needed to jam SAR, as an alternate to barrage jamming a more genuine and efficient method to adopt for is deceptive jamming. The various simulation results for generating deceptive signals are discussed in this paper.

The jamming method that involved both barrage jamming and deception jamming gave even better results.

Zhou, F., et al. [9] proposed an efficient algorithm for large scene deceptive jamming against the space-borne SAR in their paper. Firstly, the jamming scene template is broken into sub-templates. Now in the range frequency and azimuth time domain every sub-template is further decomposed into the slow time dependent and slow time independent terms. The slow time independent terms are simulated offline whereas the slow time dependent terms are simulated by using actual time 1-D frequency modulation. After this step the sub-templates are convolved simultaneously with the intercepted SAR signals. At last, fast deceptive jamming is accomplished by incorporating all the sub-templates together.

Zhang, H., et al. [10] proposed a paper, in this based on SAR jamming geometry structure and radar waveform, a deceptive jamming signal model is presented. The structure presented in this paper is also verified. This method is used to generate a jamming signal that can be used to protect single point object or multiple point objects. The jamming results are validated using SAR imaging algorithm.

Zhao, B., et al. [11] presented an improved scattered wave jamming approach for SAR in their paper. The phase and the delay time of the intercepted SAR signal are adjusted by the jammer. Then, a virtual scene is generated to give an efficient coverage of a certain region. Complete model using which the jammer signal is generated is described. Improvements are proposed which lead to enhancement in jamming area. Hence, this method helped to eliminate the restriction of realisability and it also increases the area of jamming.

Liu, Y., et al. [12] proposed a frequency-domain three-stage algorithm (FDTSA) in their paper. The jammer system is reformed into a 2-D frequency domain. The three stages mainly comprise of: the offline stage, initialization stage and the real-time modulation stage. Further implementation of this algorithm is efficiently accelerated by making using fast Fourier transform. This three stage algorithm aids to get rid of serious focus worsening of the fake or virtual scatterers and for this reasonable computational load is required.

Long, S., et al. [13] proposed a model for generating jamming signal. The vital principle of the SAR deceptive jamming is also discussed. The paper further describes flowchart on how the actual echo signal is mixed with the jamming signal and finally the true target image is distorted. Finally, two parameters are used to evaluate the effectiveness of jamming.

Xu, L., et al. [14] proposes some improvements to eliminate the restriction of jamming augmentation in the range direction and also increases the domain of the jamming area; a considerable enhancement in jamming area was witnessed with this approach than with other algorithms. To purposely form virtual objects as jamming strips on the SAR image; the m-D jamming method utilized a spinning reflector in order to cover some regions. This method using a single spinning reflector had a limitation that it could only form a long jamming strip along the azimuth direction located up to a restricted number of range cells, this lead to a restricted a region that could be protected. In this paper, an improved m-D jamming method based on phase-switched screen (PSS) is proposed, this method made use of the benefits of the PSS modulation and the advantages of the m-D jamming. The jamming strip can be increased in size along the range direction by supervising the modulation frequency and wave of the PSS. The actual area can be obscured by numerous discrete jamming strips spread in the range direction by periodically modulating PSS; in order to cover the real scene by a jamming strip which is regularly spread in the range direction, PSS is non-periodically modulated.

Meng, Z., et al. [15] proposed, an efficient scene raw data simulator, in this paper. This simulator is proposed on the basis of the effective access of 2-Dimensional frequency spectrum with high accuracy and modification of phase space variance of it. Raw signal can be reconstructed using this approach as this process is known as inverse imaging, and raw signal can be generated more efficiently using this approach as compared to any other methods. Simulation in the usual airborne platform of bistatic SAR can also be handled by this method. It can also handle bistatic Forward- looking High-speed Maneuvering-platform SAR (BFHM-SAR). This method is also applicable to high-speed maneuvering platform.

Zhao, H. [16] proposes a paper that analyses and discusses active and barrage type noise jamming methods of synthetic aperture radars. It describes the signal model of transmitting and various noise jamming methods. It also illustrates the model of jammed echo signals. It also describes various attributes of SAR and establishes an evaluation method for jamming using noise. Finally, the noise jammed image of SAR is presented.

Jiang, J., et al. [17] proposed a paper that discusses the concept of Synthetic Aperture Radar- Ground Moving Target Indication (SAR-GMTI). After this the concept of noise AM jamming, RF noise jamming, noise FM jamming and noise convolution jamming are introduced and analyzed. The paper utilizes computer simulation which contains velocity estimation and detection probability to evaluate the jamming effect. The results depict that under the proper Jamming Signal Ratio (JSR) condition, the active noise jamming can jam SAR-GMTI effectively, and under the same JSR condition, noise convolution jamming has a more efficient jamming effect than any other non-coherent jamming.

Huang, H., et al. [18] analyzed the effect of jamming using shift frequency jamming to SAR and presented an improved way, Random-SF jamming, for jamming. The Random-SF jamming is an efficient jamming method to SAR, when this method is applied without inter-pulse phase feature, SAR range matched compressed processing gain having the noise like tripe imaging output so as to blanket distributed targets, can be obtained. This method requires lesser power than is required for noise jamming.

Zhou, Y., et al. [19] proposed a 2-D partly coherent jamming method against SAR - stepped time-delay repeater jamming. During radiation of SAR it repeatedly increases or decreases time delay by a fixed increment. The paper presented that this type of jamming is capable of obtaining range as well as azimuth coherent processing gains and is also capable of covering certain areas that could be used for distributed targets protection.

Raney, R.K., et al. [20] introduced a new chirp scaling algorithm (CSA). By using the traditional Range Doppler Algorithm or related frequency domain techniques a space-variant interpolation is needed to indemnify for the migration of signal energy across range resolution cells. In complex images, interpolation leads to loss in the quality of the image and it even requires significant computation time. The proposed new CSA performs range cell migration correction precisely without interpolation. This approach makes use of complex multiplies and Fourier transforms, also the algorithm is suitable for wide-swath, large squint and large beam-width applications, it is also phase preserving. This paper presents simulation results; images generated using this algorithm, and also give quantitative measures of its performance. On basis of the quantitative comparison, the CSA provides an image quality that is equal to or even better than the one obtained using RDA.

Bamler, R. [21] proposed a paper that compares different algorithms with one another in terms of their ability to focus and their capability to deal with the space-variance of the correlation kernel: the Range Doppler algorithm with and without secondary range compression, modified Range Doppler algorithms, and the available four versions of the wavenumber domain processor. It also presents wavenumber domain algorithms theoretical derivation.

For this comparison algorithms proposed in [22], [23], [24], [25] are used. These comprise mainly of the improved RDA algorithm, w-k algorithms or wavenumber algorithms. These explain the accuracy with which the focusing correlation kernel is approximated.

Franceschetti, G., et al. [26] proposed procedures on the basis of time and frequency domains to generate the raw signal in the hybrid stripmap or spotlight mode in this paper. The paper also shows that although being highly desirable for its efficiency, two-dimensional Fourier domain approach is not workable. The paper presents 1-D range Fourier domain method which further proceeds by 1-D azimuth time-domain integration. In order to consider extended scenes this method proves to be more effective as compared to the time-domain approach. The efficiency of the simulation scheme is determined with the help of numerical examples.

Iodice, A., et al. [27] in their previous paper presented a 2-D Fourier domain SAR raw signal simulator that made use of the efficiency of Fast Fourier transforms. It considered the consequences of sensor track variations and generated a raw signal for extended scenes within fraction of seconds. But the approach is applicable to certain SAR systems only; this is because an assumption of slow deviation for narrow beam is made.

To remove this limitation, this paper makes use of 1-D azimuth Fourier domain processing which proceeds by range time-domain concatenation, this is achieved at the cost of calculation efficiency.

Bultheel, A. [28] in their paper for the estimation of the fast fractional Fourier transform compared two existing routines and presented a routine for discrete fractional Fourier transform.

To obtain these algorithm different approaches from various algorithms described in [29], [30], [31] were used. Also to prove the results comparison was drawn with respect to the previous algorithms mentioned in previous papers.

Patel, R. [32] discussed the concept of Fractional Fourier Transform (FRFT). Various properties of FRFT are discussed such as that of its working in the time-frequency distribution (as a rotation process), secondly FRFT of some signals are discussed and then its applications in various domains are described, for example image compression, target tracking, OFDM (Orthogonal Frequency Division Multiplexing), Signal processing and Image processing, Digital Watermarking, Image Encryption with Multiorders FRFT.

Deng, B., et al. [33] in their paper replaced Taylor series expansion with Legendre orthogonal. Considering a protracted RDA as an example proposed a range Doppler imaging approach based on Legendre augmentation, and on the basis of above mathematical declarations of the new phase multiplication factors are derived. The simulation results show that with very little increment of computation load the offered approach gives better results in terms of focusing than what is achieved by the available RDA with the same squint angle and is even more favorable for the large squint mode.

Yan, Z., et al. [34] introduced an approach on the basis of target scattering characteristics, such that the location of every point is transferred in the desired man-made maps to respective position in the time domain, and after this it is stored in the Digital Radio Frequency Memory (DRFM). Whenever jamming is required, the information stored in DRFM is convolved with the signals that were radiated by radar, and after this the resultant signal is again transmitted. After the processing of radar a composite map comprising of the actual and the jamming signal data is achieved. A man-made map can have a great jamming performance; if not so it still can achieve good jamming performance in a particular region.

Xiaohong, L., et al. [35] on the basis of inverse Range Doppler algorithm (IRDA) for large scene proposed a real time deceptive jamming method. To improve efficiency FFT is used in this method. In case of deceptive jamming against SAR, simulating a jamming signal for a bigger scene is tough, because of its tedious calculations. This method proved to be good but due to approximation used in this method, degradation of jamming image is observed. This problem is resolved by bettering the power that was transmitted. Simulated outputs proved the effectiveness and approximation of this approach.

Clemente, C., et al. [36] to obtain a better result in terms of resolution and noise rejection, applied FRFT to the traditional Range Doppler Algorithm. For the FRFT based Range Doppler algorithm (FRRDA) the location of the detected point scatterer is according to the location of the generated data and it has a great match to the location of the focused scatterers obtained with the RDA. The results obtained using this method confirms that the FRFT can be useful to achieve high resolution SAR processing and it also reduces the speckle noise while enhancing the resolution and focusing accuracy.

Soraghan, J.J., et al. [37] for the betterment of the existing RDA and CSA for processing the SAR, presented two new FRFT-based SAR processing algorithms, the FRFT based Range Doppler algorithm (FRRDA) and the FRFT based Chirp Scaling algorithm (FRCSA), in this paper. Instead of using the matched filtering in the RDA and CSA mapping in time domain and FRFT are utilized. Radarsat-1 data sets are utilized to assess the performance of the algorithms. The results proved that the processing methods involving FRFT provide better resolution leading to lower side lobes effects as well as better object detection.

El-Mashed, M.G., et al. [38] to achieve high resolution images for objects in SAR images, investigated the RDA based on the FRFT (RDAFRFT). For range and azimuth compression an analytical structure of RDA-FRFT is proposed with closed-form expressions. The paper also discusses channel effect. To reduce this effect three inverse techniques are proposed namely: inverse filter deconvolution, Linear Minimum Mean Square Error (LMMSE) deconvolution, and regularized deconvolution. The results of the RDA-FRFT are compared with the traditional RDA that made use of the FFT's.

Simulation results revealed better ability of focusing and side-lobe reduction ratios using RDA-FRFT. The reflectivity profile generated using the RDA-FRFT performed better as compared to the existing RDA [26]. The results also reveal that if the channel effect is considered the regularized deconvolution technique intensifies the working of the RDA-FRFT notably.

Lee, Y.J., et al. [39] discussed the parameters to evaluate the work of noise and deception jamming methods against SAR. In the view of power and SAR image efficient jammers against the SAR satellite with simulated elements were evaluated. In this paper, J/S is analyzed for SAR with RF propagation equations. Several jamming signals against SAR signal were added into SAR image through pulse compression process. Euclidean distance was used to evaluate objective jamming performance of the signals.

Kutay, A., et al. [40] considered filtering using Fractional Fourier transform, because this lead to significant reduction in error as compared to filtering using Fourier transform especially for chirp signals. Fourier transform proved suitable for time-invariant deterioration models and stationary and unwanted signals; but in case of time-varying deteriorations and non-stationary processes Fourier domain was not suitable. Hence, Fractional Fourier domain was found more suitable in such processes.

CHAPTER 3

SAR SYSTEM MODEL

Synthetic Aperture Radar operates by transmitting frequency modulated chirp signals towards the target area and then recollecting the reflected signal from the target area; after that the SAR processes the received signal to achieve the desired image. Several algorithms are available in the literature [4], [5], [6] for processing the echo to generate the images. The most common algorithms are: Range Doppler algorithm [6]; Chirp Scaling Algorithm [20]; and Omega K Algorithm [4]. For better understanding of this concept, the working principle of SAR is described below using equations; and the algorithm that is used to process the received echo to get an image is also described below.

