"GENERATION OF SYNTHETIC APERTURE RADAR IMAGES USING RANGE DOPPLER ALGORITHM"

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DECLARATION

I, Harkamal Kaur, hereby declare that the work presented in this thesis entitled, **"GENERATION OF SYNTHETIC APERTURE RADAR IMAGES USING RANGE DOPPLER ALGORITHM",** in partial fulfilment of the requirement of the award degree of Master of Engineering submitted at Electronics and Communication Engineering Department, Thapar Institue of Engineering and Technology, Patiala is an authentic record of work carried out under supervision of Dr. Ashutosh Kumar Singh (Assistant Professor, ECED, TIET, Patiala). The matter present in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 13 July, 2018

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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

Applications of self-illuminating remote sensing systems, and among those, Radar Imagery is growing rapidly. Unique properties of Synthetic Aperture Radar (SAR) system makes it one of the most popular and applicable methods of self illuminating remote sensing techniques for ground deformation monitoring, seismic studies, and many photogrammetry applications. There are several methods and algorithms for processing SAR data, each are convenient for different purposes. Two more common and reliable algorithms are developed in this thesis: a Range Doppler Algorithm and a Chirp Scaling Algorithm. Also Echo cancellation is of great potential for a radar cross section reduction in stealth technology. All the techniques developed in the last decade rely primarily on the assumption that cancellation echo and target echo synchronize in the time domain. However, the cancellation echo may lag behind the target echo when countering a synthetic aperture radar (SAR). This is because the cancellation echo generation requires extra processing time when the SAR transmits and receives large time bandwidth product signal such as linear frequency modulation pulses. In this we used the range Doppler algorithm for the processing of SAR images.

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LIST OF ABBREVIATIONS

SAR	Synthetic Aperture Radar
SLAR	Side Looking Airborne Radar
ISAR	Inverse Synthetic Aperture Radar
DRFM	Digital Radio Frequency Memory
PRI	Pulse Repetition Frequency
POLSAR	Polarimetric Synthetic Aperture Radar
LMS	Least Mean Square
FRFT	Fractional Fourier Transform
NBI	Narrow Band Interference
CEMD	Complex Empirical Mode Decomposition
LMF	Linear Modulating Frequency
GMTI	Ground Moving Target Indication
DPCA	Displaced Phase Centre Antenna
RCMC	Range Cell Migration Correction
AEC	Active Echo Cancellation
MLP	Multi Layer Protection
FMCW	Frequency Modulating Continuous Wave
RMA	Range Migration Algorithm

CHAPTER -1
INTRODUCTION

Synthetic aperture radar is a form of radar that is used to create two- or three-dimensional images of objects. A SAR is an instrument capable of obtaining a map of the reflectivity of a planetary surface. SAR uses the motion of radar antenna over a target region to provide with detailed spatial resolution than conventional beam-scanning radar. It is typically mounted on a moving surface, such as an aircraft or spacecraft. SAR has its origins in an advanced form of side looking airborne radar(SLAR)[1].

A SAR is an instrument capable of obtaining a map of the reflectivity of a planetary surface. The distance travelled by SAR device over a time taken by radar pulse to return at antenna creates the large synthetic antenna aperture[2]. So larger the aperture, higher will be the image resolution. A SAR image represents the back scatter of microwave energy over the surface being observed, and this inturn depends upon the properties such as, slope, roughness, dielectric constant and inhomogeneities. All these dependencies allow SAR images to be used in synchronicity with scattering mechanism model to measure the characteristics of earth's surface.

1.1 BASIC PRINCIPLE:

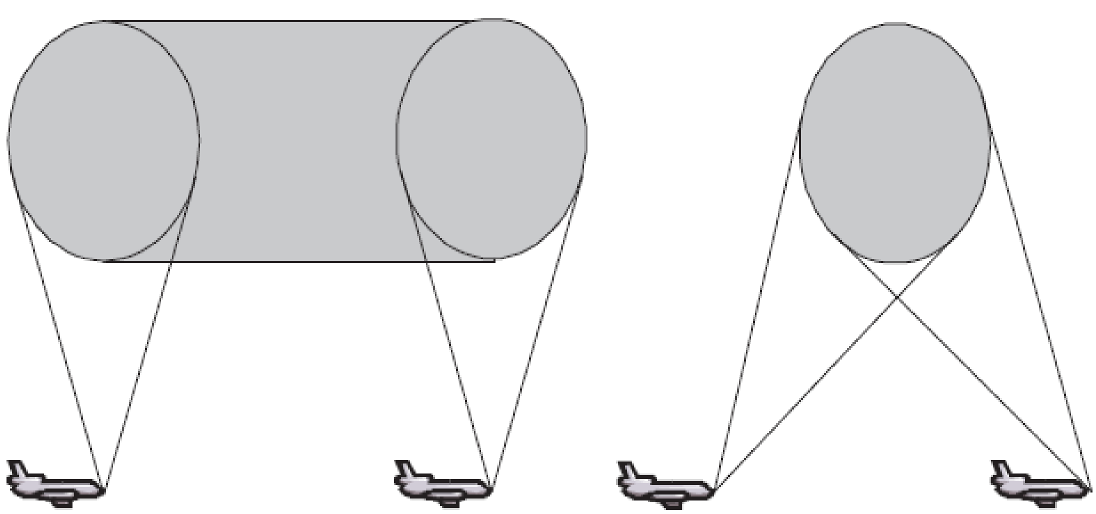
SAR is an imaging radar placed on a moving platform. Electromagnetic waves are sequentially transmitted and the reflected echoes are collected, digitized and stored by radar antenna for processing the information later on. As the transmission and reception takes place at different times, they map to different positions. The received signals are combined and are put in an order and these signals build a virtual aperture that is much longer than the physical length[3]. This is the reason it is called synthetic aperture, and gives the property of being an imaging radar.

1.2 ALGORITHM:

The SAR algorithm generally applies for phased arrays. The volume of space within which the target exists, is represented by three dimensional array of scene elements. Each element of array is a cubical voxel, which represents the probability of a reflective surface present at that location in space. Initially, each voxel is given zero density by SAR algorithm. The entire volume is iterated for each captured waveform[4]. For a given voxel and waveform, the distance from the antenna capturing the waveform and the position represented by the voxel is calculated. That separation speaks to time delay into the waveform. The value of sample at that situation in waveform is then added to the value of density of voxel. Possible echo by the target is represented at that position. The SAR handling is finished after the sum total of what waveforms have been iterated over all the voxels.

1.3 IMAGING MODES:

SAR has several imaging modes. The two basic SAR data-collection modes are stripmap mode and spotlight mode as shown in figure. In the stripmap mode, the antenna impression clears along a segment of landscape parallel to the sensor's light. In the conventional stripmap mode, the antenna is directed perpendicular to the radar light. This is known as the broadside stripmap imaging mode[5]. However, in some situations, the antenna is directed either in the forward direction or in a backward direction. This is the squinted stripmap imaging mode. In the spotlight mode, the footprint of antenna is guided continuously to illuminate an area of the territory.



(a) stripmap mode (b) spotlight mode

Figure 1.1: Basic SAR imaging modes.

The antenna platform can be operated in different configurations. A monostatic system is one where the transmitter and receiver are collocated. A bistatic SAR has separate transmitter and receiver sites. A multistatic SAR has more than two platforms, serving as a transmitter, a receiver or both. A multistatic SAR can often be analyzed as a collection of bistatic systems.

1.4 SAR JAMMING:

SAR has its own special features which are different from conventional radar. SAR jamming is more difficult because it has high processing gain. In some military scenarios SAR jamming is important[6]. Starting with its operating features, the possibility and effectiveness of several methods active for SAR jamming are analysed. SAR jamming can be done by two methods:

1.4.1 Barrage Jamming: It is a radio jamming technique, which is proficient by transmitting a band of frequencies which is huge when contrasted with transmission capacity of a solitary producer. Barrage jamming might be accomplished by presenting numerous jammers on adjoining frequencies. It can be accomplished by either utilizing a transmitter that is fit for clearing frequency sufficiently quick to influence it to seem in a steady progression over wide band, or by utilizing a solitary wideband transmitter. The favorable circumstances are accomplished at the cost of diminished sticking force at any of the given frequency.

1.4.2 Deceptive Jamming: It is an electronic warfare technique used against conical radiating radar systems. A false signal is generated which fools the radar into believing that target is on one side of boresight, which causes the radar to walk away from target. This technique is not useful against monopulse radar.

1.5 APPLICATIONS:

There are many applications for SAR imaging in physical sciences. In oceanography, to determine the direction and motion of ocean waves, images are analysed. In polar areas, the first-year ice and multi-year ice can be differentiated, which is very important for navigation. There are geological applications which covers the classification of types of rocks based on roughness and the determination of large scale structural features. SAR imaging is applicable in vegetation area as well. The scattering mechanism depends upon density and plant type. This is used for classification of crops and deforestation monitoring.

Current SAR systems are designed to obtain images at polarization, incidence angles and multiple wavelengths. This allows the extraction of more information from SAR, because the scattering mechanism are sensitive to these parameters. There is another recent development which is the emergence of applications of SAR imaging which uses the phase of image pixels. Using different polarizations the phase difference between images is obtained which can be related to scene properties[7]. A SAR is an instrument capable of obtaining a map of the reflectivity of a planetary surface. The accuracy and calliberation of images becomes more and more important as the applications of SAR imaging are becoming sophisticated. Therefore, it is important that the SAR data should be processed accurately throughout the image.

1.6 SAR PROCESSING:

In the scene to be imaged, the dimension perpendicular to the flight path is referred to as range and the dimension along the flight path is referred to as azimuth. Range resolution is obtained by transmitting a large bandwidth pulse. To improve the signal to noise ratio, a long phase encoded pulse such as linear fm chirp is transmitted, and the received signal is compressed in range dimension by the means of matched filter. Azimuth resolution would be limited to bandwidth of antenna[8]. For improving the azimuth resolution, consider a signal received from single point scatterer. At each time a pulse is transmitted and received, the moving platform is in a different position. If the received signal is demodulated coherently, then the phase of received echoes will vary with respect to azimuth position. To compress the data in azimuth direction, this phase variation can be matched, and received echoes can be processed in a phased array as elements. The length of this synthesized array, called aperture, is determined by the amount of time the scatterer is covered by antenna beam.

The distance to point scatterer can vary over aperture by more than the range resolution. This is called range cell migration. therefore in order to form the synthesized array for point scatterer, the data values aong the range migration curve need to be interpolated. also because the point scatterer response depends on the scatterer’s location in range direction, this correlation must be range variant. the objective of SAR processing algorithm is that images can be formed efficiently, but without noticeable degradation in the quality of image[9]. Approximations can be made which allows processing to be done in range time domain and the azimuth frequency. SAR processing can be thought of as using the range time delay and the Doppler history of the scatterer in order to locate its position in image.

CHAPTER 2

LITERATURE SURVEY

Many papers have been published on the recent researches and developments in the direction of improving the performance of radar and echo cancellation and generating better SAR images by reducing the noise. A brief summary is as follows:

Pyotr Y. Ufimtsev *et al*. [9], in his research mentioned a method of reducing the cross section of radar. This strategy includes the appropriate molding, use of radar absorbing materials **(RAM'S),** and active and also the passive cancellation of the scattered field. The fundamental consideration is focused on discourses of the physical structure of radar waves scattered from expansive items. These waves contains standard and diffracted rays, their beams, and shadow radiation. The shadow radiation is caused by the transverse dissemination of the radar bar in the region of the shadow limits behind the diffusing article. Shadow radiation makes solid forward dissipating and is in charge of RCS improvement everywhere bistatic edges.

