Study of High Resolution Imaging for Flying Objects through Synthetic Aperture Radar using Low Profile Antenna

P. Archanal[1], J Chattopadhyay[2]
[1,2]*Sreenidhi Institute of Science & Technology, India*

Abstract- Synthetic Aperture Radar (SAR) has been widely used for Earth remote sensing. Significant effort of both the scientific and industrial community is invested in research and development of multi-frequency, multi-polarization, and high-resolution SAR systems. One of the key issues is to realize efficient methods with low profile antenna for imaging, reconstruction, and target detection of flying objects and electrically large-scale objects. This will provide day-and-night and weather-independent images for a multitude of applications ranging from geo-science and climate change research, environmental and Earth system monitoring, 2-D and 3-D mapping, change detection and security-related applications.

In this paper, a study of SAR based on high-resolution imaging , using low profile antenna is presented. The key factor of SAR is to generate multiple images of the same object due to the platform motion. The paper demonstrates how multiple images can produce comparable resolution of an object using required signal processing algorithm. This study will be useful to understand the effects of backscattering and static scene related issues.

Keywords – Synthetic Aperture Radar (SAR),high-resolution, Range Resolution, Azimuth Resolution, low profile antenna, virtual view, SAR Imaging

I. INTRODUCTION

The history of SAR and radar in general is important when investigating methods of SAR imaging. Radar was initially developed in World War II for tracking of ships and aircrafts. Use of radio frequency has the advantage of being able to penetrate through heavy weather and darkness to locate targets where remote sensing with visible light fails. SAR techniques like polarimetry for improved parameter retrieval, interferometry for deriving the surface topography and differential interferometry for the measurement of Earth surface displacements were developed in the 80s and 90s[1].

SAR uses the motion of radar antenna over the target region by typically mounted on moving platform such as an aircraft or spacecraft ,to provide finer spatial resolution than conventional beam scanning radars. The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates larger synthetic antenna aperture. This may allow SAR to create high resolution images with comparatively small physical antennas[5]. Signal processing of the successive recorded radar echoes allows to combine these radar echoes from multiple antenna positions which forms SAR and allows the creation of high resolution of different positions of antenna. In this way Synthetic Aperture Radar (SAR) systems take advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high resolution images [2].The well ordered combination of received signals at different time ,map to different positions of the object digitized ,builds a virtual aperture that ismuch longer than the physical antenna length. This is why “synthetic aperture”, giving it the property of being an imaging radar. Here the range direction is parallel to target track and perpendicular to azimuth direction which is also known as along- track direction because it is in line with the position of the object within the antenna’s field of virtual view.In this paper different aspects of SAR imaging system is discussed and analyzed to identify the future scope of work.

II. LITERATURE SURVEY

2.1 Side-looking airborne radar :

Side-looking airborne radars normally are divided into two groups: the real-aperture systems that depend on the beamwidth determined by the actual antenna, and the synthetic aperture systems that depend upon signal processing to achieve a much narrower beamwidth in the along-track direction than that attainable with the real antenna [5].The early versions of Side Looking Airborne Radar (SLAR) systems were primarily used for military reconnaissance purposes. Until mid 1960s, high- resolution SLAR image was declassified and made available for scientific use [2].

Table 2.1 shows a comparison of a SAR image with moderate resolution and obtained with the new generation of high-resolution SAR satellites. The trend for future systems shows the need for an increased information content in SAR images that can be achieved by multi-channel operation (polarimetry, multifrequency), improved range and azimuth resolution, time series (frequent revisit of the same area) as well as observation angle diversity (interferometry and tomography). Figure 2.1shows Evolutaion of SAR with improvements in Resolution.The ultimate goal of future space-borne SAR systems is to allow a wide-swath high- resolution monitoring of dynamic processes on the Earth surface in a quasi-continuous way [3].

2.2 Improvement in image resolution with SAR

The image formed by SLAR is poor in azimuth resolution. For SLAR the smaller the beam width, the finer the azimuth resolution. In order to obtain high-resolution image one has to resort either to an impractically long antenna or to employ wavelengths so short that the radar must contend with severe attenuation in the atmosphere [8].Synthetic Aperture Radar (SAR) is a technique which uses signal processing to improve the resolution beyond the limitation of physical antenna aperture.