3.1 TRANSMITTED SAR SIGNAL

Let m_{tx} represent the transmitted SAR signal. If the carrier frequency is represented by f_c; chirp pulse duration, Tp_r; range chirp, K_{rg}; then the transmitted signal can be represented as

$$m_{tx} = rect\left(\frac{t}{Tp_r}\right)\cos\left(2\pi f_c + \pi K_{rg} t^2\right) = W(t)\cos\left(2\pi f_c + \pi K_{rg} t^2\right) \tag{3.1}$$

The bandwidth of transmitted signal is described as,

$$Bw = \left|K_{rg}\right| Tp_r \tag{3.2}$$

The range resolution is defined as

$$R_{res} \approx \frac{C}{2\left|K_{rg}\right| Tp_r} = \frac{C}{2Bw} \tag{3.3}$$

Figure (3.1) shows a linearly ramping up frequency cosine transmitted radar signal for the transmit duration and then after this duration there is a void duration left for receiving the backscattered radiations or the echo signal [4]. The duration of transmission is the pulse envelope, W. The transmitted radar pulse can be represented as

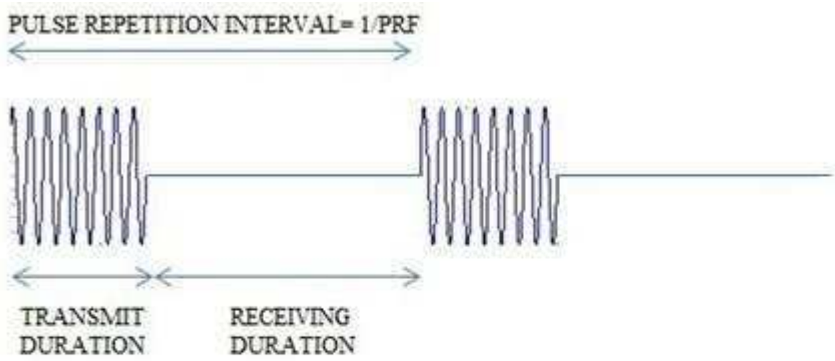

Figure 3.1 Transmitted Radar Pulse [4]

At the antenna, the magnitude of the radar signal during the transmitting and receiving duration are illustrated below in succession.

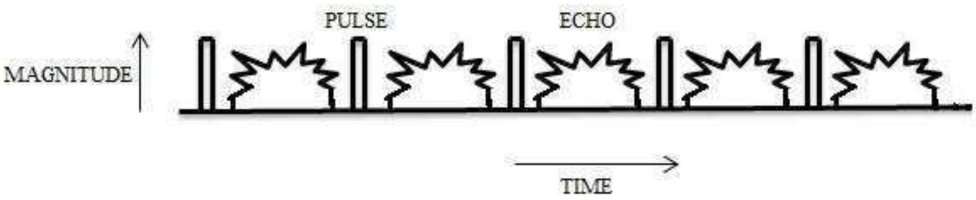

Figure 3.2 SAR Antenna Activity [4]

3.2 RECEIVED SAR SIGNAL

On receiving the signal, it first undergoes quadrature demodulation. Quadrature demodulation makes the signal imaginary, comprising of phase and a magnitude. Let the received signal be represented by $m_{rx}(t, n)$, where t represents time in range direction known as quick time, n is the time in azimuth direction known as slow time. The raw signal is shown as

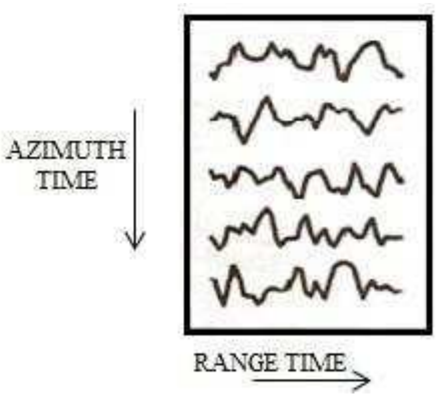

FIGURE 3.3 SAR Image Construction [4]

Target recognition is not possible from this image. So to obtain the final image processing of the SAR raw signal space is performed.

Reflections from P different point targets is expressed as

$$m_{rx}(t,n) = \sum_{l=0}^{P-1}\left[AW\left(t - \frac{2D_l(n)}{c}\right)W_{amp}(n-n_o)e^{-j4\left(\frac{f_cD_l(n)}{c}\right)+j\Pi K_{rg}\left(t-\frac{2D_l(n)}{c}\right)^2}\right] + \ noise(t,n)$$

(3.4)

Where,

A= attenuation factor due to reflection at the object

$W_{amp}(n-n_0)$= amplitude modification for beam pattern in azimuth direction

$noise(t,n)$ = AWGN noise

$\frac{2D_l(n)}{c}$ = time delay

$$D_l(n) = \sqrt{{D_{0_l}}^2 + {V_{plat}}^2 n^2}$$

(3.5)

Where,

D_0= minimum range to target

V_{plat}= platform velocity

$$W_{amp} \approx sinc^2(\frac{0.886\emptyset(n)}{\beta})$$

(3.6)

The azimuth beam-width is denoted by β.

Resolution along the azimuth direction in terms of actual antenna length, d is given as

$$R_{azi} \approx \frac{d}{2}$$

(3.7)

Squint angle is defined as the angle joining the slant range vector and the zero Doppler planes. As the SAR sensor moves towards the object the angle decreases and as the sensor moves far from the object it increases.

$$\emptyset_{sqt} = \cos^{-1}(\frac{D_{0_l}}{D_l(n)}) \tag{3.8}$$

$$\emptyset_{sqt_{max}} = \cos^{-1}(\frac{2D_{0_l}}{durationV_p}) \tag{3.9}$$

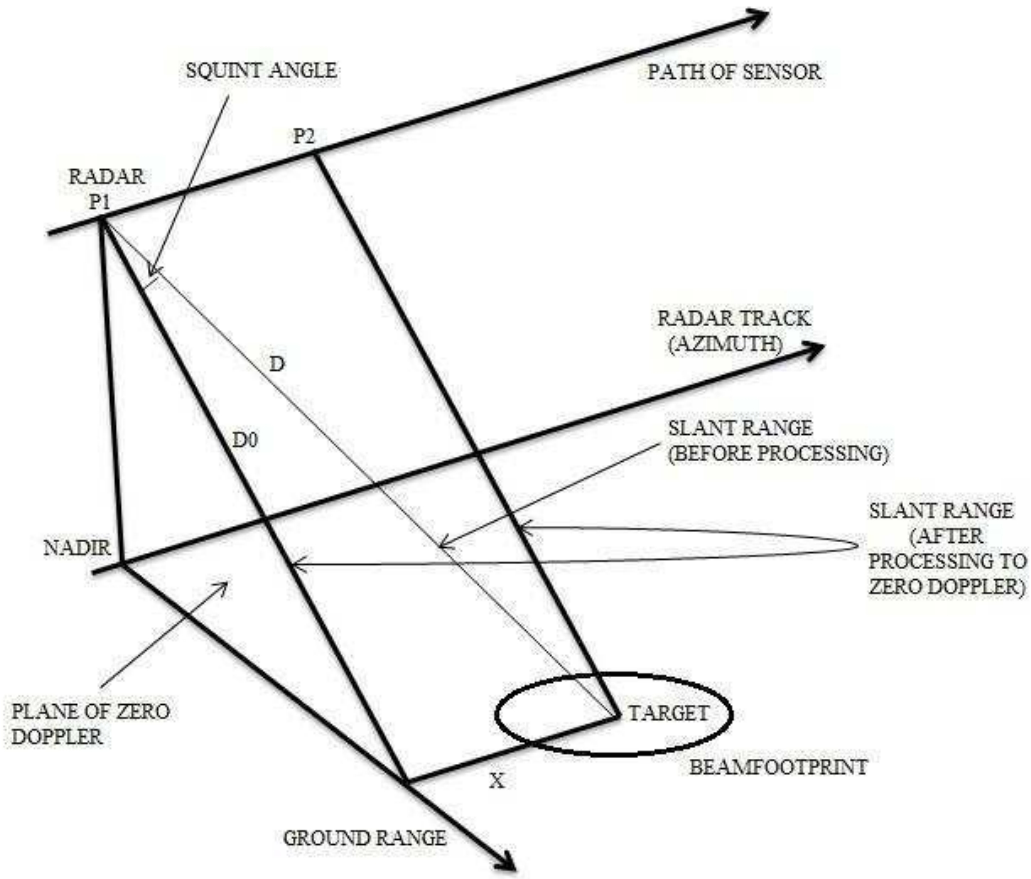

Figure 3.4 SAR Slant Range and Squint Angle Geometry [4]

Nadir is defined as a point or locus of points on the surface of the Earth directly below the sensor as it moves through its line of flight. The nadir is the point where an unbending line joining the sensor and the center of the Earth intersects the surface of the Earth. In case of radar, the nadir line defines the beginning of the range.

3.3 SAR IMAGE GENERATION USING RANGE DOPPLER ALGORITHM (RDA)

Popular methods available for forming an image using SAR are: Range Doppler Algorithm [6], and Chirp Scaling algorithm [20], Omega K Algorithm [4]. Amongst the above mentioned algorithms RDA and CSA are most widely used; and among these Range Doppler algorithm (RDA) is most popular, since it is computationally more efficient than CSA. The advantage of using CSA is that it eliminates the step requiring RCMC [18].

RANGE DOPPLER ALGORITHM as described by Akliouat, H. et al.:

The SAR raw data is processed using RDA in order to generate the final image obtained by using SAR. According to this algorithm matched filtering is performed individually in the Fourier transformed range domain and Fourier transformed azimuth domain. To achieve better time efficiency these transforms are obtained using FFTs [5].

RCMC is executed in the time domain of range and frequency domain of azimuth [6]. Hence, this is called the range-Doppler domain and lends its title to the algorithm as executing the RCMC in this domain is crucial characteristic of the algorithm. RCMC is required due to the changing position of SAR with respect to target.

The raw SAR signal is a 2-D signal. This signal is initially examined as a continuous sequence range time signal for every along the track bin [5]. The processing is as follows [5], [6]:

- In the range frequency domain every range time signal faces matched filtering. For this range FFT is applied to the range time signals. After this every matched filtered signal is converted back to the range time azimuth time domain. At output a range compressed signal is achieved, because of the fact that matched filters were used in the frequency domain of range direction.
- Next step is to attain compression in azimuth direction; to achieve this matched filters in azimuth direction are used. The compressed signal in range direction is firstly collected into a sequence of signals at different range bins with respect to azimuth time. Each signal in azimuth direction is then Fourier transformed using

FFT in azimuth direction and then RCMC is executed before matched filtering in azimuth direction.

- After azimuth matched filtering of each and every signal, next step is to perform IFFTs in azimuth direction, in order to generate the final object image.

The working of matched filter can be explained as [5]:

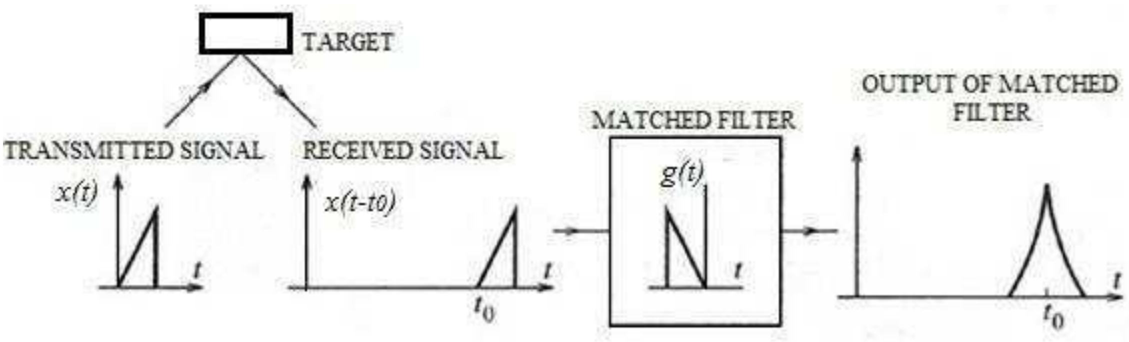

Figure 3.5 Radar Range Finding Matched Filter Example [5]

In above figure,

- $x(t)$ denotes the transmitted radar signal.
- The delay in time of $x(t)$ represents the received radar signal.
- Reversing the time of $x(t)$, it represents matched filter, $g(t)$.
- The convolution of the $g(t)$ and $x(t - t_0)$ generates a signal whose energy is focused at the delay in time of radar reflection.

The complex conjugate taken in the Fourier domain is preferred for multiplication, in place of performing correlation in the time domain for better speed. Here matched filtering is referred to as the compression of pulse because the energy of the signal received by SAR is converged to or can be described as being squeezed to the areas where signal detection is done. This procedure is further improved with use of chirp signal in the signal that is radiated by radar.

RCMC is required because of the changing distance between radar and object because of the moving platform, thereby introducing a hyperbolic trend regarding slow time n of the immediate slant range $D_l(n)$ causing range cell migration (RCM).