Giorgio Franceschetti *et al*. [10], mentioned hybrid stripmap/spotlight mode for an engineered gap radar (SAR) framework. This strategy can create microwave pictures with an azimuth determination superior to anything the one accomplished in the stripmap mode and furthermore a ground scope superior to the one of the spotlight mode. In his paper, he displayed and looked at frequency and time-domain based techniques, to reproduce the raw signal in the hybrid stripmap/spotlight mode. He said a one-dimensional (1-D) extend Fourier area approach, trailed by 1-D azimuth time-space combination. This technique is significantly more productive than the time-area one, with the goal that expanded scenes can be considered.

Youhong Lu *et al*. [11], discovered packetized audio transmission. This strategy has brought about testing prerequisites for reverberate wiping out innovation. Primary element of this innovation is the need to portray, rapidly and precisely, the echo paths in the transmission media. There are two things present in an echo path, first is constant time delay when there is no active signal, and second is the active region when there is echo signal present. Algorithm as introduced by the author is required for locating the active regions and the estimation of constant delay. He found out that there can be a large reduction in complexity and the performance can be increased profoundly. These actions take place when algorithm is applied to the active regions only.

Mehrdad Soumekh, *et al*. [12], worked on the development of radar signaling strategies and algorithms. This strategy is utilized to improve the capacity of SAR to picture focuses within the sight of digital radio frequency memory (DRFM) repeat jammers. The approach relies upon a control/modification of the transmitted flag and furthermore its parameters in the brisk time space at every circumstance of the engineered opening (beat redundancy interim (PRI)); this technique is known as heartbeat decent variety. He utilized the transmitted twitter motion in the adjusted shape and shifted the trill rate at each PRI. The variations are made in chirp rate from one PRI to another and only a user will know these variations.

Y.-J. Wang, *et al*. [13], gave a new algorithm that is to be used for echo cancellation of radar based on the group delay of LMF. The very first step of this algorithm is multiplication of received signals by the conjugate of its delayed version, this will give the frequency difference between them. The frequency difference is used to shift the frequency of received signals. According to the RCS of target, in order to get the same frequency of the signal as the echo pulse, but having opposite phase, the phase and amplitude modulations are used. The echo signal of radar is cancelled by this signal.

Feng Zhou, *et al*. [14], gave a new algorithm used for suppression i.e. Narrow-Band Interference (NBI). It uses the method of complex empirical mode decomposition (CEMD). The qulity of image will be degraded greatly with the use of this algorithm. While using this algorithm, those echoes are identified in the time domain first that contain NBI. The echoes thus obtained are decomposed using CEMD into a number of intrinsic mode functions. Following this, by the use of thresholding, the imfs corresponding to the NBI are subtracted from the echoes. As a result, using traditional SAR algorithm, a well focused SAR image can be obtained from the separate target echoes. The effective loss of data by the use of this algorithm is smaller as compared to other NBI suppression algorithms.

A. K. Agrawal, *et al.* [15], portrayed the engineering, and feature the means expected to extricate parallelism in execution of the calculation for quickened SAR image generation from satellite-borne manufactured opening radar (SAR) video information requires numerical calculations of the request of gigaflops (GFLOPs). Current parallel preparing plans disperse calculation stack among various parallel handling components (PEs) for enhancing productivity in calculation. With a specific end goal to deal with the gigantic computational errand for constant picture age, we report here the utilization of universally useful designs handling units (GPGPUs) that have demonstrated brilliant outcomes for information parallel sorts of activities.

Carmine Clemente, *et al.* [16], gave the method of the Fractional Fourier transform (frft), which is a generic form of a well identified Fourier transform. A new range of potentially favourable and useful applications were introduced by this method. These applications include detecting the chirp signal and using them. It also includes recognition of pattern and SAR. In this paper he applied FRFT to a well known range Doppler algorithm in order to get the best results in terms of noise rejection and the resolution.

Ying-chun Xiang, *et al*. [17], introduced the method that provide active stealth cancellation analysis of a warship for the LMF radar. In the modern stealth technology field one of the important developing direction is active stealth of warship. The cancellation signal was designed keeping in consideration the scattering properties of warship, the linear frequency modulated signal characterization and its matched filter. By interference cancellation between the cancellation signal and echo signal of radar, the warship stealth is achieved.

Michał Meller, *et al*. [18], in this paper he stroked upon the problems such as cancellation of potentially non-stationary and strong echoes in passive radar and also in noise radar using digital transmission. He gave a multistage procedure. With the use of LMS algorithm, initial clutters are essential which are then refined by using specifically designed filters which are matched to the spectral densities of both the clutter and the targets. When the post processing filters are non causal, the performance of the new introduced methods of cancellation is improved in comparison to causal filter based solutions.

Si-Wei Chen, *et al*. [19], mentioned the implementation of full polarimetric synthetic aperture radar (polsar) images for investigation of damage done by tsunamis. For the discrimination of damage level at the block scale of city, two polarimetric indicators are introduced. The efficiency of these indexes is validated by comparing the results from before and after a tsunami, because the difference between the damage levels can be discriminated easily. Also when the before tsunami pairs are compared, the confirmed stability of these two polarimetric indexes can be seen over long temporal duration. The results produced hence demonstrate that for the assessment of natural disaster, full polarimetric information is an important aspect.

Feng Zhou, *et al*. [20], discovered a fast algorithm that can be used for deceptive jamming of large scenes against the space-borne SAR. In this algorithm, firstly, the jamming scene template is divided into sub-templates. This division depends on the depth of focus in range dimension. The decomposition of each sub template is performed into slow time dependent and independent terms, and that too in azimuth time domain of range frequency. The generation of slow time independent is done off-line, while the generation of slow time dependent terms is done as one dimensional frequency modulation in real time. The convolution is performed of the sub templates with the intercepted SAR signal simultaneously. In the last after combining all the sub templates, fast deceptive jamming is achieved.

Raffaele Solimene, *et al.* [21], gave two important aspects in relation with the synthetic aperture radar imaging (SAR-I), which are of both reletively theoretical and applicative interest. The first objective stresses on the analysis of the frequently used SAR-I approaches. This analysis is done under the unified mathematical framework which is given by the Porter-Bojarski integral equation. The second objective deals with the providing of an updated overview about the SAR-I research generalizing previous algorithms to tackle with these unconventional scenarios

Xiaoyi Pan, *et al*. [22], gave the method of deception jamming for countering bistatic ISAR. Bistatic inverse synthetic aperture radar (ISAR) deals with spatially separated transmitting antennas and the receiving antennas. He presented a method which is successful in the generation of deceptive images from a train of intercepted bistatic ISAR chirp pulses. It is observed that the under-sampled pulses that are being retransmitted to a moving target induces a deceptive false-target images. The moving target scatters the image under the well known principle of bistatic ISAR configuration. Due to the properties of false target images and the need for jamming power this deceptive jamming is concluded as applicable.

Dejun Feng, *et al*. [23], gave the method of a method of Interrupted Sampler Repeater Jamming (ISRJ) for cancellation of target echo of radar. After explaining its principles, three conditions that are to be achieved for radar echo cancellation are, range synchronization, phase coherent and matched amplitude. After that the restrictions are deduced in the theory for key parameters of ISRJ. The restrictions are repeater power, the frequency of repeaters and the delay time. In the last, the discussion takes place over the impact of those parameters on cancellation of radar echo.

Jun Hong, *et al.* [24], gave an investigation display for foundation ionospheric impacts on MEOSAR in view of the framework attributes of MEOSAR and the spatio-fleeting inconstancy of ionosphere. Firstly the impacts initiated by foundation ionosphere and its spatio-transient inconstancy on MEOSAR picture quality are dissected. According to the eventual outcomes of our examination, we surmise that the declining of azimuth assurance, migration in azimuth and twisting in broaden picture will be not kidding for MEOSAR.

Juan Zhao, *et al.* [25], gives a novel method of reconstruction, associated with the simple fractional Fourier transform. This method is used for non-uniform azimuth sampling for creating clear SAR images. After Comparing with the traditional spectrum reconstruction method, it is found that the method given in this paper gives better performance. Even in the case of undersampling, this method can realize clear SAR images. When there is deviation of PRF from ideal to actual, there comes a rise in non-uniform azimuth sampling. And this will seriously interfere in the SAR imaging.

Xinhua Mao, *et al.* [26], gave an approach for two-stage image formation. This approach combines two strategies i.e. Fourier and sparsity-based reconstruction strategies. This approach is exceptionally impactful in the preparing of the multi-static engineered gap radar (SAR) information. In this technique abuses the square sparsity of the Fourier testing designs happens, which is containing essentially various disjoint subbands in the two-dimensional spatial frequency domain. These different subbands are closely distributed and also within each subband the nyquist criteria is satisfied. In this approach, first the fourier based method is used for the production of coarse resolution images. These images are then combined for the production of high resolution image by exploiting the technique of sparse reconstruction. By the use of this method, the results of SAR image are improved significantly, over the fourier based techniques. When this method is compared to the direct sparse reconstruction, it is found that the computational complexity is reduced to a great extent.

Yongcai Liu, *et al*. [27], gave the method of a frequency-domain three-stage algorithm. This is used for the active deception jamming against synthetic aperture radar. The main issue which arises during decepting jamming of SAR is that the jamming signal is not generated efficiently. Both the factors, i.e., computational complexity and the focus depth of the false scatterers of the deception template are to be taken into consideration. In this method, there is an intentional reformation in the jammer system in the 2 dimensional frequency domain. Following this, the fast fourier transform accelerates the implementation of FDTSA very effectively. The modulation process of a repeat jammer is divided into three steps. First step includes the offline stage, second step consists of initialization stage, and the third and the last stage is the real time modulation stage.

Long Huang, *et al*. [28], gave the method of the influencing of rebound jamming on synthetic aperture radar (SAR) GMTI. Ground moving-target indication (GMTI) has wide use in the measurement of ground traffic and ocean surface currents. The rebound jamming signal can either be deceptive jamming or barrage jamming. This depends on the time delay. When there is constant time delay between the pulses, the jamming is focused on that part which is the morphed image of the targeted imaging area. After applying the displaced phase-center antenna (DPCA) processing, cancellation of image will take place whose azimuth is near to the azimuth of jammer and similar to the stationary targets, while there is no change in the other part of the DPCA image. When the time delay between each pulse is random, in that condition the rebound jamming is the barrage jamming and that too for both the SAR image and the DPCA image.

Bo Zhao, *et al*. [29], gave the method of a deception jamming method (SAR) based on multiple receivers for synthetic aperture radar. To perform the deceptive jamming using this method, the parameters of hostile SAR are treated as a whole unit. The accuracy rate can be achieved higher By doing the measurement of the range differences between the different receivers, rather than the one we could achieve by directly detecting each of the parameters. The squint angle is also included in the parameters, is also included in the parameters the multireceiver system gets. However the squint angle is very difficult to obtain for the electronic reconnaissance,   so this method deals with the squint SAR.