Table 2.1:Comparison of a SAR image with moderate resolution

Satellite	Country	Year	Band	Frequency (GHz)	Wavelength (cm)	Incident Angle (deg)	Polarization	Pulse Bandwidth (MHz) / (Range Resolution (m))	Azimuth Resolution (m) / (Looks)
SEASAT	USA	1978	L-band	1.275	23.5	23	HH	19 / (7.9)	6 / (1)
SIR-A	USA	1981	L-band	1.275	23.5	50	HH	6 / (24.9)	6.5 / (1)
SIR-B	USA	1984	L-band	1.275	23.5	15-65	HH	12 / (12.5)	6 / (1)
ERS-1/2	Europe	1991/95	C-band	5.25	5.7	23	VV	15.5 / (9.7)	25 / (3)
ALMAZ	USSR	1991	S-band	3.0	10	30-60	HH	- / 15*	15 / (2)
JERS-1	Japan	1992	L-band	1.275	23.5	39	HH	15 / (10)	30 / (4)
SIR-C / X-SAR	USA	1994	L-band	1.25	23.5	15 - 55	HH, HV, VH, VV	10 / (15) 20 / (7.5)	7.5 / (1)
			C-band	5.3	5.7				
	Germany		X-band	9.6	3	54	VV		6 / (1)
RADARSAT-1	Canada	1995	C-band	5.3	5.7	20 - 50	HH	11.6 / (12.9) 17.3 / (8.6) 30 / (5)	28 / (4) 50/ (2-4) 100 / (4–8)
SRTM	USA	2000	C-band	5.25	5.7	54	HH, VV	20 / (7.5)	15 / (1)
	Germany		X-band	9.6	3	54	VV	8 / (18.7)	8 – 12 / (1)
ENVISAT	Europe	2002	C-band	5.25	5.7	15 – 45	HH, HV, VH, VV	9 / (16.6)	6 / (1) 150 / (12) 1000 / (18-21)

Synthetic Aperture Radar (SAR) is a technique which uses signal processing to improve the resolution beyond the limitation of physical antenna aperture. In SAR, forward motion of actual antenna is used to 'synthesize' a very long antenna. SAR allows the possibility of using longer wavelengths and still achieving good resolution with antenna structures of reasonable size can be taken as reference graph from figure 2.1 as Evolution of SAR with improvements in resolution .It is equipped with multi-frequency, multi-polarization SAR that operates in the L, C and X-band and provides HH, VV, VH and HV polarization [2].

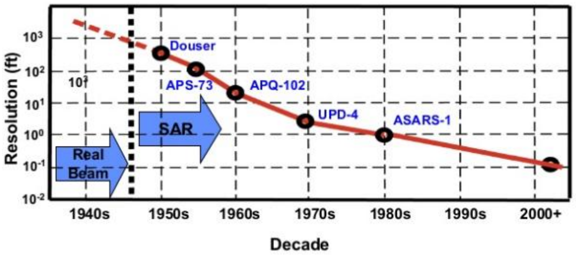


Figure 2.1: Evolutaion of SAR with improvements in Resolution

2.3. Comparision of SLAR with SAR with present techniques

SLAR can be used if all points lie in a plane surface, and this modification can result in excessive distortion in mountain areas[1]. SAR allows the possibility of using longer wavelengths and still achieving good resolution with antenna structures of reasonable size which motivates to study SAR for achieving high resolution imaging using low profile antenna. SAR is a complicated data processing of received signals and phases from moving targets with a small antenna, the effect of which is to should be theoretically convert to the effect of a large antenna, that is a synthetic aperture length.

The synthetic aperture length is the beam width by range which a real aperture radar of the same length, can project in the azimuth direction.Basically by the theory of resolution in the azimuth direction is given by half of real aperture radar as shown:

Real beam width : $\beta=\lambda/D$
Real resolution: $\Delta L=\beta R=Ls$ (synthetic aperture length)
Synthetic beam width : $\beta s=\lambda/2Ls=D/2R$
Synthetic resolution : $\Delta Ls=\beta sR=D/2$
where λ :wavelength ,D: aperture of radar ,R: slant range

The brief discussion of how aperture synthesis changes the azimuth resolution to half of the along-track antenna length, require basic knowledge of SAR geometry which is described in this paper in section 3.3,it is the key note of comparing SAR with SLAR.