The flowchart is as follows:

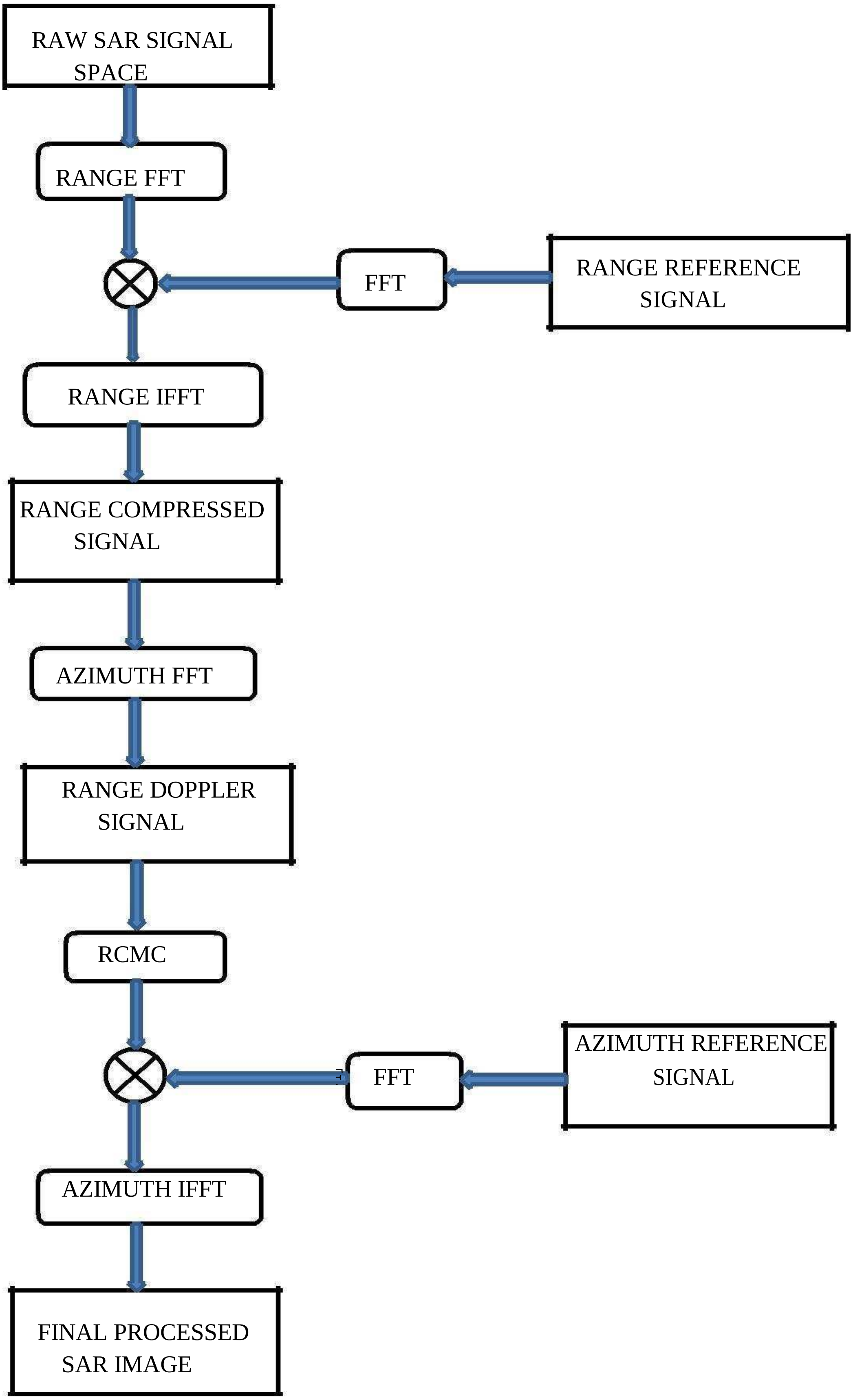

Figure 3.6 Flowchart of Range Doppler Algorithm [5]

SAR image formation using the Range Doppler Algorithm can be better understood by generating a point target image. The generation of this image involves the following steps:

1. The first step is generating appropriate raw data signal, which represents the echo signal received by SAR. This is as shown in figure (3.7)

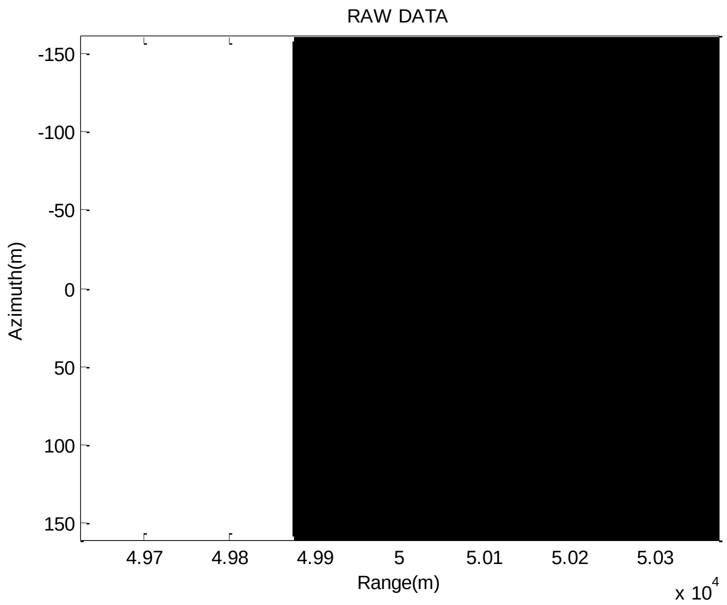

Figure 3.7 Raw Data for Point Target Generation

2. The next step is range compression, which involves taking FFTs along range direction and then applying matched filter. The result is as shown in figure (3.8)

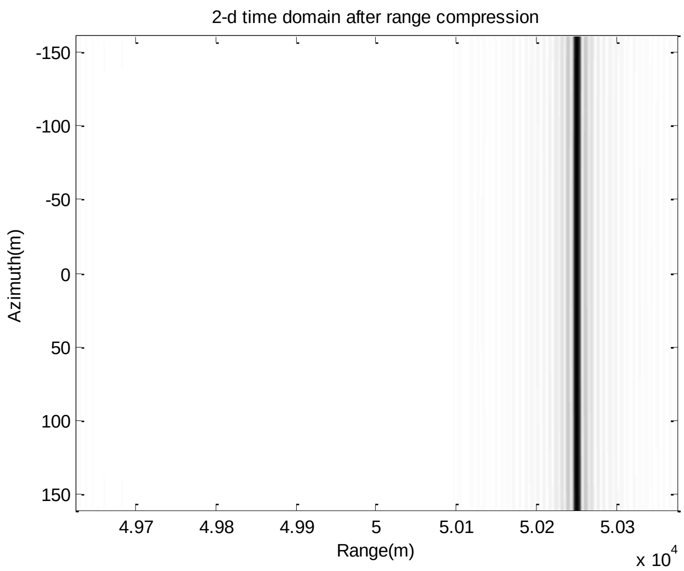

Figure 3.8 Range Compressed Image

3. Next step is to apply RCMC. The effect of this is as shown in figure (3.9)

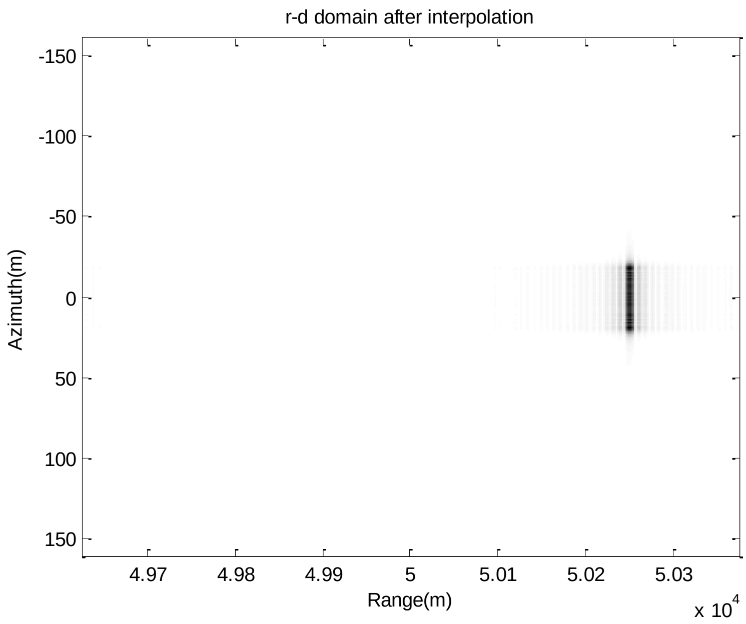

Figure 3.9 Image after RCMC

4. Last step is azimuth compression, which involves taking FFTs of above obtained signal along azimuth and then applying matched filter. The final result obtained is as shown in figure (3.10)

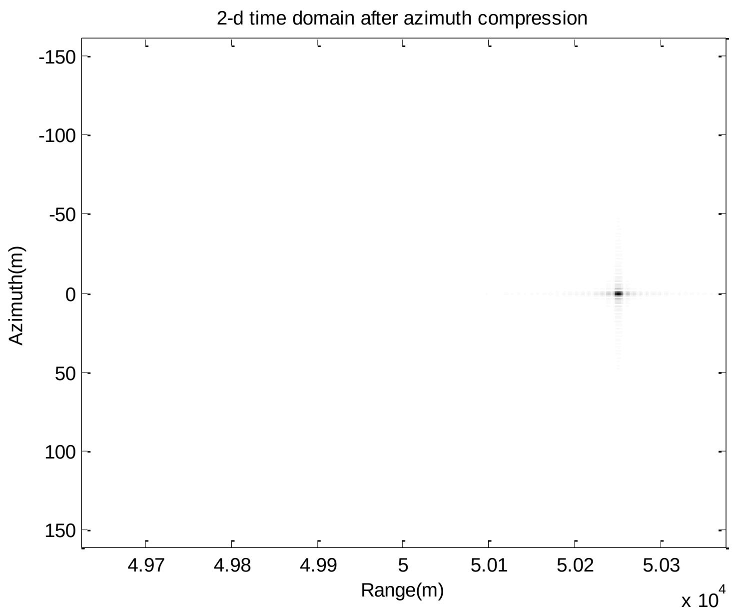

Figure 3.10 Azimuth Compressed Image

3.4 JAMMING MODEL

The main function of jammer is to generate a jamming signal for the deception template and mix it with the backscattered radiations of the actual area [12]. The term deception template stands for deceptive electromagnetic signatures that may consist of a virtual scene or many virtual objects that are to be created by the jammer. The working of jammer may be briefed as [12]:

- Detection and interception of signal emitted by SAR.
- Modulating the intercepted signal in accordance with the deception template.
- At last, above generated signal is transmitted back to radar and is mixed with the backscattered radiations of the actual area.

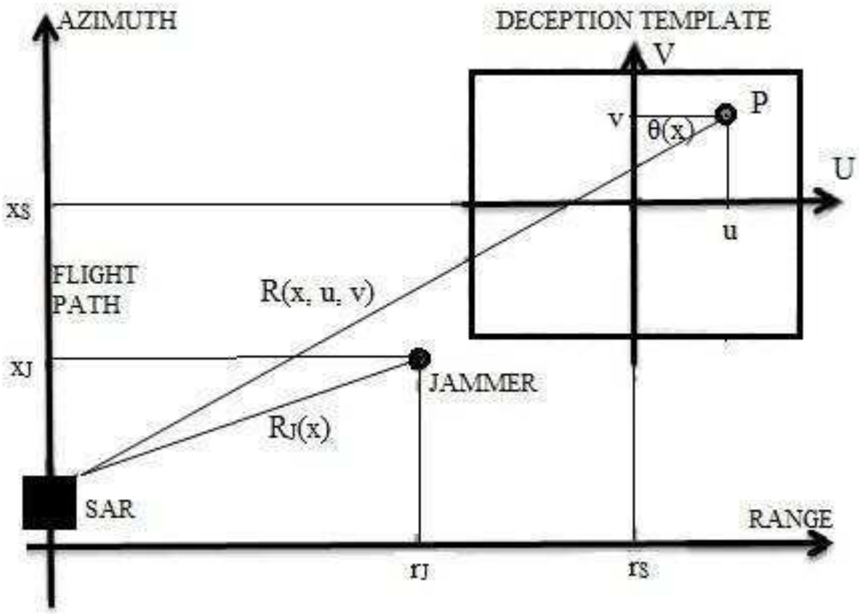

Figure 3.11 Geometry for Jamming and Imaging in the Slant Plane [12]

The above figure (3.11) depicts the geometry of deception template [12]. The SAR platform trajectory coincides with azimuth axis. In the deception template for depicting the backscattering coefficients of the artificial scatterers, a coordinate system (U, V) has been launched. (r_J, x_J) are coordinates of the jammer and (r_S, x_S) are coordinates of the deception template center. In the deception template, point P represents an artificial point scatterer. The coordinates of P in the system (U, V) are (u, v); σ (u, v) is its backscattering coefficient; θ(x) is immediate squint angle of P; $R_J(x)$ is the immediate distance from the jammer to SAR antenna and R(x, u, v) is immediate distance from P to SAR antenna.