Kaizhi Wang, *et al.* [30], introduced An adaptive SAR imaging algorithm. He assumed the received radar data to be echoes from isolated point targets, hence constructed a signal model. The estimation is performed for the signal model parameters. Also these parameters can be used for characterization of a single scatterer. Then the parameter space that has been estimated can be mapped for the formation of a SAR image. For the validation of this algorithm, Simulation experiment is used.

Qun Zhang, *et al.* [31], introduced the method to deal with Range Cell Migration Correction (RCMC). RCMC is an important issue to deal with Randomly Stepped Frequency SAR Imaging. In this paper he used the newly introduced algorithm that is compressive sensing (CS) algorithms for the correction of range migration and the formation of SAR images of random data. With the use of this algorithm, the randomly stepped data of frequency echo and the observed value of evenly stepped frequency echo data are made equal. Also with this method, the range migration correction operator is integrated into the part of sparse representation. After migration correction is done via CS reconstruction algorithm, High-resolution range profiles (HRRP) are obtained directly. After that the azimuth pulse compression completes the imaging of target scene.

Letao Xu, *et al*. [32], gave the method of a three stage active cancellation against synthetic aperture radar. This method uses the frequency and time-delay modulation. In this method, First step includes the interception of target echo by a canceller for the estimation of the echo that is scattered over the target. Second step includes the generation of cancellation echo by frequency and delay-time modulation of the intercepted target echo. Third step includes the retransmission of this cancellation echo to SAR. When it is compared with the other present techniques, this method can effectively generate cancellation echo in real time and no phase shifter is required. All above that, use of this method regulates no restrictions on the cancellation and target echo synchronization. This tell us that we can get the effective cancellation when the cancellation echo is lagged behind the target echo in time domain.

Letao Xu, *et al*. [33], introduced a novel method which is capable of performing cancellation of synthetic aperture radar (SAR) target echo. This method is based on a dual-antenna system which uses the sub-Nyquist sampling. This method is capable of concealing SAR target and also for the formation of train of false targets simultaneously. First, he presented the design of the dual-antenna active-echo-cancellation (AEC) system. Then comes the description of sub-Nyquist sampling principles. Then, the most important parameters for sub-Nyquist sampling, i.e., the delay time and sampling rate are analyzed.

Letao Xu, *et al*. [34], gave the novel method of active cancellation method against synthetic aperture radar (SAR), which is theoretically based on the intermittent sampling. The cancellation signal is intermittent sampled to form the desired jamming signal. The jamming signal can both cancel the real target echo and form verisimilar false targets on SAR image simultaneously. First, the basic principles of SAR target active cancellation are introduced. Then, the active cancellation method based on intermittent sampling is theoretically derived. On this basis, the effects of the parameter error and key intermittent-sampling parameters on active cancellation and false-targets generation are studied. The key factors affecting the active cancellation and the distribution of two-dimensional false targets are also given.

Anders Kusk, *et al*, [35], presented an apparatus to create manufactured SAR pictures of items set on a messiness foundation is portrayed. The reason for existing is to produce pictures for preparing Automatic Target Recognition and Identification algorithms. The apparatus utilizes a business electromagnetic recreation program to figure radar cross areas of the protest utilizing a CAD-display. The crude estimations are contribution to a SAR framework and landscape demonstrate, which models warm clamor, territory mess, and SAR centering to deliver engineered SAR pictures. Cases of SAR pictures at 0.3m and 0.1m determination, and a correlation with genuine SAR symbolism from the MSTAR dataset is exhibited.

Meng Qi, *et al.* [36], gave a scheme of bistatic SAR having three channels for the detection of ground moving targets. According to the characteristic of bistatic SAR, for focusing the moving target and for the improvement of the signal to clutter ratio frft technique was chosen. While we perform the suppression of clutter and estimation of the parameters of moving target with some clutter suppression interferometer techniques. From the knowledge spatial geometry model and echo signal model of the system, the method of moving target parameters estimation was induced.

M. Tria, *et al.* [37], new capacities in SAR imaging are provided by the author, which improves the response of reflectors, and they respond differently to different bandwidth and angles. The first use of the multidimensional persistent wavelet change technique in SAR imaging permits to feature the recurrence and rakish conduct of these reflectors.

L. Ferro-Famil, *et al.* [38], gave a technique to manage the examination of the non-stationary conduct of scatterers in polarimetric SAR imaging. A strategy in view of persistent wavelet and indistinguishable polarimetric deteriorations is connected to extricate the polarimetric time-recurrence marks of scatterers. These marks portray scatterers as indicated by their polarimetric/or fiery conduct versus the produced recurrence and the perception point. At that point, marks from reference targets are utilized to prepare a multi-layer perceptron (MLP). After this, SAR imaging information are characterized by the MLP. The effectiveness of this strategy is illustrated, for the deterministic targets (man-made targets). It can be clarified by the way that the man-made targets display a solid non-stationary conduct. Yet, for the vegetation and overhang the outcomes are not persuading.

Yarlequé Medina, *et al*. [39], gave the method of Synthetic aperture radar (SAR) imaging by processing of frequency modulated continuous wave (FMCW). By the use of this method, 2D images of high resolution mapped areas are produced. In his paper, he presented a totally developed FMCW radar at 2.36 ghz. This radar can fit in a mini-UAV and have the efficiency to acquire and store data.

Zhijuan Ma, *et al*. [40], gave the method of Multi-aspect mode of SAR. This method exhibits great efficiency in identification of target. In his paper, he presented an airborne investigation that is performed to accomplish high determination multi-edge SAR imaging. The starter consequences of this investigation are illustrated. The application possibilities of multi-edge SAR imaging is broke down.

Lei Zhang, *et al.* [41], gave a novel algorithm to remove the lingering RCM for very squinted airborne SAR with the sub aperture (SA) handling, because of the systematic articulation of the remaining RCM in SA picture area. Squint minimization preparing (SMP) with a range-walk adjustment is generally used to disentangle the range and azimuth coupling for exceptionally squinted manufactured opening radar (SAR) imaging. In any case, SMP destructs the azimuth move invariance of traditional SAR exchange work, which extremely corrupts the range cell relocation adjustment (RCMC) exactness.

Kaizhi Wang, *et al.* [42], studies the method of Improved Azimuth Compression with fractional fourier transform (FRFT). Contrasted with utilizing great coordinated sifting procedure, the picture centered by FRFT has better resolutions. It has been established that under the condition that twitter's data transfer capacity keeps the same, the more extended heartbeat span, the higher determination of the flag after FRFT activity to this trill. His paper applies FRFT to range and azimuth pressure. Semi Newton strategy (QNM) would be used to look the ideal turn plot for azimuth pressure.. At each range receptacle, focuses with high flag mess proportion (SCR) have been used on the grounds that flag's entropy is delicate to clamor, driving it isn't legitimate to apply full length tests. The correct range cell migration correction (RCMC) and movement remuneration tasks are fundamental and before applying FRFT.

Bikram Singh, *et al.* [43], This paper examines an investigation on Synthetic Aperture RADAR imaging utilizing a compact workstation based Frequency Modulated Continuous Wave RADAR. The point of the paper is to look at Ground Penetrating Radar information with the convenient FMCW RADAR after Auto Estimation of Soil Permittivity handling. The permittivity of the dirt is assessed by iterative calculation, where the dirt is considered as homogeneous. Articles covered under the grounds were recognized utilizing the FMCW RADAR and conceivable novel applications are talked about.

N. H. Kaplan, *et al*. [44], gave a new algorithm for the reduction of speckle. This algorithm is based on lattice filters used for SAR imaging. According to his method, the lattice filter is used ofr performing the subband decomposition of speckled images. Then with the use of high pass and low pass filters having lattice structures, the decomposition os noisy image is performed into subband image. Then according to the variation of noise in each subband, estimation of threshold value is done and after that, on the subband images soft thresholding is applied. By the use of inverse lattice filters, the despeckled image is produced from the subband images that are thresholded. The method introduced in this paper i.e., speckle reduction is applied to RADARSAT/SAR images. A comparison is performed between this method of speckle reduction and median filtering and also with speckle reduction method based on stationary wavelet transform.

CHAPTER 3

SAR IMAGING

A SAR is an instrument capable of obtaining a map of the reflectivity of a planetary surface. By using radar as the main component, SAR has several advantages as it can penetrate through weather systems; operate during both night and day; and can track over a thousand targets at any time. There is a significant military use of SAR because of its possibility to perform surveillance and targeting. Civilian use of SAR aims more towards environmental monitoring, oceanography and planetary exploration (Venus, Mars). Insar can provide information regarding changes that have occurred in either topography over a defined time span (hours, days, years) or movements of objects between two SLC images. Insar depends on true-phase, i.e. the phase is correct after the raw data has been processed.

From a general point of view, a SAR works as follows: The radar transmits a pulse and samples the received signal. Once the radar has sampled the received signal, it moves to a point along the flight direction where it repeats the action. By doing so, the radar synthesizes a long antenna by spending time and a small antenna rather than using a long antenna to gain a fine resolution in the flight direction. By using the radar as the main component, the SAR can detect and calculate the distance from the SAR to the target it tracks.

3.1 RANGE DOPPLER ALGORITHM:

The RDA forms the crude SAR information to deliver the SAR picture space or last picture. The RDA performs coordinated shifting independently in the Fourier changed range and azimuth areas. The Fourier changes are computed by means of quick Fourier transforms (ffts) for the effectiveness of processing time. Range cell migration correction (RCMC) is performed in the range time and azimuth repeat space. This space is known as the range-Doppler region and gives its name to the computation as playing out the RCMC in this space is the describing feature of the count when stood out from other SAR dealing with estimations.

The raw signal space SAR input is the two-dimensional flag as appeared in Figure 8. The two-dimensional flag is first examined as an arrangement extend time signals for every azimuth container. Each range time flag experiences coordinated sifting in the range recurrence/azimuth time space through range ffts connected to the range time signals. After each flag is changed once again into the range time/azimuth time space, the outcome is the range packed flag as the coordinated separating was performed in the range recurrence area. Keeping in mind the end goal to get azimuth pressure, azimuth coordinated sifting must be performed. The range compacted flag is then made into an arrangement out of signs as for azimuth time at various range receptacles. Each azimuth signal is Fourier changed by methods for an azimuth FFT and RCMC is performed before azimuth composed filtering in the range-Doppler territory. After azimuth facilitated isolating of each flag and azimuth reverse quick Fourier changes (iffts), the last target picture is procured.

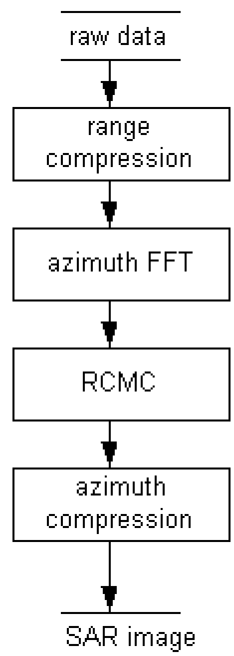


Figure 3.1: RDA block diagram.