III. IMAGING WITH SYNTHETIC APERTURE RADAR

The principle idea behind SAR is to synthesize the effect of large aperture physical radar for detection of objects or targets in radar imaging to provide high-range resolution of two-dimensional images independent from daylight, cloud coverage and weather conditions[10].SAR is sensitive to small surface roughness by providing control over such factors as power, frequency, phase, polarization, incident angle, spatial resolution and swath width, all of which are important when designing and operating a system for the extraction of quantitative information which is helpful in the detection of objects. In this figure 3.1, the flight direction is denoted as azimuth and the line-of-sight as slant range direction. On the surface, range direction is said ground range direction. The point just below the platform is said nadir. The nearest point to the nadir of the fan shaped beam from Antenna is known as near range and farthest point is known as far range. Distance between near range and far range is the swath.

Where slant range =Time Delay * c/2, in which distances are measured between the antenna and the target ground range, and also distances are measured between the platform or beam ground track and the target.

Range 'R' is determined by measuring the time from transmission of a pulse to receiving the echo from a target and resolution are achieved in Synthetic Aperture Radar (SAR) is determined by the transmitted pulse width i.e. narrow pulses yield fine range resolution [8].

A synthetic aperture is produced by the forward motion of the radar. As it passes a given scatterer, many pulses are reflected in sequence. By recording and then combining these individuals signals, a "synthetic aperture" is created in the computer providing a much improved azimuth resolution.

Taking Azimuth Angle =arcsine[c x f /2v], to note that some details of the structure of the echoes produced by a given target change during the time the radar passes by. This change is explained also by the Doppler effect which among others is used to focus the signals in the azimuth resolution. When the target is entering the beam, the Doppler shift is positive because the source to target distance is decreasing and vice versa We will illustrate these points with an analogy to figure 3.1.

Radar images can then be synthesised by scanning the incidence angle and sequentially synthesising images for the different beam positions as shown in Figure 3.2. Swath widening is achieved by the use of an antenna beam which is electronically steerable in elevation. The imaged area from each particular beam is said to form a sub-swath. Determining the radar operation time between two or more separate sub-swaths in such a way as to obtain full image coverage of each swath.From the geometry of an imaging radar is shown in figure 3.1. θV is determined by the width(Wa)and length of antenna, and wavelength of transmitted signal (λ). This relation is written as

$$\theta_V = \lambda / W_a \tag{3.1}$$

The antenna is mounted on a platform such as an aircraft that travels along a flight path with velocity v. It illuminates the shaded path i.e shadow on the ground as the aircraft moves in the direction of flight path. The width (Wg) of the ground swath is given as

$$W_g = \frac{\lambda R}{W_a \cos\theta} \tag{3.2}$$

where θ is the incidence angle (lookangle) of the beam, R is the slant range from the antenna to the midpoint of swath[6]. The RF energy transmitted from antenna has a duration τp and is repeated at a given interval, pulse repetition interval (PRI) that can be inverted to obtain the pulse repetition frequency (PRF).

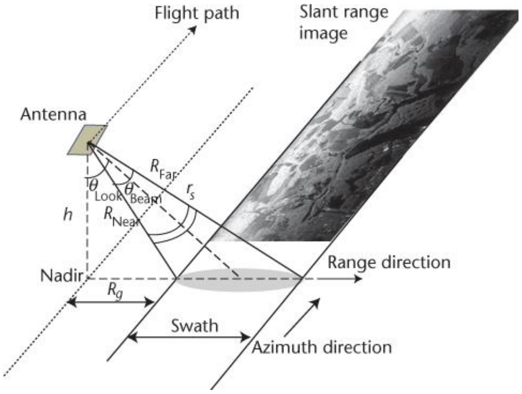


Figure 3.1:SAR Imaging Geometry

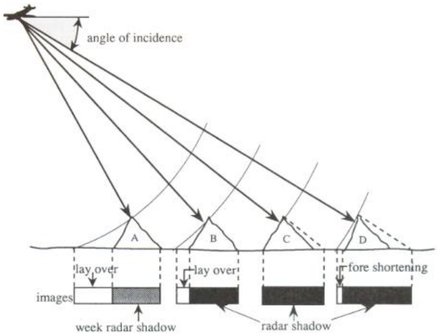


Figure 3.2: Geometric Distortions in SAR

3.1 Range resolution

Range resolution is the ability of radar system to distinguish between two or more targets on the same bearing but at different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator. If the pulse width is relatively large then the two adjacent targets cannot be distinguished as two but instead their echoes will be mixed and they will appear as a single target at the receiver end. Pulse width is the primary factor in range resolution[4].Unlike normal radars, in SAR obtaining fine range resolution, a short pulse duration is needed.

From Figure3.3 by precisely measuring the time difference between the transmitted pulse between a target and the ground range, is measured on the basis of the travel time of the transmitted microwave pulses and the receipt of the reflected energy, radar is able to determine the distance of the reflecting object (called range or slant range).