3.4.1 JAMMING SIGNAL GENERATION

In order to jam the SAR, the following method is available:

- The first step is to get the image data, which is achieved on the basis of Deception Template using the methods presented in [24], [25].
- The next step is to generate the jamming signal, which is generated using the following steps:

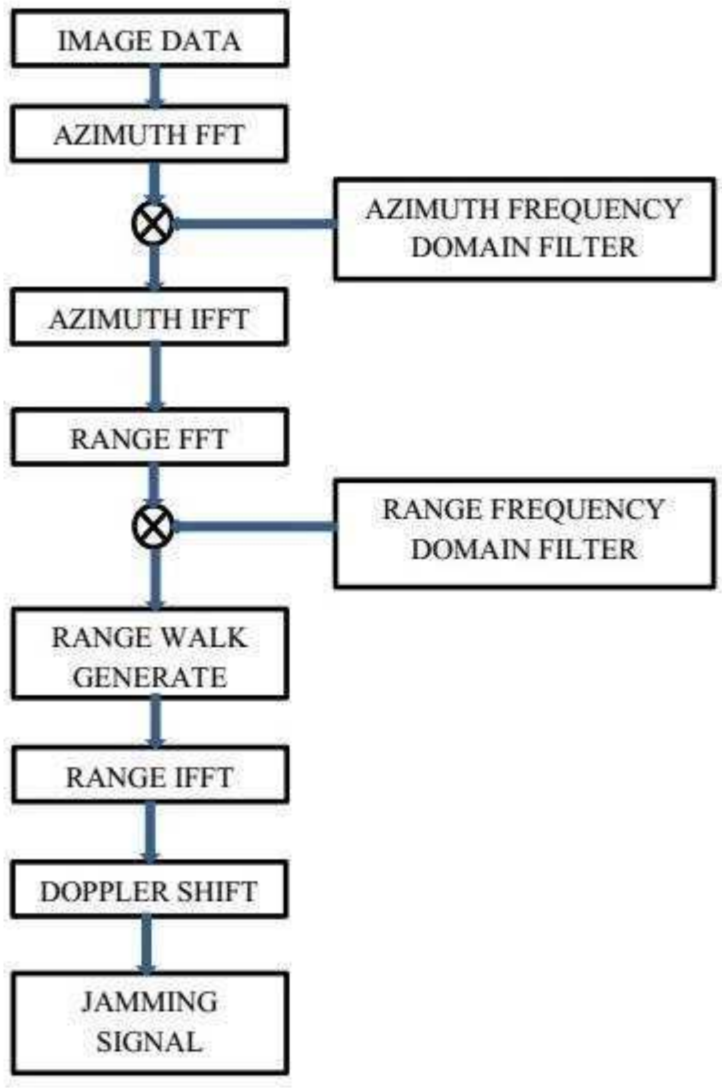

Figure 3.12 Flowchart for Jamming Signal Generation [10]

- The next step now is to mix the echo from actual target and the jamming signal.
- The final step is to perform image processing of the above resultant signal so as to obtain the protected scene/ jammed image.

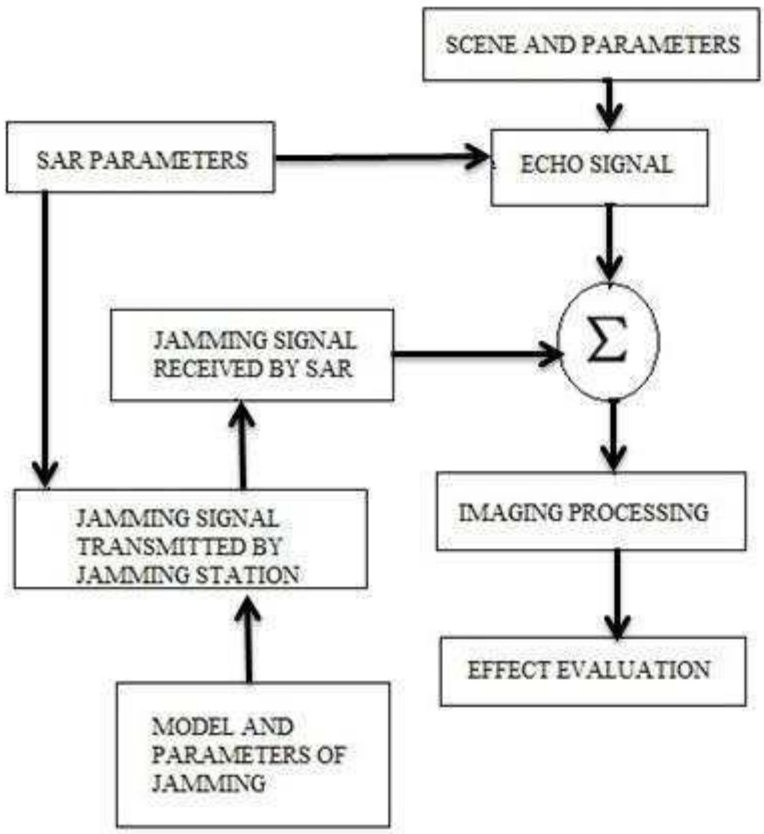

Figure 3.13 Flowchart of Simulation and Evaluation [13]

In order to generate a jamming signal that highly resembles the original echo signal, it is important that the jammer has knowledge about the SAR parameters. Higher the jamming signal resembles the echo, lesser is the power required by the jammer.

Image processing involves making use of suitable algorithm, to get the desired image using SAR. Here, Range Doppler Algorithm is used for image processing because it is computationally more efficient, and capable of giving satisfactory result.

3.5 RESULTS

The concept of jamming is explained by using three reflectivity profiles: two random objects; two airplanes; single airplane. The results obtained are as follows:

3.5.1 JAMMING OF TWO RANDOM OBJECTS

The actual image of two random objects, which is to be protected is the one shown in figure (3.14). The jamming signal scene generated is shown in figure (3.15); finally figure (3.16) depicts the jammed image.

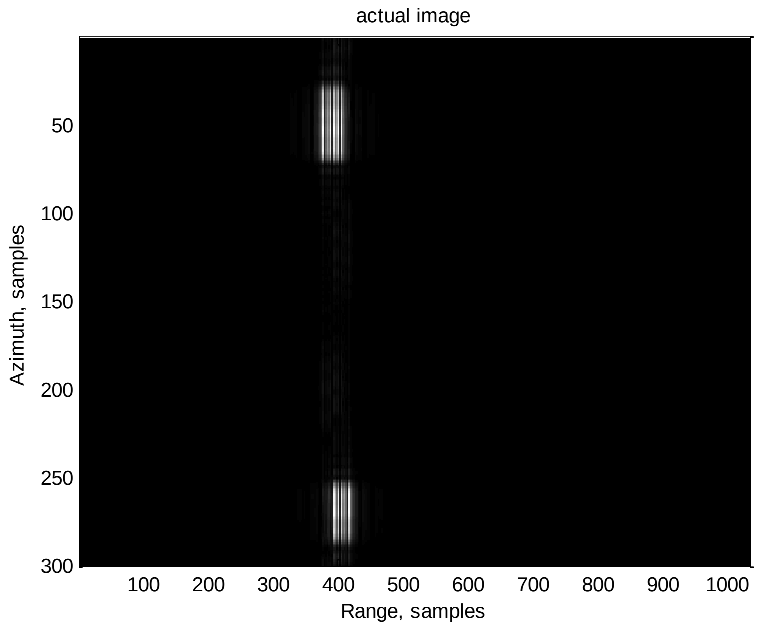

Figure 3.14 Actual Image of Two Random Objects

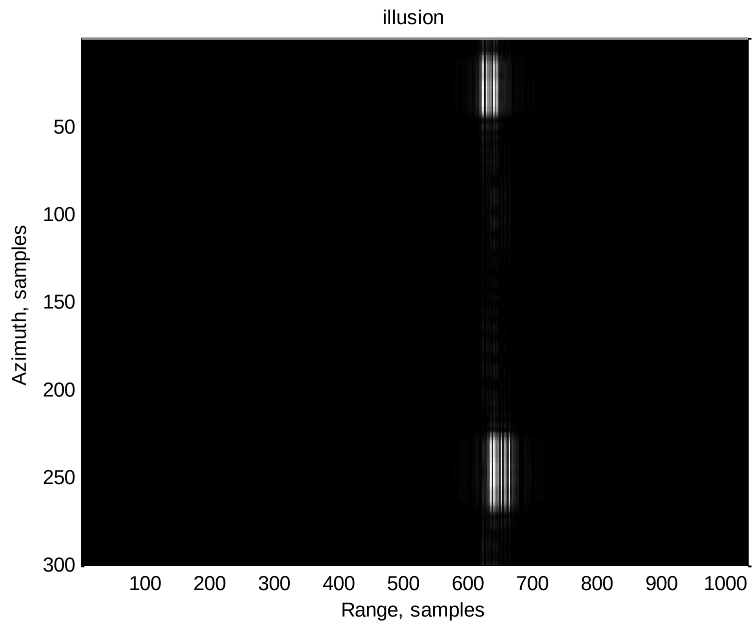

Figure 3.15 Illusion Scene

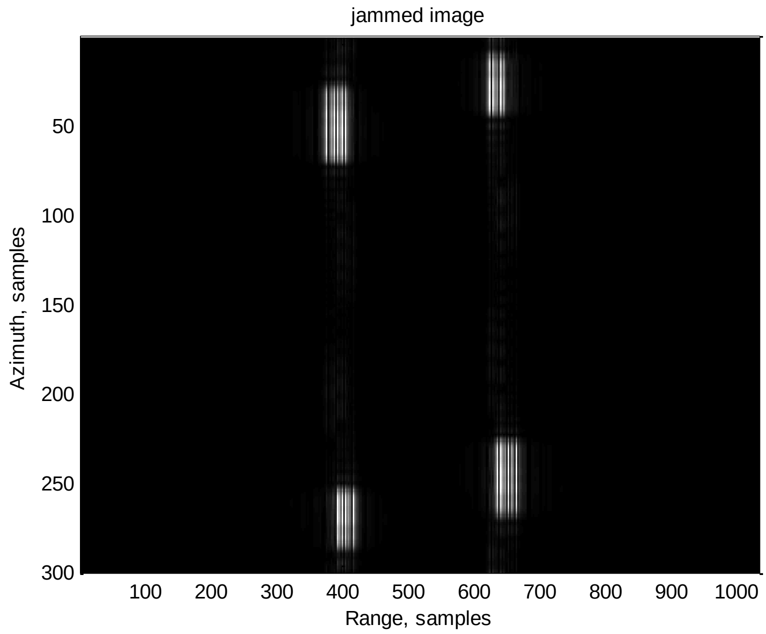

Figure 3.16 Jammed Image

3.5.2 JAMMING OF TWO AIRPLANES

The actual image of two airplanes, which is to be protected is the one shown in figure (3.17). The jamming signal scene generated is shown in figure (3.18); finally figure (3.19) depicts the jammed image.