3.2 RANGE RESOLUTION:

The range resolution, ΔR, is defined as the minimum separation between two points with same reflected energy, and that they can be distinguished as two unique points by the SAR system after being processed[1]. This separation can be found by using Equation, where ΔR is the range resolution in slant range, Δf is the bandwidth of the transmitted pulse (1/τ) and c is the speed of light. The factor 2 is because of the round-trip the signal must conduct, i.e. The travel back and forth.

$\Delta R = c / 2\Delta f$ (1)

According to the equation, if a pulse is transmitted from an antenna, the length of the pulse will determine the smallest distance between the buildings to be considered as unique after processing. If the separation is smaller than Equation above, the two reflected pulses will merge into one long pulse and we cannot separate them during SAR processing, as shown in Figure 3.2. If the separation is equal or greater than Equation, the two reflected pulses will be unique and will be separated after SAR processing, as shown in figure 3.3.

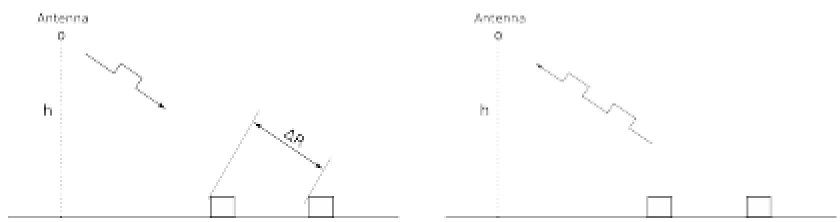


Figure 3.2: Range resolution with good distance between objects.

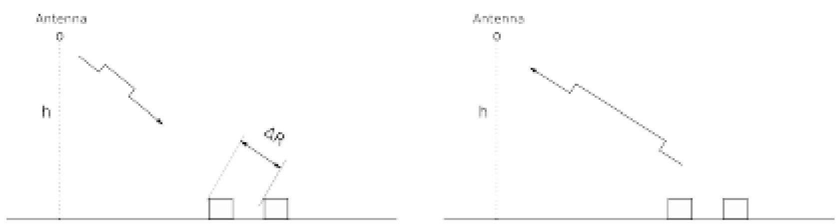


Figure 3.3: Range resolution with too small distance between objects.

With the given Equation as the reference for the range resolution, it might be desirable to lower the pulse length to a minimum. However, in SAR processing, this causes new problems. One of them is that the received signal must produce a sufficient echo signal so the Signal-to-Noise Ratio (SNR) can be considered reliable[39,1].

3.3 AZIMUTH RESOLUTION:

To understand how the resolution in the azimuth direction can be found, the definition of the resolution of a Real Aperture Radar (RAR) must first be found.

The resolution of a RAR, ΔXRAR, is found by using the equation given below. The distance between the ground and the antenna is designated by the symbol R, the length of the antenna is designated with the symbol L and the wavelength of the transmitted pulse is designated with the symbol λ.

$$\Delta X_{RAR} \cong R\lambda\ L \qquad (2)$$

3.3.1 Synthetic Aperture Resolution

The most important discovery that led to the development of SAR, was the observation that two point targets with different angles, with respect to the SAR, had different speeds at any fixed position relative to the SAR platform. From this, it was discovered that the different point targets would have two distinctive Doppler frequency shifts. It is this uniqueness that allows the extraction of the synthetic aperture resolution. The Doppler frequency, f_d, at any relative fixed position in the azimuth direction, x, can be described as in Equation 2.3. Note that the position is with respect to the SAR[40]. In the equation, Vr represents the relative speed of the SAR and λ designates the wavelength of the transmitted frequency.

$$f\mathrm{D} = \frac{-2\mathrm{Vrx}}{\lambda \mathrm{R}} \qquad (3)$$

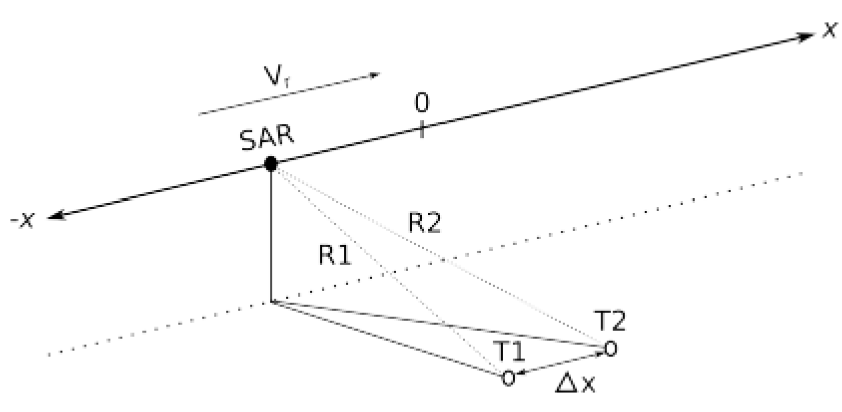


Figure 3.4: Azimuth resolution.

By expanding this equation from a fixed point to the difference between two fixed points, we can use Equation to find the Doppler bandwidth. It should also be noticed that when calculating the bandwidth, the result cannot be negative; therefore the sign is shifted and is positive.

$$fD = \frac{2Vrx}{\lambda R} \quad (3)$$

3.3.2 Linear Frequency Modulation:

It could be observed that the bandwidth of the transmitted pulse, Δf, determined the resolution in the range direction. However, when designing the physical transmitting system, a high frequency signal with a very narrow bandwidth requires a great amount of energy from the power supply, regardless of the width of the pulse. Therefore, to have fine resolution but still have a feasible design with feasible power consumption, a linear frequency modulated signal (LMF) is used[41]. The LFM signal is a signal that increases the frequency over time, providing a good SNR and reduces the power consumption when compared to a high frequency signal. In SAR processing, the important factor for the range resolution is the bandwidth of the frequency and not the carrier frequency of the system. Figure 2.8 show that the frequency of the lfm signal increases over time, therefore providing a wide bandwidth and a good resolution.

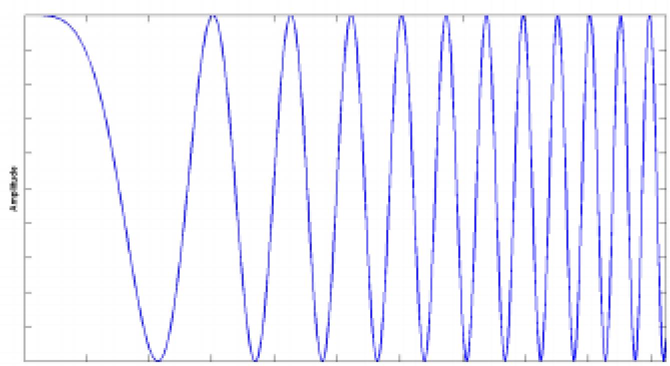


Figure 3.5: Linear frequency modulated signal.

3.4 Pulse Compression:

An important operation that must be conducted in SAR processing is the pulse compression of the received signal. Using other words, it is "designed to minimize peak power, maximize SNR, and obtain fine resolution of the sensed object[40]. In detail, the SAR system performs a linear filtering process of the signal in the frequency domain using three mathematical processes: Discrete Fourier Transformation, matched filtering and inverse Discrete Fourier Transformation.

3.4.1 Discrete Fourier Transformation:

Discrete Fourier Transformation (DFT) is a mathematical process whereby a signal is converted from the time domain to the frequency domain. Figure 3.5 shows a signal in the time-domain that consists of different sine-tones added up and the energy of the different frequencies in the frequency domain.

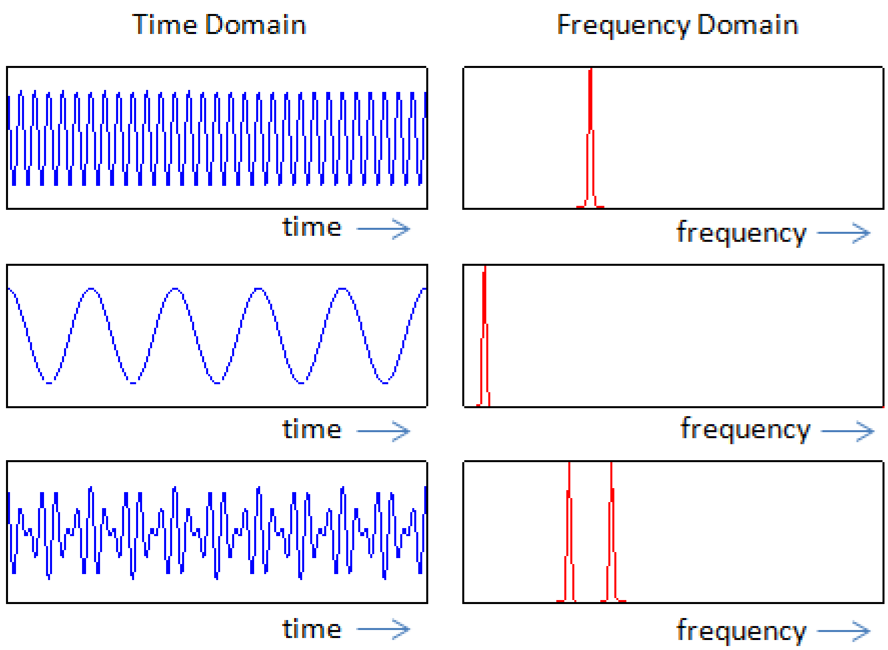


Figure 3.6: Signal before and after DFT.

3.4.2 Fast Fourier Transformation:

One disadvantage of using the DFT in a processing system is that it requires N^2 operations to complete the transformation. If N can be factorized into smaller sections, an alternative version of the DFT can be used, the Fast Fourier Transformation (FFT)[43]. By using this transformation instead of the DFT/IDFT, the number of operations will be reduced from N^2 to $N\log_v(N)$ where N is the power of v. Very often, the FFT is used in processing when N is a power of either 2 or 4 (designated radix-2 and radix-4).

3.4.3 Matched Filter:

In SAR processing, a matched filter is a process whereby a known signal is removed from an unknown signal and the output is the energy of the unknown signal without the known signal. In SAR processing this means removing the transmitted pulse from a received signal and the result will be a signal carrying the compressed pulse of the received signal. Equation shows the concept of matched filter in the time domain. The unknown signal, x[k], is multiplied with the time-reversed filter coefficients, h[n-k]. It should be noted that matched filter is also defined as a "convolution filter" since a convolution process is performed in the time domain. However, in SAR processing, the matched filter is applied in the frequency domain because of the length the matched filter must have in the time domain to process the filtering. From here on, the matched filter will always be defined in the frequency domain if not stated otherwise.

$$y[n] = \sum_{k=-\infty}^{\infty} h[n-k]x[k] \qquad (4)$$

3.5 RANGE COMPRESSION:

Range compression consists of the three mathematical processes mentioned earlier. The received signal is first converted from the time domain to the frequency domain by the FFT, then filtered by the matched filter before being transformed back to the time domain by the IFFT. Figure shows how range compression is conducted.

Figure 3.7: Range compression.

3.6 AZIMUTH COMPRESSION:

Whereas range compression uses the transmitted pulse as a reference when filtering the received signal, azimuth compression is dependent on which processing algorithm has been used to process the raw SAR data. Several algorithms exist to process the data, each with its own advantage and disadvantage.