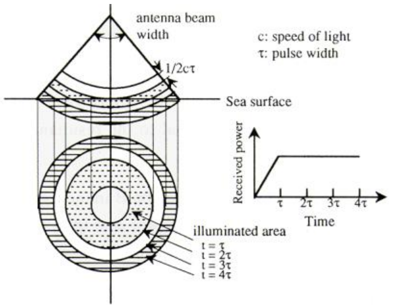


Figure3.3: SAR illumination with different pulse durations

From the time (t=0), when the first edge of pulse arrives at the surface, to the time (t=τ) when the end edge of a pulse with a width of τ arrives at the surface, the received power increases linearly. The received pulses are composed of echoes from various parts ground surface. Therefore the travel time can be calculated by averaging the received pulses. As radar range resolution depends on the bandwidth of the received signal, which is inversely proportional to the pulse duration. So short pulses are better for range resolution. The amplitude versus time of the return pulse is a recording of the reflectivity of the surface. If adjacent reflectors appear as two distinct peaks in the return waveform then they are resolved in range.

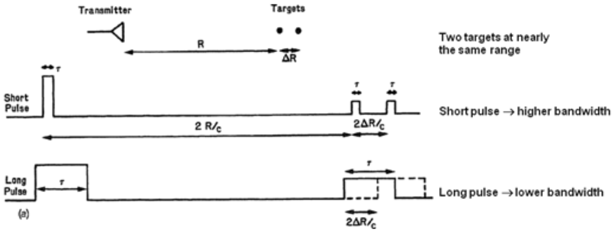


Figure 3.3: Range resolution for varied pulse width

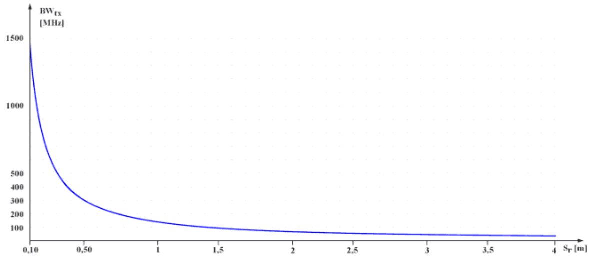


Figure 3.4: Graph Range resolution vs Transmitter Bandwidth

The nominal slant range resolution is Δr = Cτ/2 where τ is the pulse length, C is the speed of light =3.00 × 10^8 m s and θ is the look angle. The factor of 2 accounts for the 2-way travel time of the pulse. The incident angle or look angle of microwave to a target is the angle from the normal line. The smaller the look angle,the larger the back scattering intensity .Range resolution is infinite for vertical look angle of (0 ◦, 90◦) and improves as look angle is increased to 20 ◦ to 50 ◦ practically. The ground range resolution is geometrically related to the slant range resolution by Rr = Cτ /2 sin θ .

Thus range resolution is independent of the height of the spacecraft. Hence range resolution can be improved by increasing the bandwidth of the radar using Pulse compression .The ability to compress the pulse depends on the bandwidth of the transmitted pulse (B) in MHz ,not by its pulse width. Shorter wavelength will enable higher bandwidth as bandwidth is only a small fraction of carrier frequency. Receiver needs at least the same bandwidth to process the full spectrum of the echo signals. Range resolution, Rr, is related to signal bandwidth, B.

$$Rr \propto 1 / B \qquad (3.3)$$

This allows very high-resolution to be obtained with long pulses, thus with a higher average power. Figure 3.4shows the variation of slant range resolution with bandwidth.

3.2 Azimuth resolution

The other dimension is called azimuth 'ΔLs' (or along track) and is perpendicular to range. Synthetic Aperture Radar's (SAR) ability to produce relatively fine azimuth resolution differentiates it from other radars can be described from two cases i.e Doppler processing viewpoint and by time width of compressed chrip in azimuth direction.