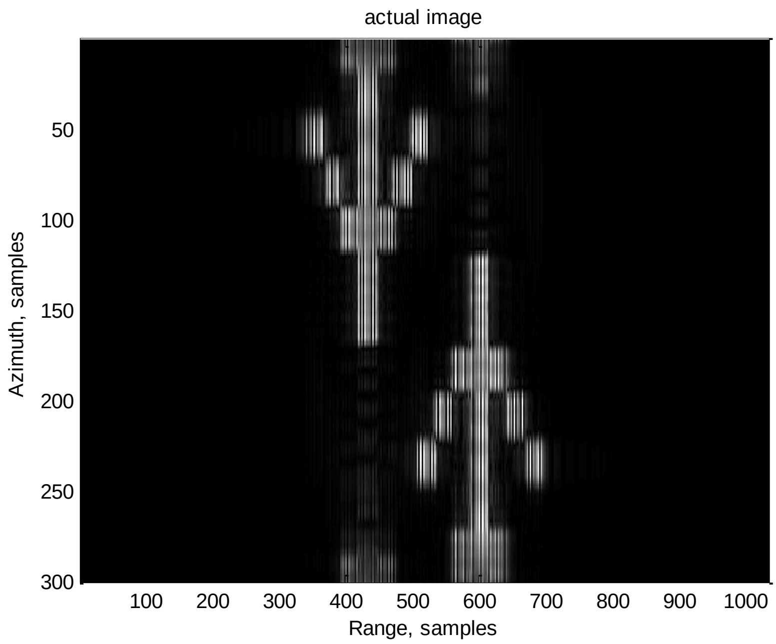

Figure 3.17 Actual Image of Two Airplanes

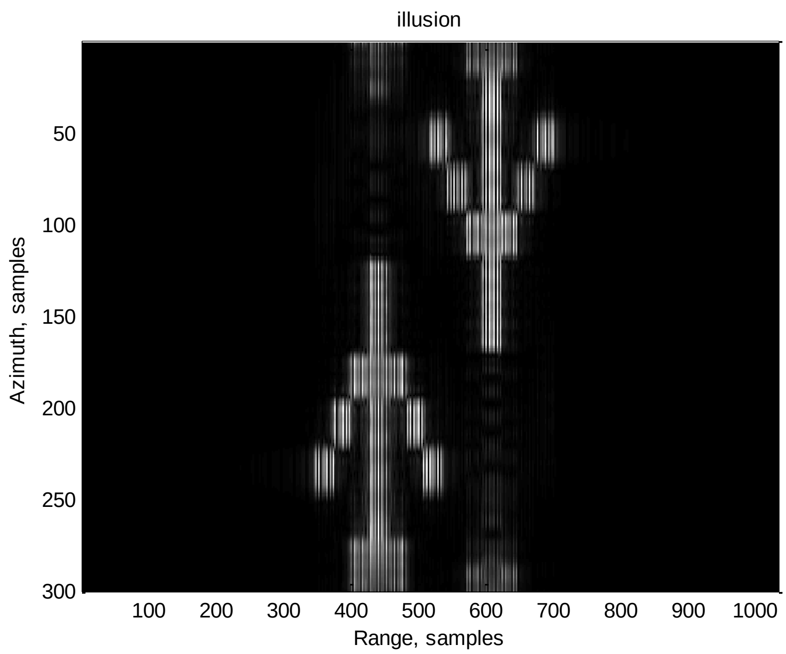

Figure 3.18 Illusion Scene

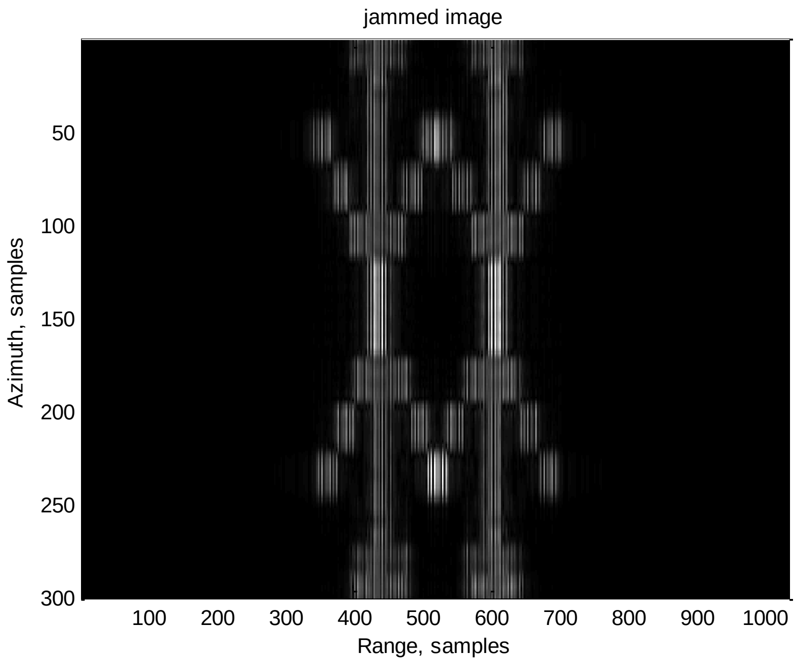

Figure 3.19 Jammed Image

3.5.3 JAMMING OF A SINGLE AIRPLANE

The actual image of a single airplane, which is to be protected is the one shown in figure (3.20). The jamming signal scene generated is shown in figure (3.21); finally figure (3.22) depicts the jammed image.

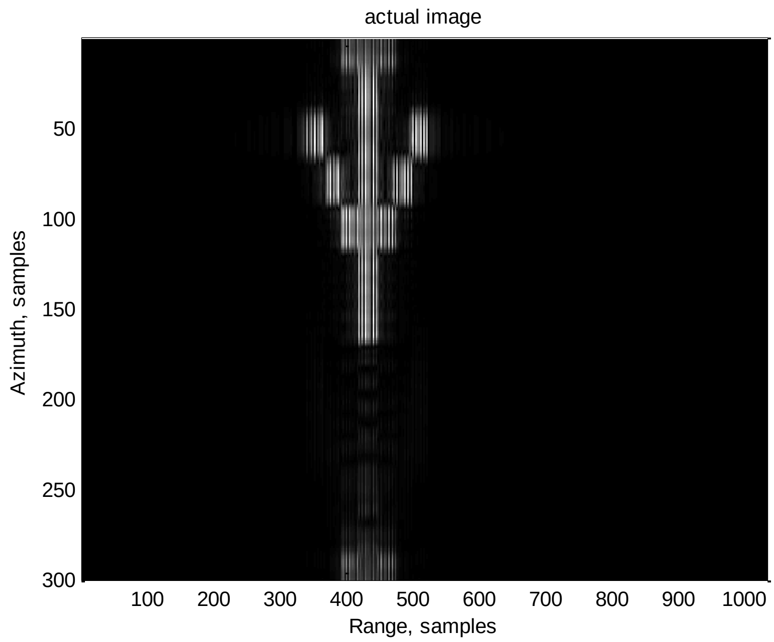

Figure 3.20 Actual Image of a Single Airplane

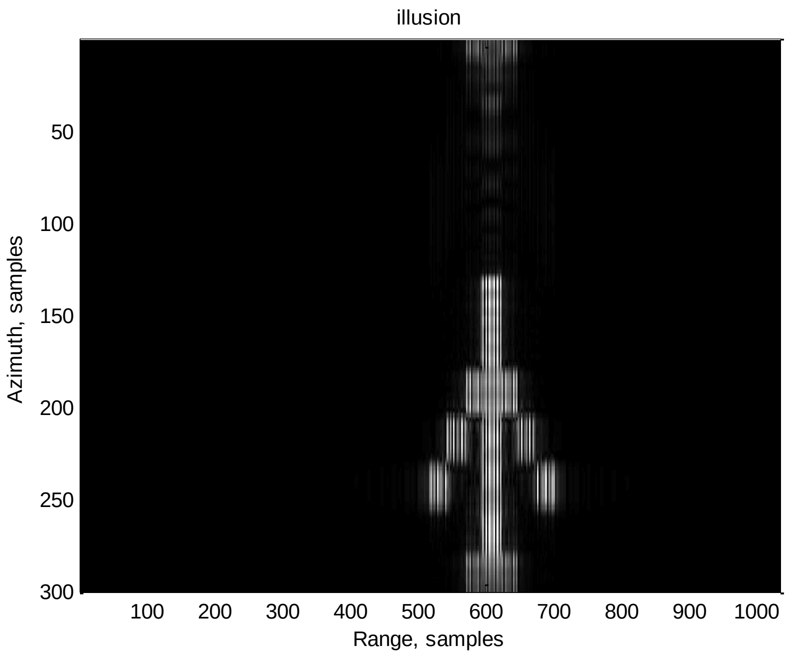

Figure 3.21 Illusion Scene

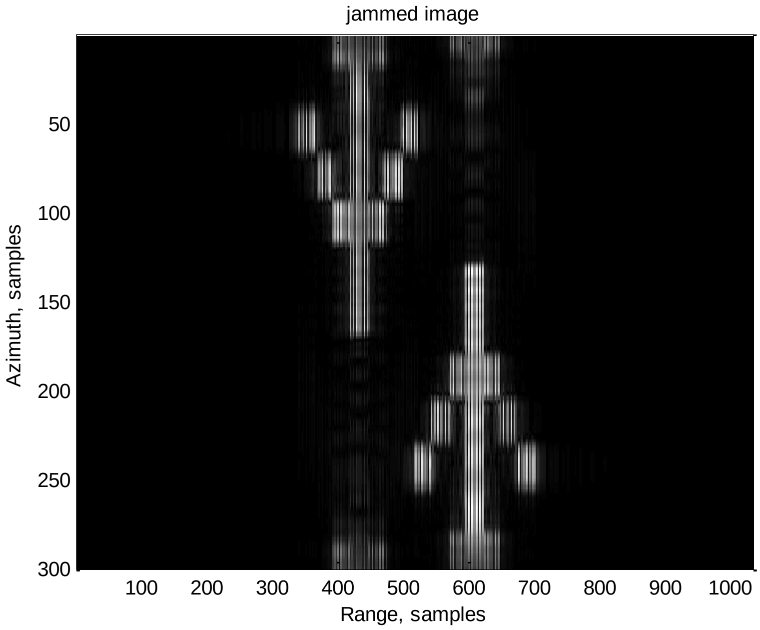

Figure 3.22 Jammed Image

CHAPTER 4

JAMMING ALGORITHM USING FRFT

In the above available method for generating jamming signal if FFT is replaced by Fractional Fourier Transform (FRFT) then even better results are obtained in terms of well-focused scatterers.

4.1 OVERVIEW OF FRFT

FRFT is essentially time frequency dissemination. It can be described as the generalization of FFT. FRFT is rich in theory, very flexible for applications. Hence, FRFT promisingly offers something in almost every area where Fourier transforms are applicable. A supplementary degree of freedom (order of the transform) which gives significant gains is enabled using FRFT. FFT can be called as the special case of FRFT. So any field that utilizes Fourier transforms can make use of FRFT for further improvements. To solve some classes of differential equations effectively in the area of quantum mechanics Namias introduced FRFT [41]. The discrete implementation of FRFT was introduced by Ozaktas, et al. [42]. After this, a variety of applications using FRFT have been made known, mainly in the area of optics.

The FRFT of a signal x (t) is described as: [43], [44]

$$X_P(t,u) = F^P[x(t)] = \int_{-\infty}^{\infty} x(t) K_\alpha(t,u)dt \tag{4.1}$$

Where,

$F^P[.]$ = FRFT operator

$K_\alpha(t,u)$ = kernel of FRFT

$$K_\alpha(t,u) = \begin{cases} \sqrt{\dfrac{1-jcot(\alpha)}{2\pi}} \exp\left(j\dfrac{t^2+u^2}{2}\cot(\alpha) - tu\csc(\alpha)\right), & \alpha \neq n\pi \\ \delta(t-u), & \alpha = 2n\pi \\ \delta(t+u), & \alpha = (2n+1)\pi \end{cases} \tag{4.2}$$

Where,

$$\alpha = P\frac{\pi}{2} \tag{4.3}$$

The computation of FRFT can be explained as a series of steps viz. multiplying with chirp in one domain, after this take FFT, and then multiplying with a chirp in the transform domain and then performing complex scaling. So, chirps form the basis functions for FRFT.

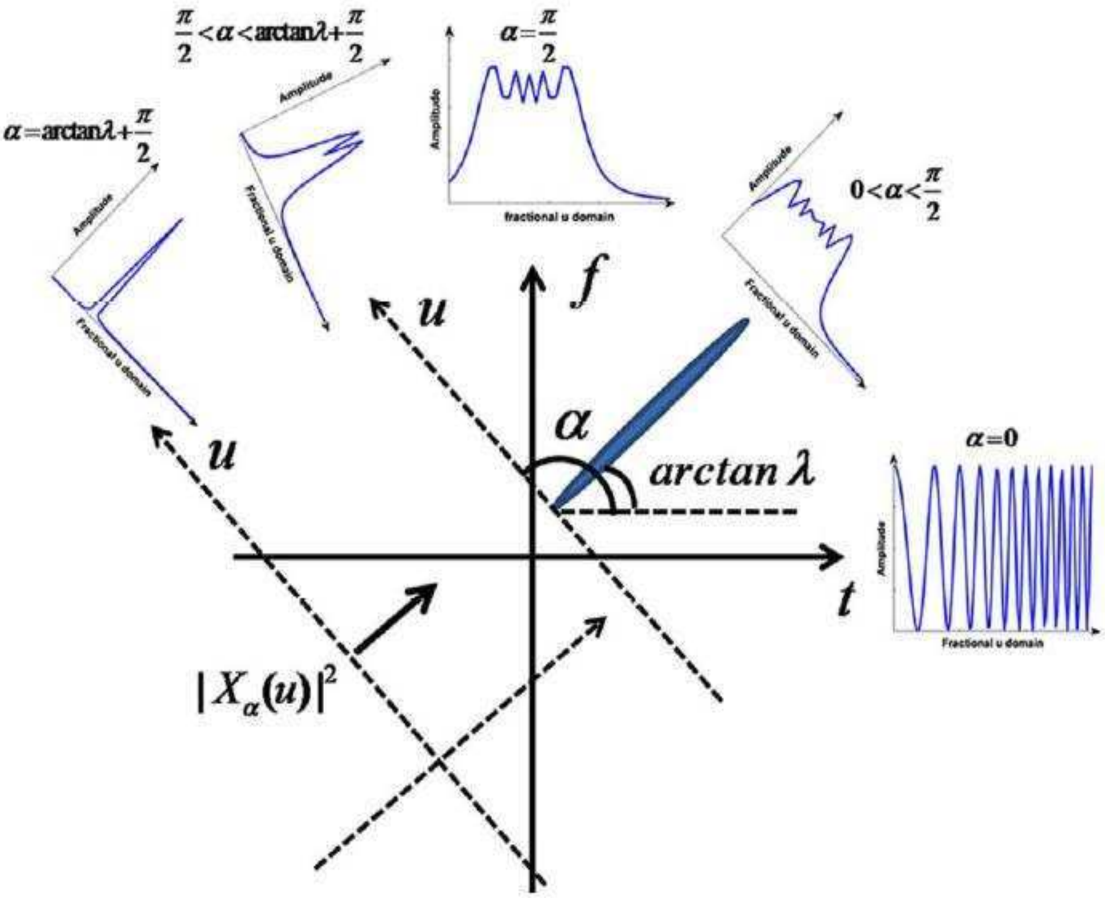

Figure 4.1 FRFT of the Chirp Signal *x(t)* with Different Order of Transform [43]

4.2 DESIRABLE FEATURES OF FRFT FOR JAMMING SYNTHETIC APERTURE RADAR

The signals that SAR transmits are frequency modulated chirp signal. The matched filters used in range and azimuth direction utilize chirp signal. In the time or frequency domain chirps are not compact. The basis functions in FRFT are the chirps; there exist an order in FRFT domain for which it is compact. So by using FRFT, improved solutions to problems can be obtained where chirps signals are involved. Jamming SAR using FRFT can help get rid of serious focus worsening of the false scatterers and for this reasonable computational load is needed.