3.6.1 Range Cell Migration Correction:

The first important process after the range compression is the Range Cell Migration Correction (RCMC). After being range compressed, the data gets an undesired feature where the target appears to be migrating over several range cells. This feature is called Range Cell Migration (RCM) and Figure 3.8 show how it occurs. When the SAR passes a target, the slant ranges from the SAR to the target varies, creating a hyperbolic shape of the received energy. This causes the range information of the target to "migrate" over several range cells as the SAR moves in the azimuth direction[39]. There are several causes to why RCM occurs: rotation of the earth, the width of the antenna aperture (the wider aperture, the more RCM) and the height of the SAR relative to the ground. Since the energy of the target(s) is spread over several cells, the final processed SAR product will have a reduced resolution relative to Equation above.

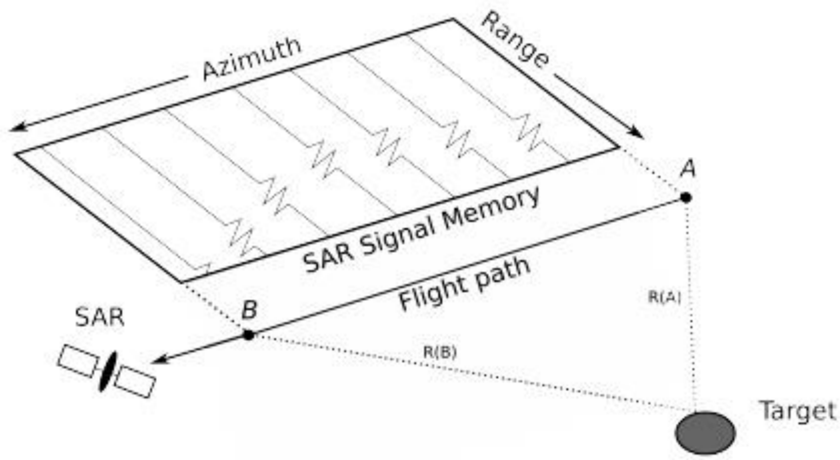


Figure 3.8: Range Cell Migration.

The RCMC is a processing method that corrects the RCM of the point target from several range cells to only one if the RCMC are performed correctly. In some algorithms, this requires the data to be resampled so the target is located in a correct position. However, doing this is resource demanding for the SAR system and since SPECAN was designed to be a real-time processing algorithm, an easier way to correct the migration had to be developed.

Figure 3.9 shows how the skewing and deskewing is performed on four range targets. The top left figure shows the SAR signal data after being range compressed. The RCM is linear. The data is skewed in either left or right position, depending on where the center point of the figure has been located. Very often this value is set to be in the center of the SAR data. The top right figure shows the same SAR data after being RCMC. The bottom left figure shows the azimuth compressed target points in skewed position and the deskewed lines.

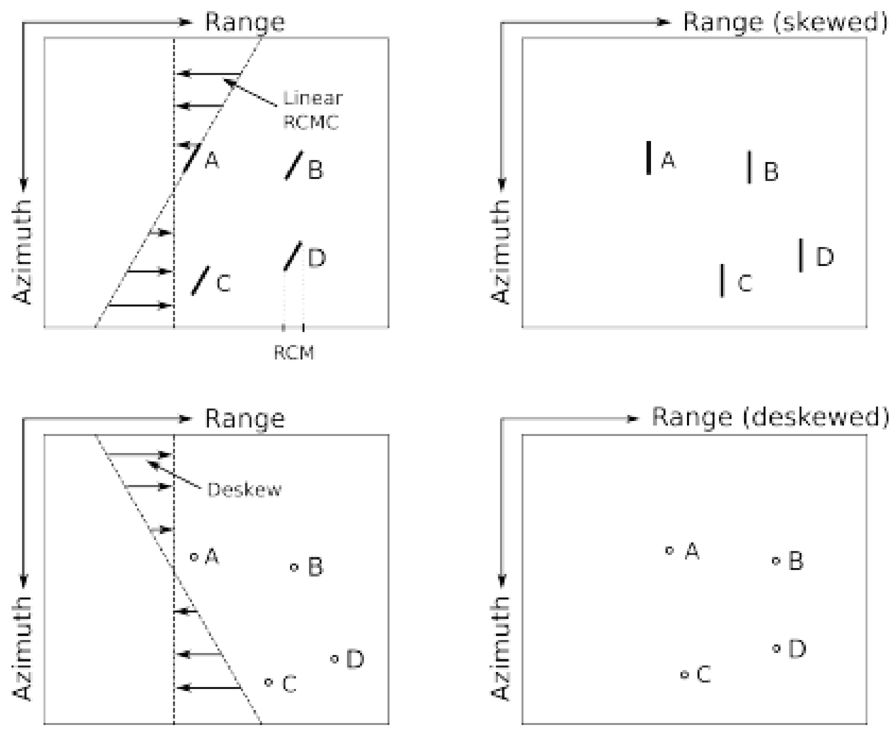


Figure 3.9: Correction of range cell migration.

Figure 3.10 show how the received energy and the received frequency appears of a target as the SAR has moved in the azimuth direction. The distance from the target causes the received signal to generate a Doppler frequency (just as an ambulance that is passing) and the energy has its peak when the target is at is closest. When performing the azimuth compression, the goal is to focus the Doppler frequency to one point.

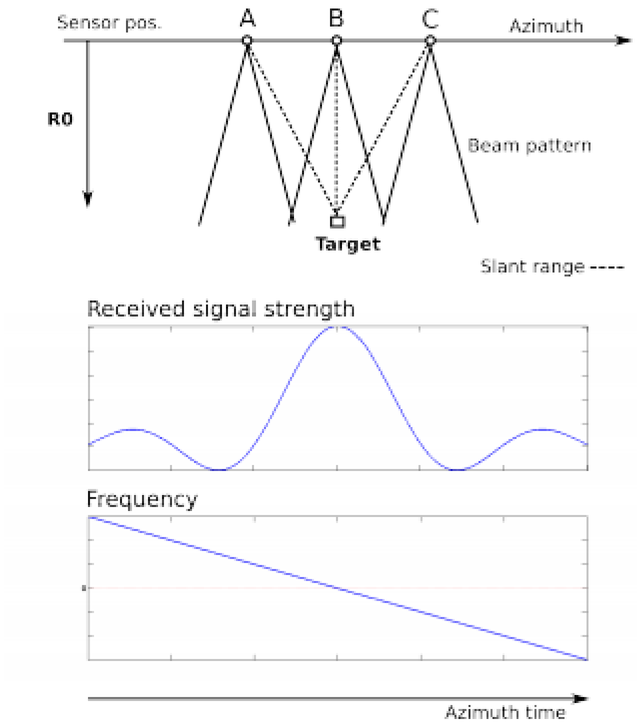


Figure 3.10 Azimuth beam pattern, signal strength and frequency

3.6.2 Pulse Repetition:

Frequency As can be seen in Figure 3.11, it is assumed that the frequency component covers an area of one Pulse Repetition Frequency (PRF). PRF is a precalculated value that determines how often a new pulse can be transmitted from the SAR without interfering from other pulses that are being received or reflected. The PRF is found by looking at the time interval between two transmitted pulses, the Pulse Repetition Interval (PRI). Figure 3.12 shows the definition of the PRI and Equation show how to calculate the PRF from this.

$$PRF = 1/PRI$$

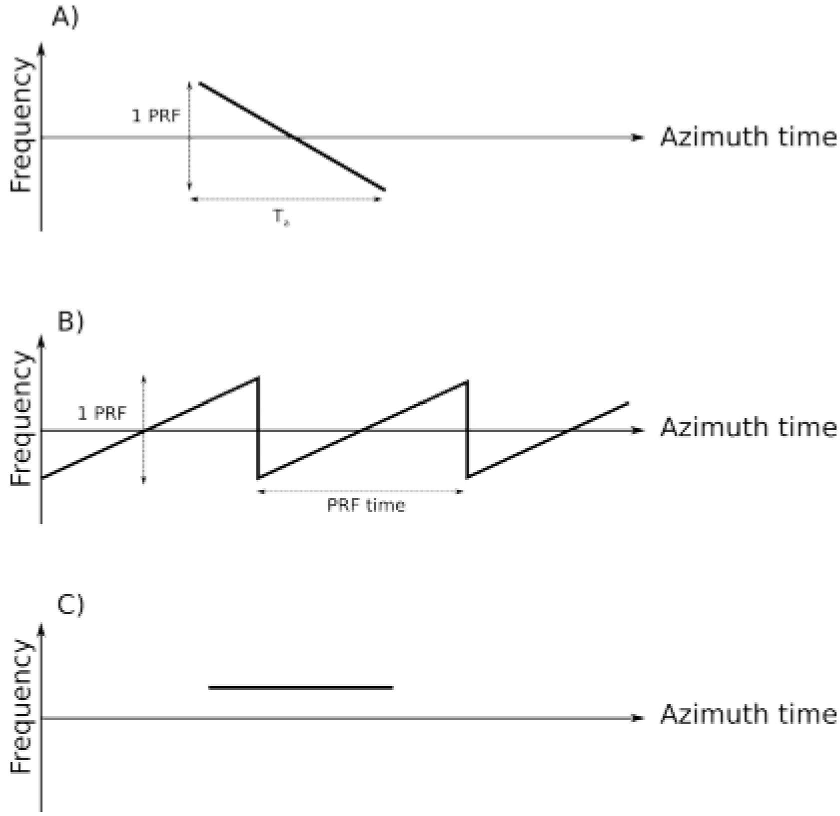


Figure 3.11 The deramping effect in SPECAN processing

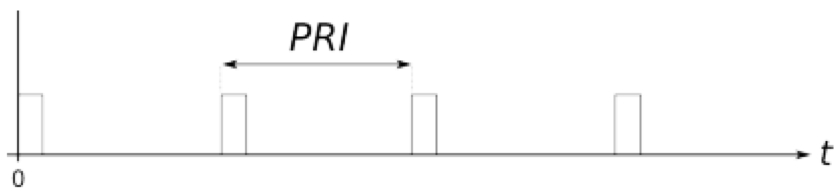


Figure 3.12 Pulse Repetition Interval

To satisfy Nyquist, i.e. to ensure the Doppler is sufficiently well samples, an expression for PRF is used. Equation show the expression where v is the satellite velocity and D is the antenna length. For Envisats ASAR antenna where the antenna has a length of 10 meters and the velocity is roughly 7000 m/sec, the PRF should be over 1400 Hz to satisfy Nyquist.

$$PRF > \frac{2v}{D} \tag{5}$$

After the deramping operation is completed, the SAR system performs an FFT operation. The main difference between the SPECAN algorithm and the other SAR processing algorithms is that it processes only sections of the azimuth data instead of all samples in the azimuth direction. This drastically reduces the resources needed but also reduces the resolution of the system.

3.6.3 Phase Compensation:

The phase information from the raw data is very important. Therefore, producing a SLC image will not be sufficient. After the range and azimuth compression, the phase of the image must be corrected so that the insar product becomes correct. This is done by conjugating the phase terms in the descalloped signal and modify the time variable used in the exponential terms. The goal of the phase compensation is to make sure that the phase of each target has its peak period instead of constant linear growth.

CHAPTER 4

RESULTS AND DISCUSSION

A raw SAR image is taken, the signal space of this raw signal is shown with jet color map, the lower magnitudes are represented by cooler color, and higher magnitudes are represented by hotter colors. Throughout the image space the AWGN can be seen, and the entire azimuth and the centre of range is spanned by SAR echoes.