4.3 THE FLOWCHART FOR JAMMING SIGNAL GENERATION

The below shown flowchart is achieved combining the ideas put forward by Liu, Y. et al. [12] and Long, S. et al. [13]. The main difference being that instead of using FFT, FRFT is used. While generating the original image also FRFT- RDA is used, i.e. replacing FFT by FRFT in the conventional RDA.

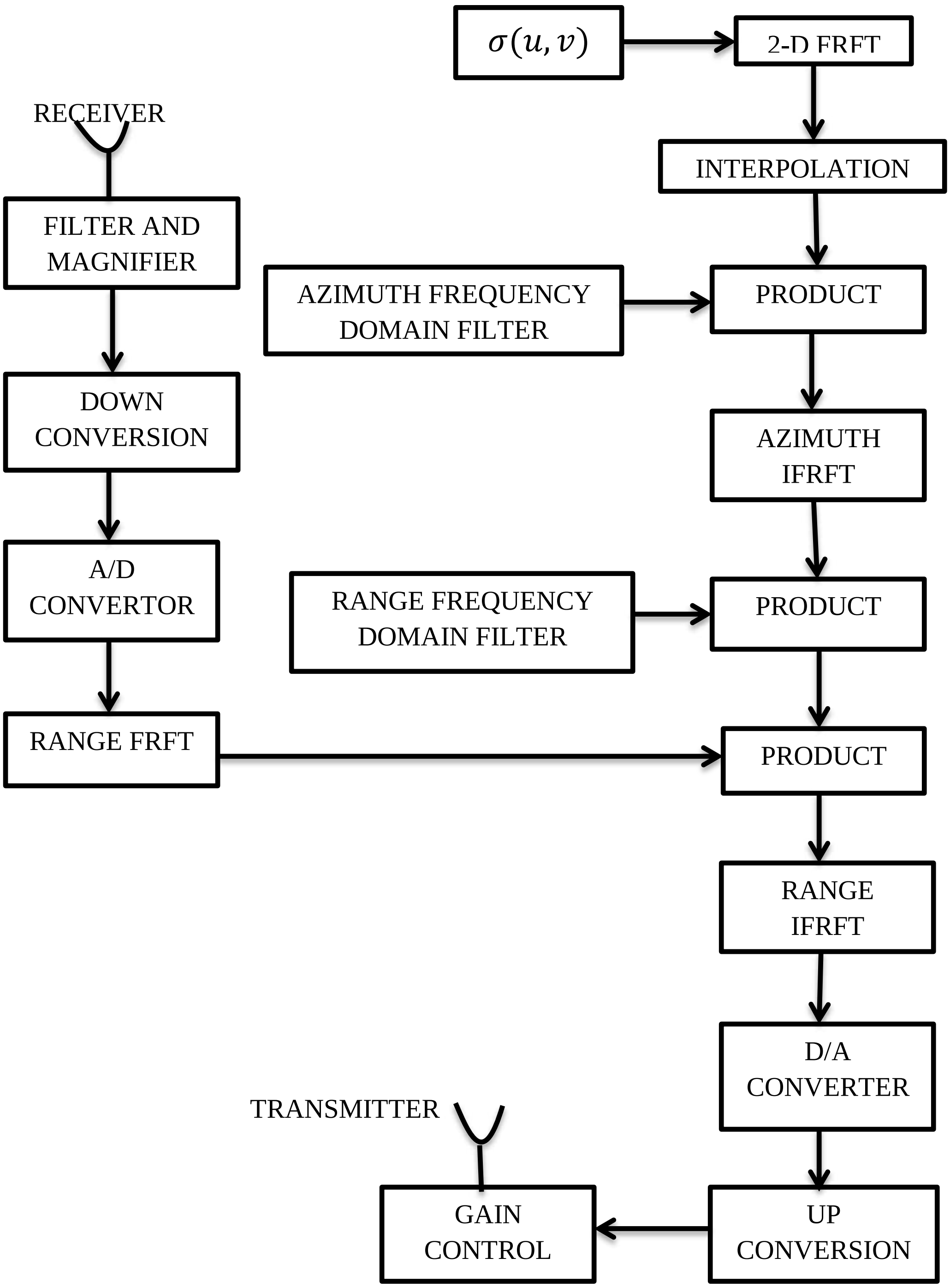

Figure 4.2 Proposed Flowchart for Jamming Signal Generation

- 2-D FRFT of $\sigma(u, v)$ is taken. A 2D interpolation is performed before performing multiplication and the inverse FRFT (IFRFT) so as to remove the non-uniformity in the samples.
- The reference signal for azimuth frequency domain filter is:

$$S_a = e^{j\pi K_{az} n} \tag{4.4}$$

  Where,

  K_{az} = azimuth chirp rate

- The reference signal for range frequency domain filter is:

$$S_r = e^{j\pi K_{rg}(t-t_d)^2} \tag{4.5}$$

  Where,

  K_{rg} = range chirp rate

- The signal transmitted by SAR is received then passed through stages comprising of a string of preprocessing including the antialiasing filter, an amplifier, a down convertor, an analog to digital convertor, range FRFT, and by post-processing's comprising of range IFRFT, a digital to analog convertor, an up convertor, gain controller.
- Finally, the jamming signal simulated using above method is again transmitted towards the radar.

4.4 RESULTS OBTAINED USING PROPOSED METHOD

The results are proved for the same reflectivity profiles as discussed in previous chapter; namely: two random objects, two airplanes, single airplane.

4.4.1 JAMMING OF TWO RANDOM OBJECTS

The actual image of two random objects, which is to be protected is the one shown in figure (4.3). The jamming signal scene generated is shown in figure (4.4), this scene comprises of two random artificial objects; finally figure (4.5) depicts the jammed image. In the jammed image it becomes difficult to distinguish actual targets from artificial objects.

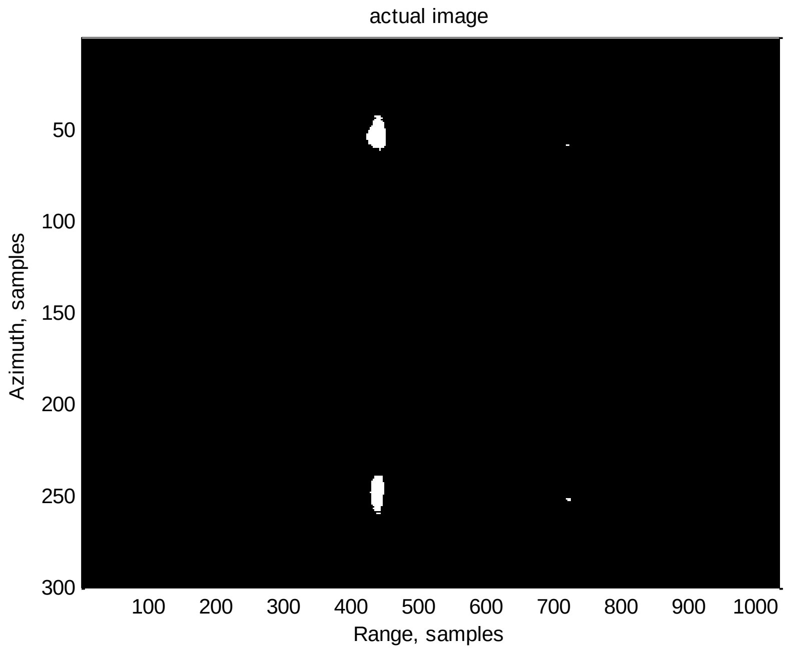

Figure 4.3 Actual Image of Two Random Objects

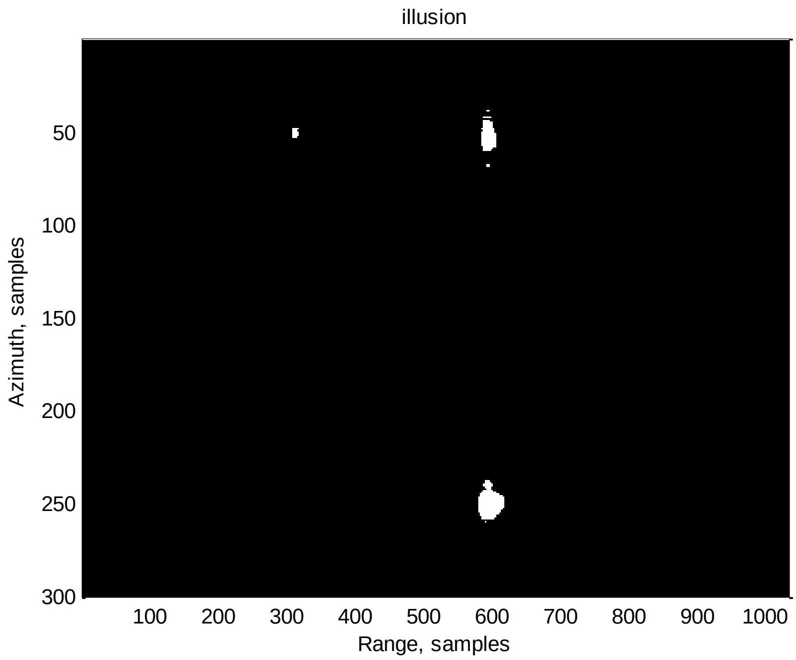

Figure 4.4 Created Illusion Scene

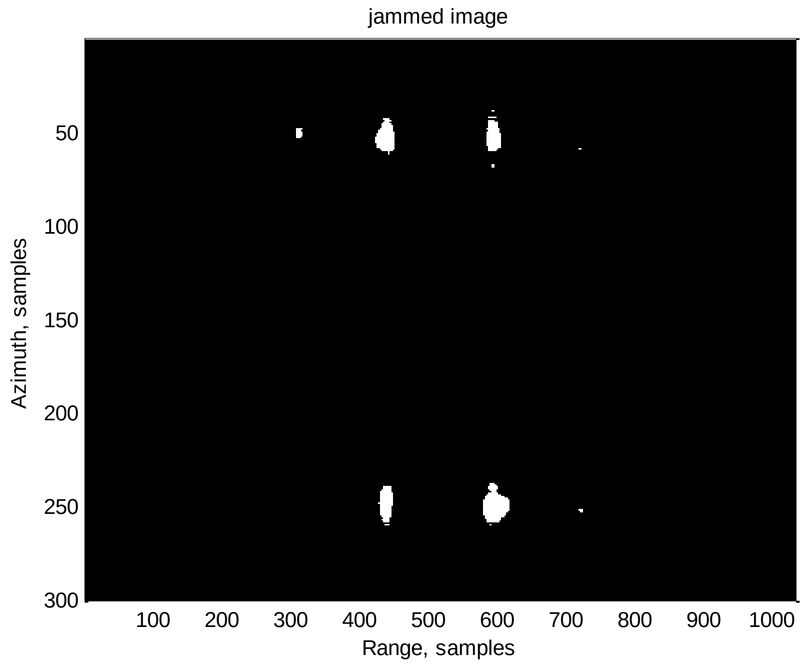

Figure 4.5 Jammed Image

4.4.2 JAMMING OF TWO AIRPLANES

The actual image of two airplanes, which is to be protected is the one shown in figure (4.6). The jamming signal scene generated is shown in figure (4.7); finally figure (4.8) depicts the jammed image.

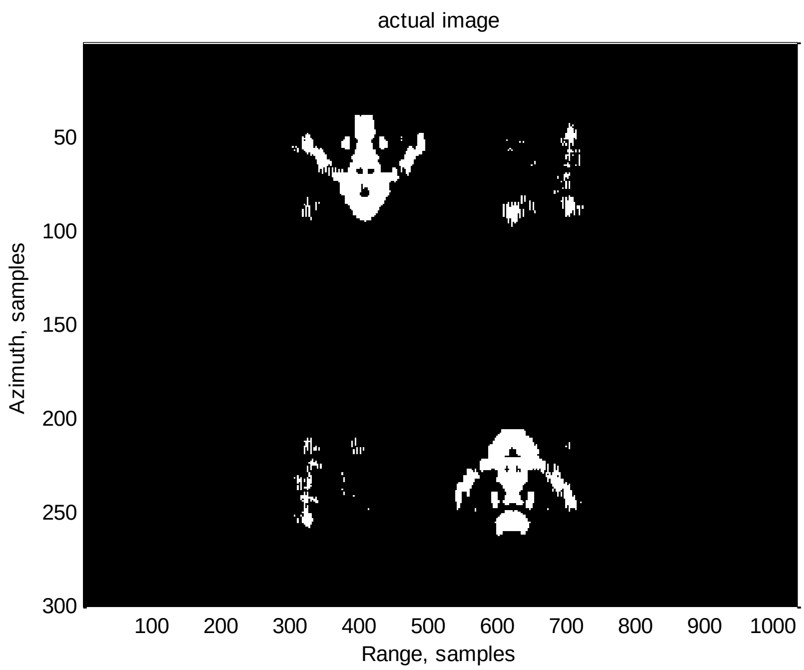

Figure 4.6 Actual Image of Two Airplanes

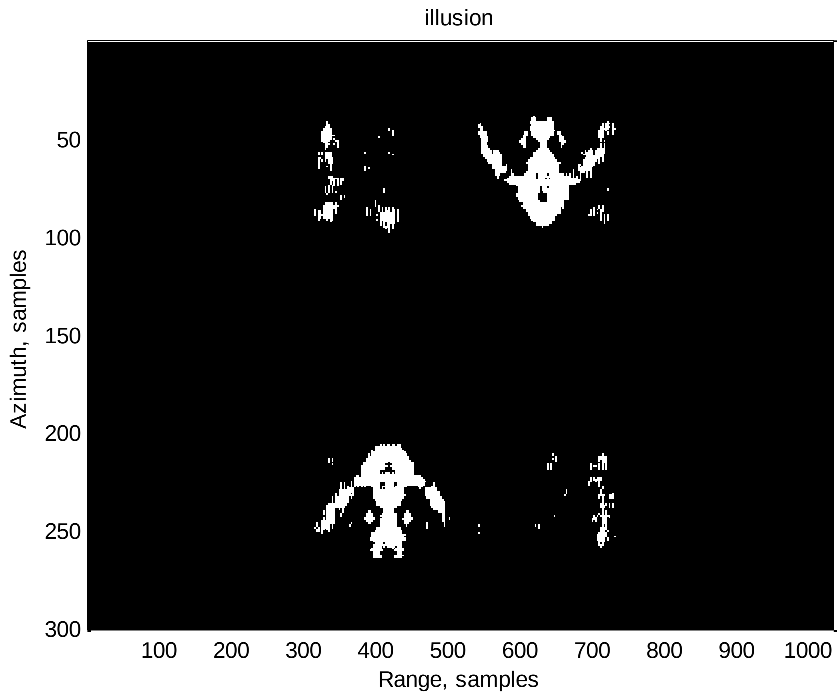

Figure 4.7 Created Illusion Scene

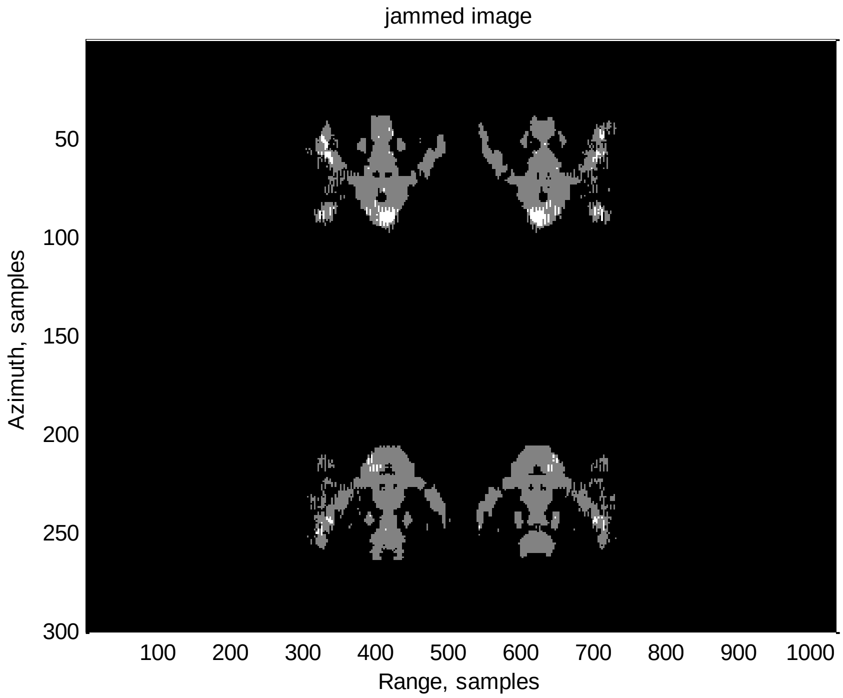

Figure 4.8 Jammed Image

4.4.3 JAMMING OF A SINGLE AIRPLANE

The actual image of a single airplane, which is to be protected is the one shown in figure (4.9). The jamming signal scene generated is shown in figure (4.10); finally figure (4.11) depicts the jammed image.

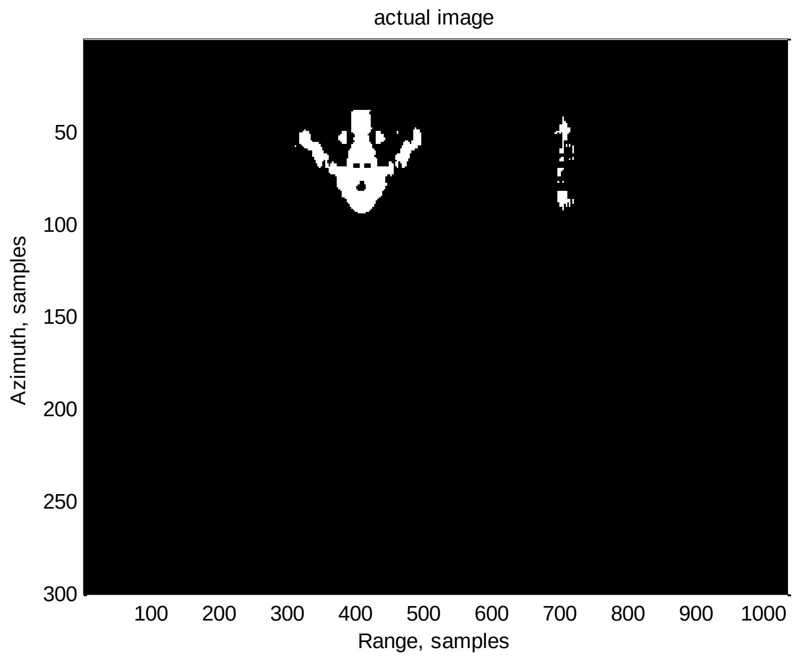

Figure 4.9 Actual Image of a Single Airplane

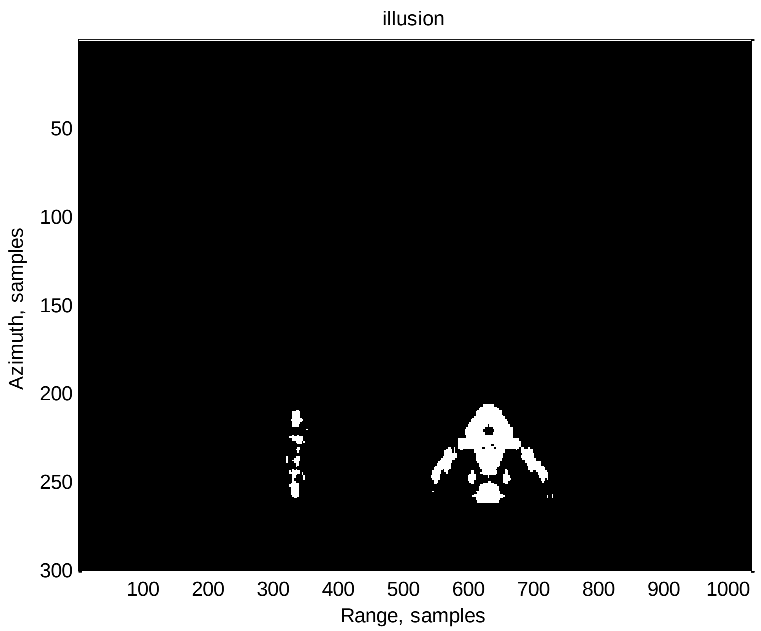

Figure 4.10 Created Illusion Scene

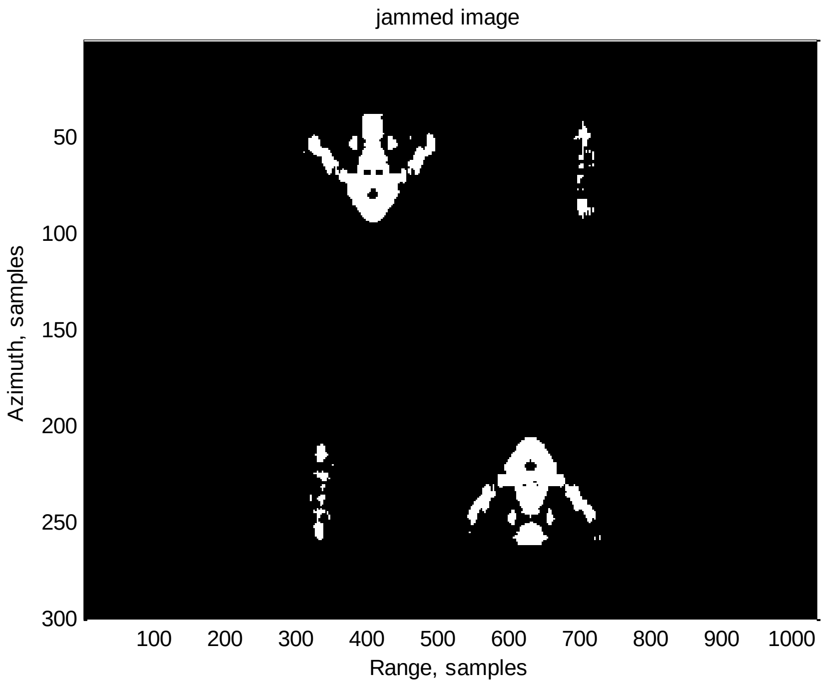

Figure 4.11 Jammed Image

CHAPTER 5

RESULT AND DISCUSSION

The results for different reflectivity profiles using the available and the proposed algorithm have been described above. Mainly three reflectivity profiles have been discussed: two random objects; two airplanes; single airplane. From the results obtained in chapter 3 and chapter 4, it becomes clear that more focused images are obtained using the proposed method for the same reflectivity profiles.

To prove this point a graph of jamming signal generated by the available approach and the proposed approach are plotted subsequently for the reflectivity profile: two airplanes.

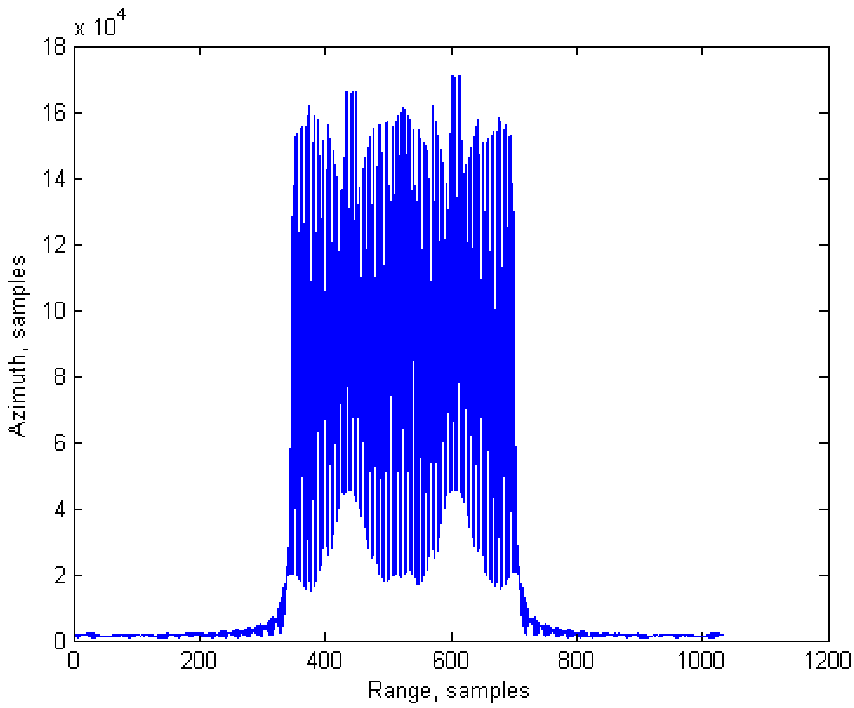

Figure 5.1 Jamming Signal Generated using FFT

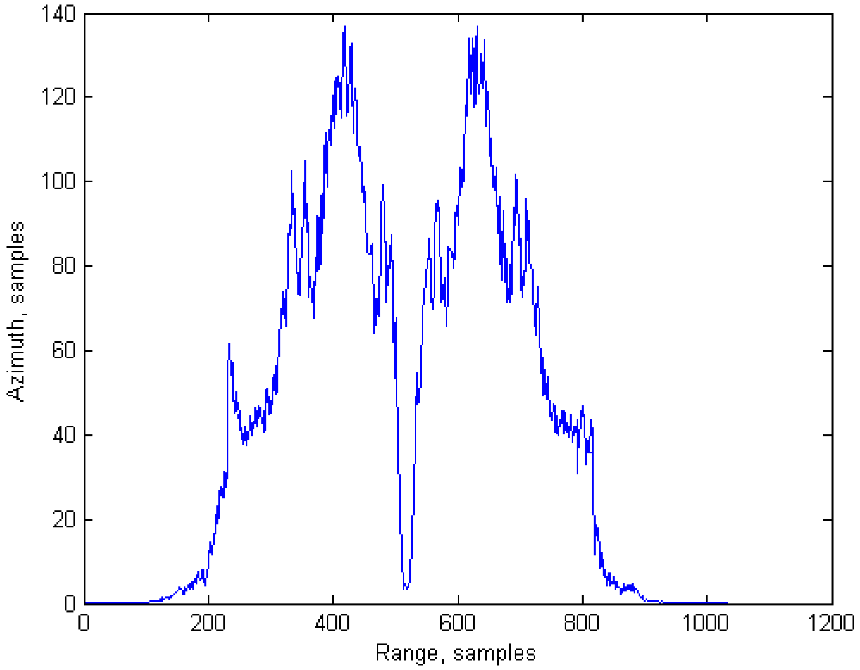

Figure 5.2 Jamming Signal Generated using FRFT

On comparing figure 5.1 and 5.2, it can be stated that a more focused jamming signal is generated using the proposed method. Hence we get rid of the serious focus worsening of fake scatterers.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