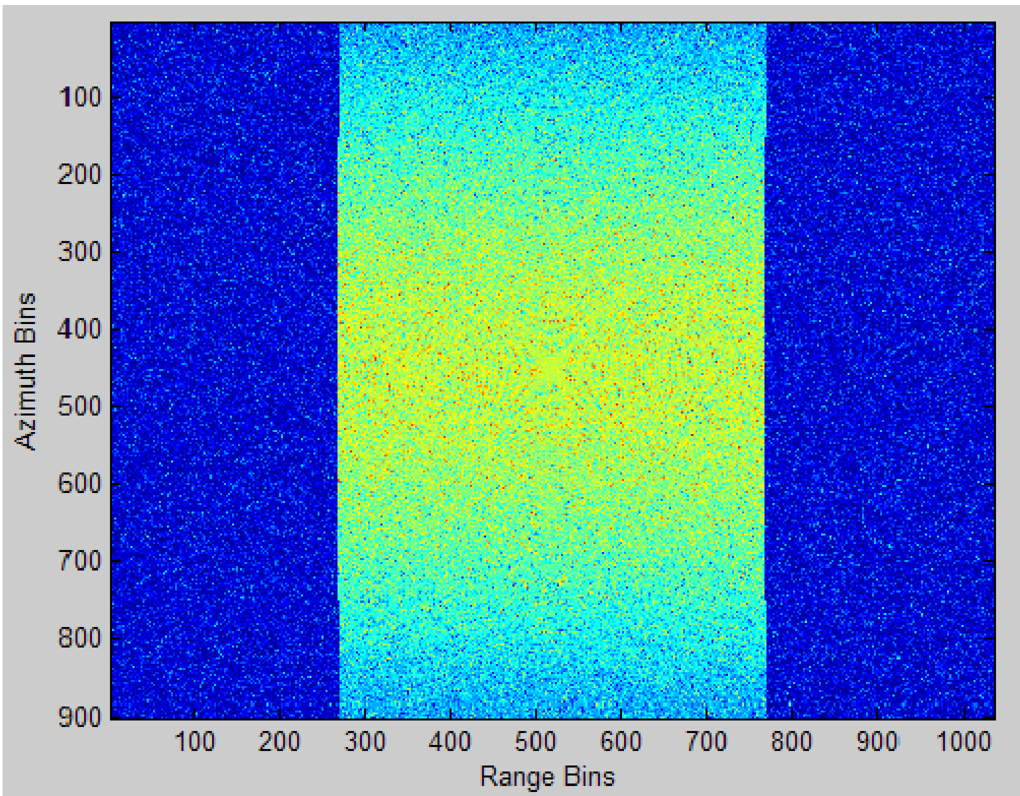


Figure 4.1: Raw SAR image.

The raw signal obtained is zoomed in to the centre. Due to positive up-chirp of FM rate, the frequencies of the sinusoid increases further away from target.

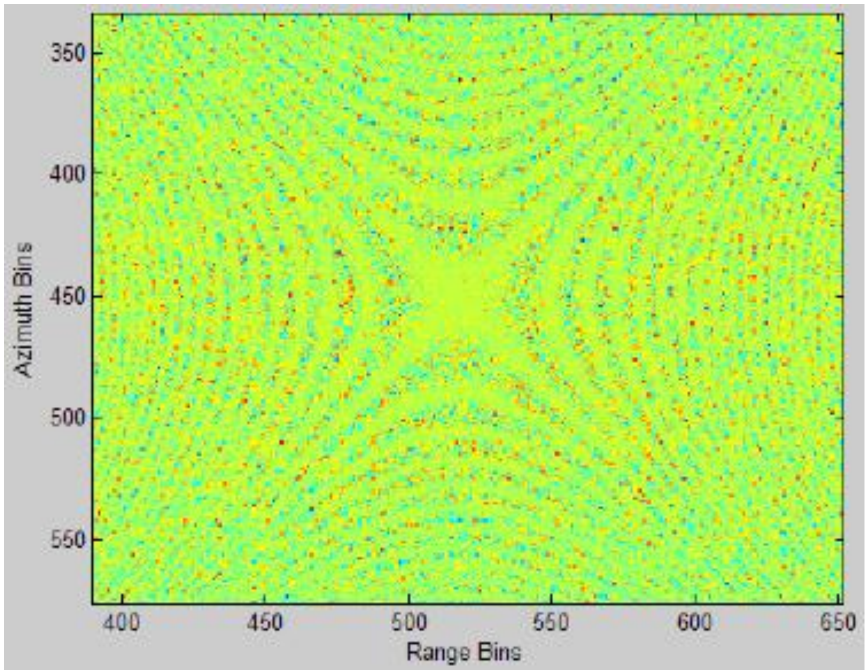


Figure 4.2: Zoomed in centre raw signal space.

The raw SAR flag is encouraged into the RDA. The range reference motion in the range frequency domain are collected first. The upper left corner demonstrates the range time extent of reflection, and range time period of reflection is contained in the upper right corner. The range recurrence extent segment is contained by bring down left corner, and the range recurrence stage part is contained by finished right corner.

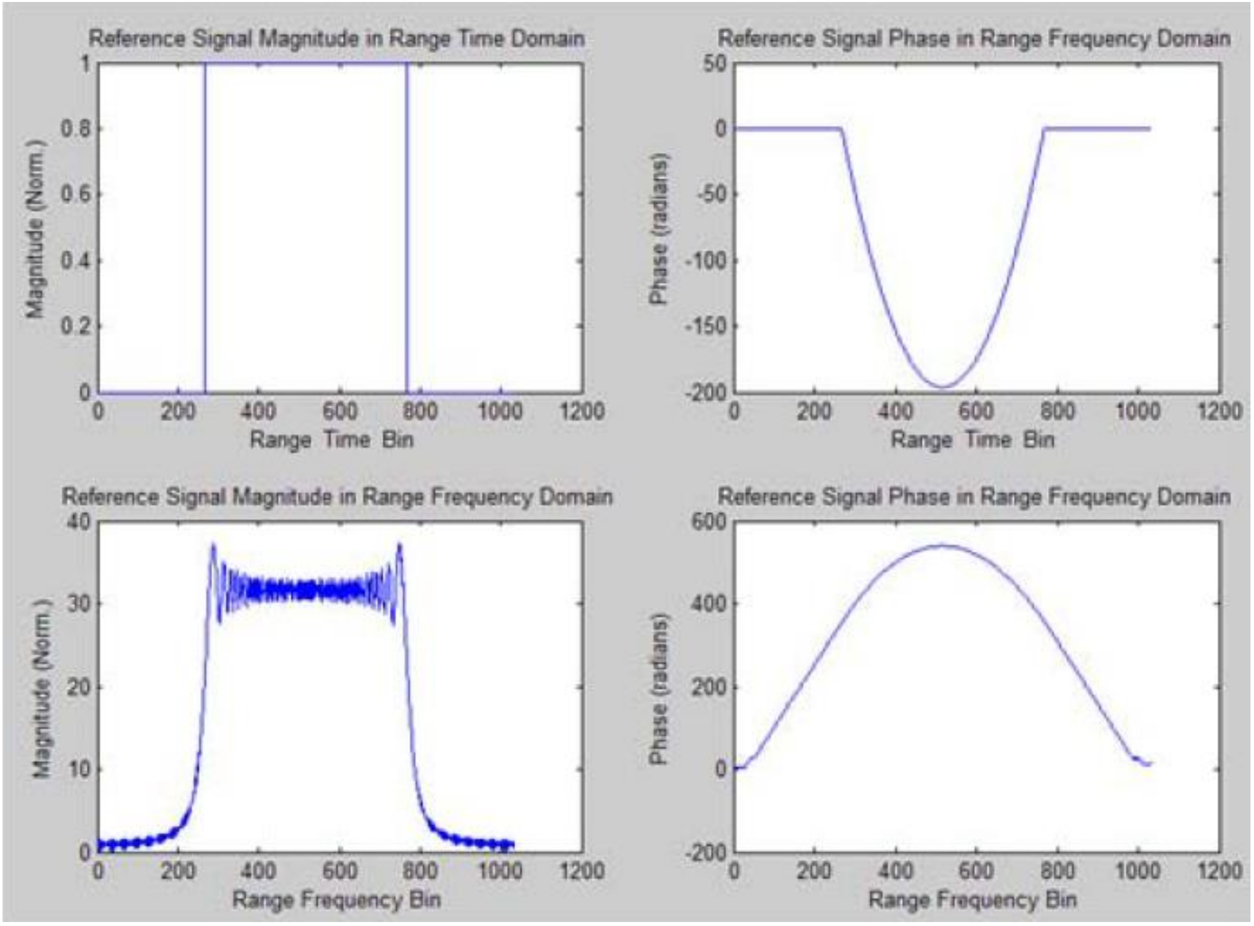


Figure 4.3: Range reference signal.

In the wake of building the range reference motion, by utilizing the estimation for low squint point cell relocation is figured.

After calculation of the range reference signal and range cell movement in RDA, compacting of SAR signal space makes next stride. The raw signal is sustained into RDA which is then sent through a range time area FFT. The fourier transform of each signal is taken. The contribution of coordinated channel is appeared in upper left corner and the term beat pressure gets its name. The task is performed for each 900, territory signals and the yield of this coordinated separating process is appeared as range compressed signal in figure 4.4.

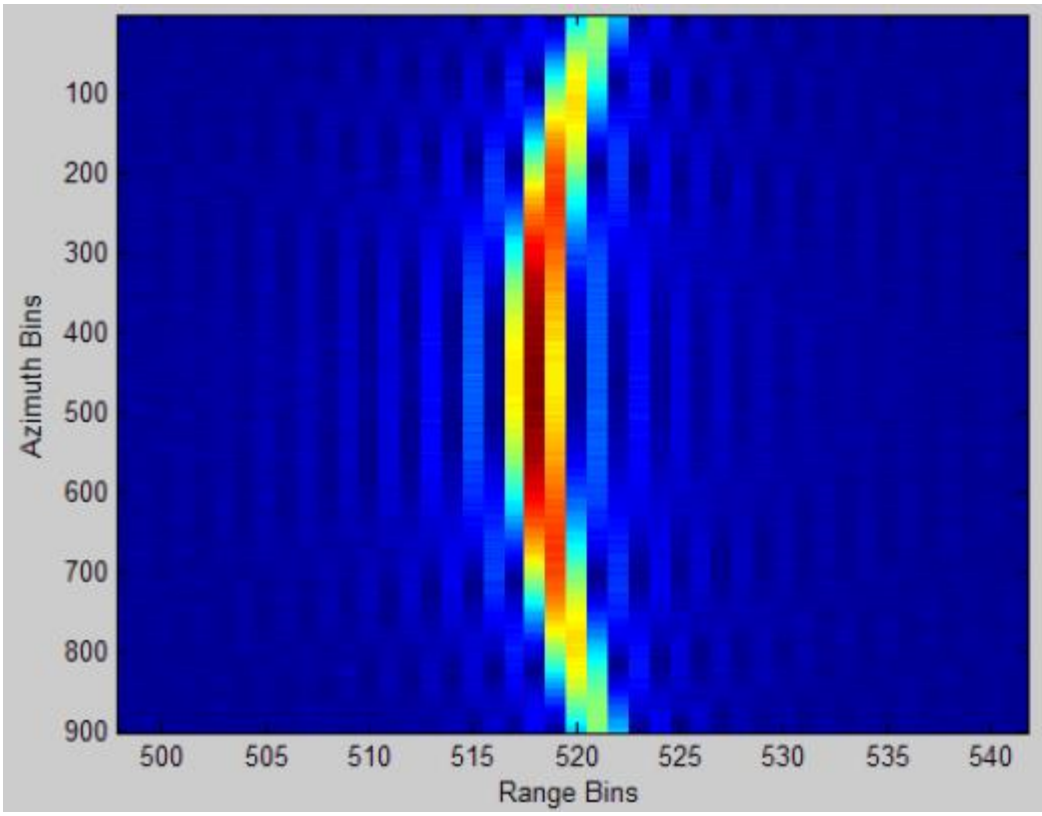


Figure 4.4: Range compressed image.