From the above discussion, it can be concluded that jamming of SAR is difficult. Jamming of SAR requires high processing gains as compared to jamming conventional radar. Serious focus worsening of the fake or virtual scatterers and maintaining reasonable computational load are the main problems that a jamming technique needs to tackle.

The fractional Fourier transform is a time-frequency analysis tool and it is gaining tremendous attention in signal processing. Almost any field which uses FFT can be implemented using FRFT.

Jamming of SAR using FRFT can help get rid of serious focus worsening of the virtual scatterers and maintain a reasonable computational load. As shown in figure (5.1) and (5.2), it can be concluded that Jamming signal generated using FRFT is more focused as compared to the one obtained using FFT.

6.2 FUTURE SCOPE

The dissertation presents the results of the algorithm already available and also for the work carried out on the application of FRFT in jamming synthetic aperture radar. But nothing has been discussed regarding the future work that could be carried out. Some possible areas for further studies or improvement are suggested below:

- FRFT is preferable for processing non-stationary signals. So, jamming moving targets using FRFT can produce good results.
- The algorithm used for generating jamming signal is efficient but consumes more time. So, this area needs improvement.

APPENDIX A: SAR SIMULATION PARAMETERS

PARAMETER	VALUE
Pulse Repetition Frequency	300 Hz
Duration	1 second
Velocity of Platform	200 m/s
Carrier Frequency	4.5 GHz
Actual Length of Antenna	2 m
Chirp Pulse Duration	2.5 μs

REFERENCES:

[1] Richards, M.A., Fundamentals of Radar Signal Processing, second edition, Mc Graw-Hill, 2014.

[2] Franceschetti, G.; Lanari, R., Synthetic Aperture Radar Processing, CRC press, 1999.

[3] Jennifer, R.J., “Development and Analysis of wavelet based speckle reduction algorithms for synthetic aperture radar images,” PHD thesis, Anna University, 2013.

[4] Cumming, I.G and Wong, F.H., Digital Processing of Synthetic Aperture Radar Data: Algorithms and Implementations. Norwood, MA: Artech House, Inc., 2005.

[5] Schlutz, M., “Synthetic Aperture Radar Imaging Simulated in MATLAB,” Master’s Thesis, California Polytechnic State University, San Luis Obispo California, 2009.

[6] Akliouat, H.; Smara, Y.; Bouchemakh, L., “Synthetic aperture radar image formaton process: application to a region of North Algeria,” Proc. Envisat Symposium 2007, Montreux, Switzerland, 2007.

[7] Nan,L.; Changwen, Q., “Research on Jamming Synthetic Aperture Radar Technologies,” 1st Asian and Pacific Conference on Synthetic Aperture Radar, APSAR, pp. 563 - 566, 2007.

[8] Shenghua, Z. ; Dazhuan, X. ; Xueming, J. ; Hua, H., “A study on active jamming to synthetic aperture radar,” 3rd International Conference on Computational Electromagnetics and Its Applications proceedings, pp. 403-406, 2004.

[9] Zhou, F.; Zhao, B.; Tao, M.; Bai, X.; Chen, B.; Sun, G., “A Large Scene Deceptive Jamming Method for Space-Borne SAR,” IEEE Transactions on Geoscience and Remote Sensing, Vol. 51, No. 8, 2013.

[10] Zhang, H.; Tang, Y.; Wu, G.; Sun, L., “SAR Deceptive Jamming Signal Simulation,” 1st Asian and Pacific Conference on Synthetic Aperture Radar, pp. 61-64, 2007.

[11] Zhao, B.; Zhou, F.; Tao, M.; Zhang, Z.; Bao, Z., “Improved method for synthetic aperture radar scattered wave deception jamming,” IET Radar Sonar Navigation, Vol. 8, Iss. 8, pp. 971–976, 2014.

[12] Liu, Y.; Wang, W.; Pan, X.; Dai, D.; Feng, D., "A frequency-domain three-stage algorithm for active deception jamming against synthetic aperture radar," IET Radar Sonar Navigation, Vol. 8, Iss. 6, pp. 639–646, 2014.

[13] Long, S.; Hong-rong, Z.; Yue-sheng, T.; Chang-yao, Z., "Research on deceptive jamming technologies against SAR," Second Asian-Pacific Conference on Synthetic Aperture Radar, China, pp. 521–525, 2009.

[14] Xu, L.; Feng, D.; Wang, X., "Improved synthetic aperture radar micro-Doppler jamming method based on phase-switched screen," IET Radar Sonar Navigation, Vol. 10, Iss. 3, pp. 525–534, 2016.

[15] Meng, Z.; Li, Y.; Li,C.; Xing, M.; Bao, Z., "A raw data simulator for Bistatic Forward-looking High-speed Maneuvering-platform SAR," Signal Processing, Vol. 117, pp. 151–164, 2015.

[16] Zhao, H., "Simulation of Barrage-Type Jamming for Synthetic aperture radars," ISECS International Colloquium on Computing, Communication, Control, and Management, Vol. 2, pp. 462-465, 2008.

[17] Jiang, J.; Wu, Y. ; Wang, H., "Analysis of Active Noise Jamming Against Synthetic Aperture Radar Ground Moving Target Indication," 8th International Congress on Image and Signal Processing (CISP), pp. 1530-1535, 2015.

[18] Huang, H.; Huang, Z.; Zhou, Y., "Jamming Research to SAR based on Frequency Characteristic," 2nd International Conference on Signal Processing Systems (ICSPS), Vol. 2, pp. V2-144 - V2-147, 2010.

[19] Huang, H.; Zhou, Y., "An inter/intra-pulse partly coherent jamming style against Synthetic Aperture Radar," IEEE 11th International Conference on Signal Processing (ICSP), Vol. 3, pp. 2020-2022, 2012.

[20] Raney, R.K. ; Runge, H. ; Bamler, R. ; Cumming, I. G., "Precision SAR processing using chirp scaling," IEEE Transactions on Geoscience and Remote Sensing, Vol. 32 , Iss. 4, 1994.

[21] Bamler, R., "A Comparison of Range-Doppler and Wavenumber Domain SAR Focusing Algorithms," IEEE Transactions on Geoscience and Remote Sensing, Vol. 30, Iss. 3, pp. 706-713, 1992.

[22] Smith, A.M., "A new approach to range-Doppler SAR processing," International Journal of Remote Sensing, Vol. 12, pp. 235-251, 1991.

[23] Rocca, F., Prati, C, and Guarnieri, A.M., "New algorithms for processing of SAR data," ESA Contract Report, ESRIN Contract No. 7998/88/F/FL(SC), 1989.

[24] Raney, R. K. and Vachon, P.W., "A Phase Preserving SAR Processor," in: Processing IGARSS '89, pp. 2588-2591, 1989.

[25] Franceschetti, G. and Schirinzi, G., "A SAR processor based on two dimensional FFT codes," IEEE Transactions on Aerospace and Electronic System, Vol. 26, pp. 356-366, 1990.

[26] Franceschetti, G.; Guida, R.; Iodice, A.; Riccio, D.; Ruello, G., "Efficient simulation of hybrid stripmap/spotlight SAR raw signals from extended scenes," IEEE Transactions on Geoscience and Remote Sensing, Vol. 42, Iss. 11, pp. 2385–2396, 2004.

[27] Franceschetti, G., Iodice, A., Perna, S., Riccio, D. "Efficient simulation of airborne SAR raw data of extended scene," IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, Iss. 10, pp. 2851–2860, 2006.

[28] Bultheel, A.; Sulbaran, H.E.M., "Computation of the fractional Fourier transform," Applied and Computational Harmonic Analysis, Vol. 16, pp.182–202, 2004.

[29] Pei, S. C.; Yeh, M. H.; Tseng, C. C., "Discrete fractional Fourier-transform based on orthogonal projections," IEEE Transactions on Signal Processing, Vol. 47, Iss. 5, pp. 1335–1348, 1999.

[30] Ozaktas, H.M.; Kutay, M.A.; Bozdagi, G., "Digital computation of the fractional Fourier transform," IEEE Transactions on Signal Processing, Vol. 44, Iss. 9, pp. 2141– 2150, 1996.

[31] Candan, C.; Kutay, M.A.; Ozaktas, H.M., "The discrete fractional Fourier transform," IEEE Transactions on Signal Processing, Vol. 48, Iss. 5, pp. 1329–1337, 2000.

[32] Patel, R., "Review Paper on Fractional Fourier Transform," International Journal of Innovative Research in Science and Engineering, Vol. 2, Iss.5, 2016.

[33] Deng, B.; Qin, Y.; Li, Y.; Wang, H.; Li, X., "A Novel Approach to Range Doppler SAR Processing Based on Legendre Orthogonal Polynomials," IEEE Geoscience and Remote Sensing Letters, Vol. 6, Iss. 1, 2009.

[34] Yan, Z.; Guoqing, Z.; Yu, Z., "Research on SAR Jamming Technique Based on Man-made Map," CIE International Conference on Radar, pp. 1-4, 2006.

[35] Xiaohong, L.; Peiguo, L.; Guoyi, X., "Fast Generation Of SAR Deceptive Jamming Signal Based On Inverse Range Doppler Algorithm," IET International Radar Conference, pp. 1- 4, 2013.

[36] Clemente, C.; Soraghan.J.J., "Fractional Range Doppler Algorithm for SAR Imaging," European Radar Conference (EuRAD), pp. 248-251, 2010.

[37] Soraghan, J.J.; Clemente, C., "Range Doppler and chirp scaling processing of synthetic aperture radar data using the fractional Fourier transform," IET Signal Processing, Vol. 6, Iss. 5, pp. 503–510, 2012.

[38] El-Mashed, M.G.; Zahran, O.; Dessouky, M.I.; El-Kordy, M.; Abd El-Samie, F.E., "Synthetic aperture radar imaging with fractional Fourier transform and channel equalization," Digital Signal Processing, Vol. 23, pp. 151–175, 2013.

[39] Lee, Y.J. ; Park, J.R. ; Shin, W.H. ;Lee, K., "A study on jamming performance evaluation of noise and deception jammer against SAR satellite," 3rd International Asia-Pacific Conference on Synthetic Aperture Radar (APSAR), pp. 1-3, 2011.

[40] Kutay, A.; Ozaktas, H.M.; Ankan, O.; Onural, L., "Optimal filtering in fractional Fourier domains," IEEE Transactions on Signal Processing, Vol. 45, Iss. 5, pp. 1129-1143, 1997.

[41] Namias, V., "The Fractional Order Fourier Transform and its Application to Quantum Mechanics," Journal of the Institute of mathematics, Vol. 25, pp. 241-265, 1980.

[42] Ozaktas, H.; Zalevsky, Z.; Kutay,A., FrFT with Applications in Optics and Signal Processing, John Wiley and Sons Publication, 1st edition, 2001.

[43] Capus, C.; Brown,K., "Short-Time Fractional Fourier Methods for Time-Frequency Representation of Chirp Signals," Journal of Acoustical Science of America, Vol. 113, ISS. 6, pp. 234-240, 2003.

[44] Capus, C.; Rzhanov, Y.; Linnett, L., "Analysis of Multiple Linear Chirp Signals," IEE Seminar on Time-Frequency Analysis and Application, pp. 1-7, 2000.

[45] Poularikas, A.D., Transforms and Applications Handbook, 3rd edition, 2010.

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