In the azimuth frequency and range time area, alluded to as the range-Doppler space, first the RCMC is performed and after that the azimuth coordinated separating happens. at the point when the picture is changed over once again into azimuth time area with FFTs after RMC, the resultant flag is appear as in figure 4.5.

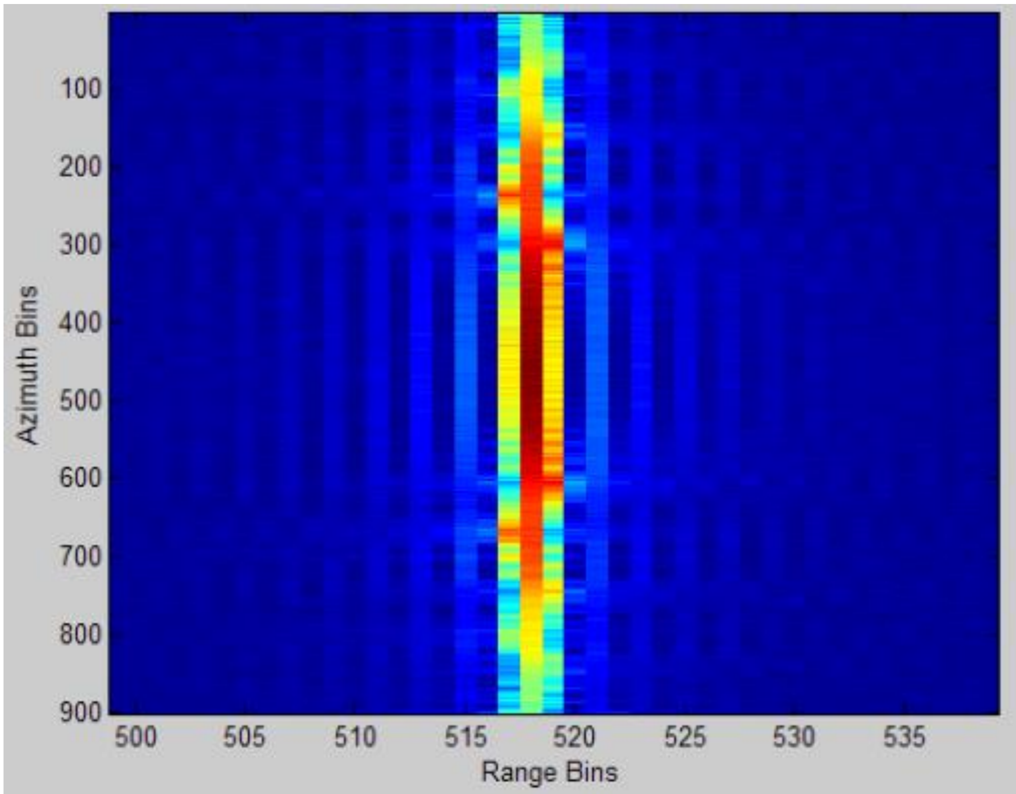


Figure 4.5: Image after RCMC.

Before the image is converted back to the azimuth time and range time domain, and final image is shown, azimuthal matched filtering is performed, which is the final filtering procedure. It is performed same as range matched filtering. The final image generated from two- dimensional simulation of a single point target is shown as in figure 4.6.

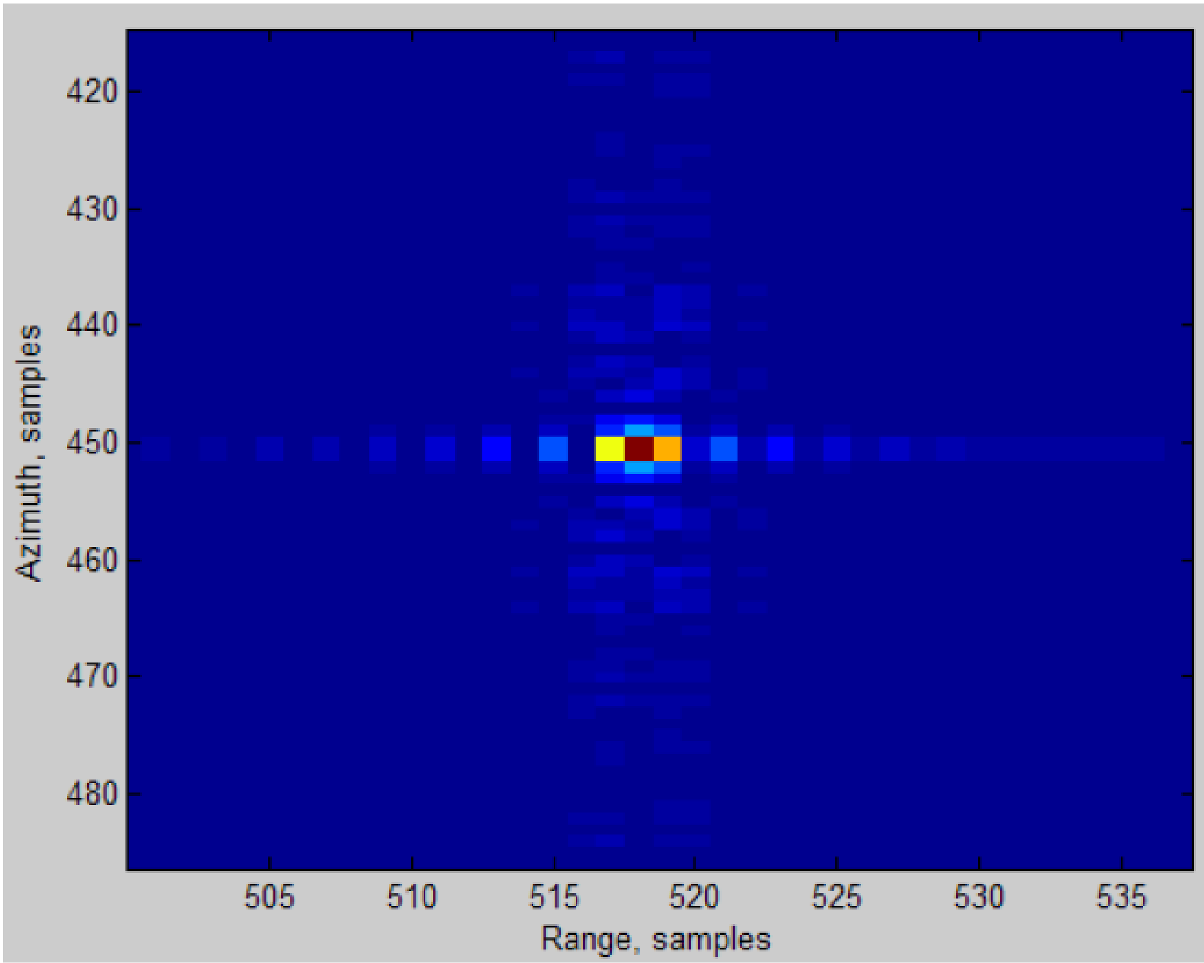


Figure 4.6: Final processed SAR image of single point target.

Figure 4.1 is an objective displayed after a Boyevaya Mashina Pekhoty (BMP), which is a land and/or water capable followed infantry battle vehicle. Figure 4.2 is a tank demonstrated after a T-84. The vehicles were chosen because of fluctuating size, highlights, length to width proportions, and turret position. The pictures were planned in Adobe Photoshop and spared in 8-bit grayscale GIF arrange.

Figure 4.7: BMP target image profile.

Figure 4.8: Tank target image profile.

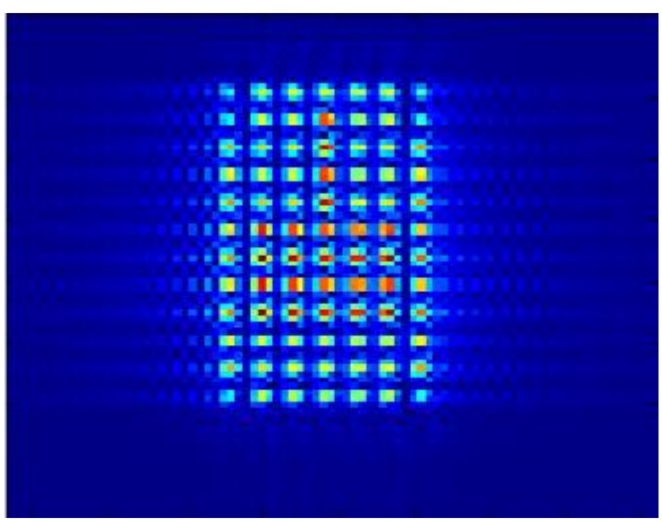


Figure 4.9: BMP final processed image.

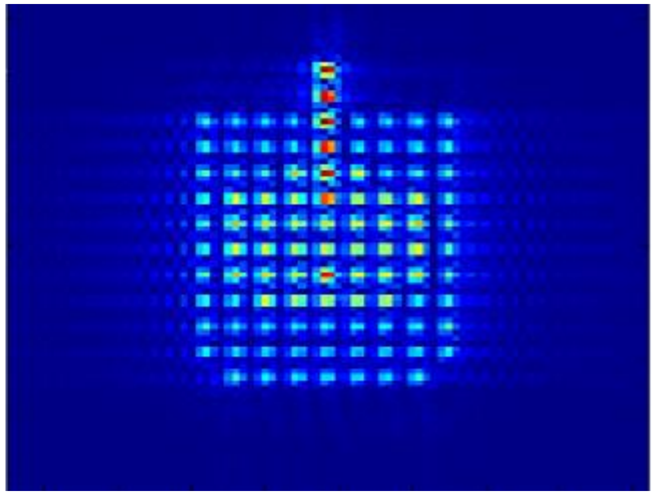


Figure 4.10: Tank final processed image.

The RCMC is outwardly compelling as pixels can be seen to not be enclosed by the range course. the turrets in the info pictures, which were the most astounding power, are likewise the most noteworthy force, in yield SAR pictures.

Spectral leakage is the spreading of vitality in the frequency space because of signs being limited restricted in time area. For example, the Fourier change of a limitless time length sine wave is a delta work at the recurrence of the sine wave, which is limited in frequency.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

The SAR images obtained by the use of range Doppler algorithm. The Fourier transforms are calculated via 900 point fast Fourier transforms (FFTs) for processing time efficiency. Range cell migration correction (RCMC) is performed in the range time and azimuth frequency domain. There are a few territories of future work for continuations on this task. An imperative territory of future work is the enhancement of the SAR reverberate age succession with the goal that more mind boggling targets can be recreated and imaged. A superior technique for three-dimensional target profile picture age can be produced such the utilization of a three-dimensional CAD program. Other three-dimensional imaging setup geometries can be executed other than stripmap SAR. One final zone of work for this recreation, either two-dimensional or three dimensional, would be the reimplementation of the SAR following calculation expelled from the two-dimensional SAR imaging reenactment.

REFERENCES

[1] C. Elchi. spaceborne radar remote sensing: applications and techniques, *IEEE press*, 1988

[2] J.C. Curlander and R. N. McDonough, synthetic aperture radar, systems and signal processing. john wiley and sons, Inc, New York, 1991

[3] J. Way and E.A. Smith. the evolution of synthetic aperture radar systems and their progression to the EOS SAR, *IEEE, Translational on geosciences and remote sensing*, 1991

[4] Attema, E. P. (1991). The active microwave instrument on-board the ERS-1 satellite. *Proceedings of the IEEE, 79*(6), 791-799.

[5] Nemoto, Y., Nishino, H. I. D. E. O., Ono, M., Mizutamari, H., Nishikawa, K., & Tanaka, K. (1991). Japanese earth resources satellite-1 synthetic aperture radar. *Proceedings of the IEEE*, *79*(6), 800-809.

[6] Raney, R. K., Luscombe, A. P., Langham, E. J., & Ahmed, S. (1991). RADARSAT (SAR imaging). *Proceedings of the IEEE*, *79*(6), 839-849.

[7] Jordan, R. L., Huneycutt, B. L., & Werner, M. (1995). The SIR-C/X-SAR synthetic aperture radar system. *IEEE Transactions on Geoscience and Remote Sensing*, *33*(4), 829-839.

[8] Ulaby, F. T., Held, D., Donson, M. C., McDonald, K. C., & Senior, T. B. (1987). Relating polaization phase difference of SAR signals to scene properties. *IEEE Transactions on Geoscience and Remote Sensing*, (1), 83-92.

[9] P.Y. Ufimtsev. "Comments on diffraction principles and limitations of RCS reduction techniques", *Proceedings of the IEEE*, 1996

[10] Franceschetti, Giorgio Guida, Raffaella, "Efficient simulation of hybrid stripmap/spotlight SAR raw signals from extended scenes.(Author Abstr*", IEEE Transactions on Geoscience and Remo*, Nov 2004.

[11] Youhong Lu, R. Fowler, W. Tian, L. Thompson. "Enhancing echo cancellation via estimation of delay", *IEEE Transactions on Signal Processing*, 2005

[12] Soumekh, Mehrdad. "SAR-ECCM using phaseperturbed LFM chirp signals and DRFM repeat jammer penalization.(synthetic aper", IEEE Transactions on Aerospace and Elect,

Jan 2006 Issue

[13] Y.-J. Wang, G.-Q. Zhao, and H.-W. Wang, “Echo cancelling algorithm for the LFM radar”, J. Xidian Univ., vol. 35, no. 6, pp. 1031–1035, December. 2008.

[14] F. Zhou, M. Xing, X. Bai, G. Sun, and Z. Bao, “Narrow-band interference suppression for SAR based on complex empirical mode decomposition,” IEEE Geoscience Remote Sensing Letters, vol. 6, no. 3, pp. 423–427, July 2009.

[15] Agrawal, A. K., Bhattacharya, C., Somawanshi, P., Khadtare, M., & Karandikar, S. K. (2011, September). Accelaerated SAR image generation on GPGPU platform. In Synthetic Aperture Radar (APSAR), 2011 3rd International Asia-Pacific Conference on (pp. 1-4). IEEE.

[16] Clemente, C., & Soraghan, J. J. (2010). Fractional RDA and enhanced FrCSA for SAR imaging.

[17] Y.-C. Xiang, C.-W. Qu, F. Su, and M.-J. Yang, “Active cancellation stealth analysis of warship for LFM radar,” in Proceeding 10th International Conference ICSP, Oct. 2010, pp. 2109–2112.

[18] M. Meller, “Cheap cancellation of strong echoes for digital passive and noise radars,” IEEE Transaction Signal Process., vol. 60, no. 5, pp. 2654–2659, May 2012.

[19] S.-W. Chen and M. Sato, “Tsunami damage investigation of built-up areas using multitemporal spaceborne full polarimetric SAR images,” IEEE Transaction Geosciece Remote Sensing, vol. 51, no. 4, pp. 1985–1997, April 2013.

[20] F. Zhou, B. Zhao, M. Tao, X. Bai, B. Chen, and G. Sun, “A large scene deceptive jamming method for space-borne SAR,” IEEE Transaction Geoscience Remote Sensing, vol. 51, no. 8, pp. 4486–4495, August 2013.

[21] Solimene, Raffaele, Ilaria Catapano, Gianluca Gennarelli, Antonio Cuccaro, Angela Dell'Aversano, and Francesco Soldovieri. "SAR Imaging Algorithms and Some Unconventional Applications: A unified mathematical overview", IEEE Signal Processing Magazine, 2014.

[22] Feng, Dejun, Qixiang Fu, Wei Wang, Yongcai Liu, Xiaoyi Pan, and Guoyu Wang. "On deception jamming for countering bistatic ISAR based on sub-Nyquist sampling", IET Radar Sonar & Navigation, 2014.

[23] D. Feng, L. Xu, W. Wang, and H. Yang, “Radar target echo cancellation using interrupted-sampling repeater,” IEICE Electronic Express, vol. 11, no. 8, pp. 1–6, April 2014.

[24] Liang Li, Jun Hong, Feng Ming. "Study aboutionospheric effects on Medium-Earth-Orbit SAR Imaging", 2014 *IEEE Radar Conference*, 2014

[25] Juan Zhao, Xia Bai. "Unambiguous SAR imaging from non-uniform sampling with simple fractional Fourier transform", 2014 *IEEE Geoscience and Remote Sensing Symposium*, 2014

[26] Xinhua Mao, Yimin D. Zhang, Moeness G. Amin. "Two-stage multi-static passive SAR imaging with reduced complexity", 2014 *IEEE Radar Conference*, 2014

[27] Feng, Dejun, Xiaoyi Pan, Dahai Dai, Yongcai Liu, and Wei Wang. "A frequency-domain three stage algorithm for active deception jamming against synthetic aperture radar", *IET Radar Sonar & Navigation*, 2014.

[28] Huang, Long, Chunxi Dong, Zhibo Shen, and Guoqing Zhao. "The Influence of Rebound Jamming on SAR GMTI", *IEEE Geoscience and Remote Sensing Letters*, 2015.

[29] Zhao, Bo, Feng Zhou, and Zheng Bao. "Deception Jamming for Squint SAR Based on Multiple Receivers", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 2015.

[30] Gao, Yesheng, Kaizhi Wang, and Xingzhao Liu. "An adaptive SAR imaging algorithm", 2012 International Waveform Diversity & Design Conference (WDD), 2012.

[31] Qun Zhang, Yi-chang Chen, Zhi-an Li, Yong-an Chen, Yong Wu. "Range migration correction for random stepped-frequency SAR imaging", 2014 *International Radar Conference*, 2014

[32] Xu, Letao, Dejun Feng, Yongcai Liu, Xiaoyi Pan, and Xuesong Wang. "A Three-Stage Active Cancellation Method Against Synthetic Aperture Radar", *IEEE Sensors Journal*, 2015.

[33] Letao Xu, Dejun Feng, Dahai Dai, Xiaoyi Pan, Xuesong Wang. "A dual-antenna active echocancellation method for synthetic aperture radar", *2016 10th European Conference on Antennas and Propagation (EuCAP),* 2016

[34] WU, X. F., WANG, X. S., & LU, H. Z. (2009). Study of Intermittent Sampling Repeater Jamming to SAR [J]. *Journal of Astronautics, 5*, 049.

[35] Meng Qi, Zhulin Zong. "A New Method of Moving Targets Detection and Imaging for Bistatic SAR", *2014 Seventh International Symposium on Computational Intelligence and Design*, 2014

[36] Tria, M., Ovarlez, J. P., Vignaud, L., Castelli, J. C., & Benidir, M. (2004, September). SAR imaging using multidimensional continuous wavelet transform. In *EUSIPCO* (pp. 1179-1182).

[37] Duquenoy, M., Ovarlez, J. P., Ferro-Famil, L., Pottier, E., & Vignaud, L. (2010). Scatterers characterisation in radar imaging using joint time–frequency analysis and polarimetric coherent decompositions. *IET radar, sonar & navigation*, *4*(3), 384-402.

[38] Yarleque Medina, Manuel Augusto, Alvarez Navarro, Sthefany Martinez Odiaga, Hansel Joussef, Martin Platriez. "Synthetic aperture radar (SAR) imaging based on low-cost FMCW radar for mini-UAVs", *2016 IEEE ANDESCON*, 2016

[39] Lulu Tan, Zhijuan Ma, Xuelian Zhong. "Preliminary result of high resolution multiaspect SAR imaging experiment", 2016 CIE International Conference on Radar (RADAR), 2016

[40] Kusk, A., Abulaitijiang, A., & Dall, J. (2016, June). Synthetic SAR image generation using sensor, terrain and target models. In *EUSAR 2016: 11th European Conference on Synthetic Aperture Radar, Proceedings of* (pp. 1-5). VDE.

[41] Guanyong Wang, Lei Zhang, Qingrong Hu. "A novel range cell migration correction algorithm for highly squinted SAR imaging", *2016 CIE International Conference on Radar (RADAR),* 2016

[42] Qianrong Lu, Kaizhi Wang, Xingzhao Liu. "Improved SAR imaging algorithm using FRFT", *2016 CIE International Conference on Radar (RADAR),* 2016

[43] Sudipto Bordoloi, Bikram Singh, Roshan Dhakal, Sagar Dutta. "Ranging and SAR imaging of underground targets using laptop based FMCW RADAR", *2016 International Conference on Circuits, Controls, Communications and Computing (I4C)*, 2016

[44] Karasakal, G., Kaplan, N. H., & Erer, I. (2009, August). Speckle noise reduction in SAR imaging using 2-D lattice filters based subband decomposition. In *Signal Processing Conference, 2009 17th European* (pp. 2598-2602). IEEE.

[45] A. R. Robinson and K. H. e. Brink, The Global Coastal Ocean: Multiscale Interdisciplinary Processes. Harvard University Press, 2005.

[41] A. Limited, Wavemill : Instrument Design Document. EADS Astrium, 2008.

[42] I. G. Cumming and F. H. Wong, Digital Processing of Synthetic Aperture Radar Data. Artech House Inc., first ed., 2005.

[43] A. Ambardar, Digital Signal Processing - A Modern Introduction. Thomson Ltd., international student ed., 2007.

[44] A. Thompson, J. Curlander, N. McLagan, T. Feather, M. D'Iorio, and J. Lam, "Scansar processing using the fastscan system," in Geoscience and Remote Sensing Symposium Proceedings, 1994. IGARSS '94. 1994 IEEE International, vol. 2, pp. 1187 – 1189, vol.2, aug. 1994.

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