(i)The target's Doppler frequency determines its azimuth position. Utilizing the Doppler effect cannot increase the range resolution but it does greatly increase the azimuth resolution. When a detector moves with respect to a source of waves, a shift in frequency is observed known as the Doppler effect[3]. To calculate the Doppler frequency shift for a specific target, we first calculate dR/dt the relative speed with which the target and antenna approach each other.To find the R-directional component of Vrel (the velocity with which the target approaches the sensor), we can project Vrel (parallel to x) onto a line parallel to R to get

$$\therefore v = v_{rel}\frac{x}{R}$$

$$v = v_{rel}\cos\left(\frac{\pi}{2} - \theta\right) = v_{rel}\sin\theta \qquad (3.4)$$

One could form a longer synthetic aperture by steering the transmitted radar beam which follows the target by practical aspects. Since the return echo will be shifted by the same amount, the Doppler frequency shift for the target is

$$f_d = \frac{2v}{C} f_s = \frac{2v_{rel} \sin\theta}{C} . \frac{C}{\lambda} = \frac{2v_{rel} x}{\lambda R} \tag{3.5}$$

This value provides a means of determining exactly where the echo signal came from. From the equation for Doppler frequency shift fd , the azimuth resolution can be calculated as

$$\delta x = \left(\frac{\lambda R}{2v_{rel}} \right) \delta f_d \tag{3.6}$$

where δfd is the resolution of the Doppler frequency shift approximately equal to the inverse of the time during which the point target was in the beam, $\delta \text{fd} \approx 1 / \text{tspan}$. This time span can be calculated as

$$t_{span} = \frac{\text{arc length}}{v_{rel}} = \frac{R\theta_H}{v_{rel}} = \frac{R\lambda}{L_a v_{rel}} \tag{3.7}$$

Therefore the azimuth resolution of synthetic aperture radar is given by

$$\delta x = \left(\frac{\lambda R}{2v_{rel}} \right) \left(\frac{L_a v_{rel}}{R\lambda} \right) = \frac{L_a}{2} \tag{3.8}$$

Making the antenna length L as short as possible to form a complete aperture without aliasing longer wavelengths back into shorter wavelengths we must pulse the radar at analong-track distance of L/2 or shorter. This result of δx= La / 2 is not strictly true, however, since we assumed that a constant Doppler frequency shift was observed during the entire time tspan. In fact, δfd changes throughout the observation and is only approximately constant for a time much less than tspan[2].To understand why such a rapid pulse rate is necessary, consider the maximum Doppler shift from a point that is illuminated at a maximum distance ahead of the radar where vo is the carrier frequency = C/λ and v is the velocity of spacecraft relative to the ground. The maximum Doppler shift occurs at a maximum angle of

sin θA=λ
So Δν =$\overline{L}$
for (θA =45 ◦ to 90 ◦). $\frac{2v0}{c\sin\theta_A} = \left(\frac{2C}{\lambda}\right)\left(\frac{v}{C}\right)\left(\frac{\lambda}{L}\right) = \frac{2v}{L}$ (3.9)

This corresponds to a maximum along-track distance between samples of L/2.One way of achieving better along-track performance is to boost frequency; another is to increase along-track antenna positions; a third is to decrease the target range. None of these options are very effective from space. However, resolution is determined by the Doppler bandwidth of the received signal, rather than the along-track width of the radar's antenna beam pattern. This is the key step to understanding the principles upon which SAR is based on time width of compressed chrip in azimuth direction[12].

(ii)From the geometry of SAR is shown in Fig. 3.5, the along track performance antenna beam illuminates the target when beam reaches position tn and continues to illuminate the target for a distance until it reaches tn+3. The length LSA called "synthetic aperture length".The time to fly the array through point target is given by Integration or dwell time

$$T = \frac{L_{SA}}{V} \tag{3.10}$$

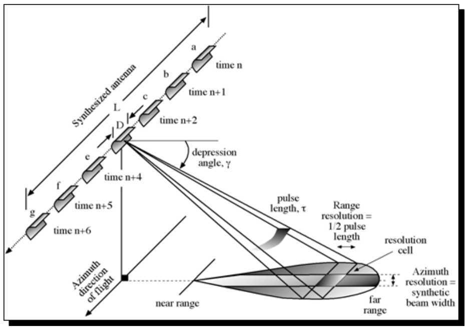


Figure 3.5:SAR Imaging to determine azimuth resolution

Considering the SAR imaging geometry we take that at along track direction total antenna length as 2LSA to the ground.Note that LSA is basically the arc length of along track beamwidth θA.

$$\text{LSA} = R\theta A = \frac{R\lambda}{D_{AT}} \tag{3.11}$$

Where DAT is along track antenna length

Now if $R(t) = \sqrt{x_o^2 + R_o^2}$

Let us define the beams position at any time t as 'x' and the alongtrack velocity 'v'.The broad side slant range to target as R and the slant range to the target at any time is R(t).

$$R(t) = \sqrt{(vt)_o^2 + R_o^2}$$

$$R(t) = R_0 \sqrt{(vt)_o^2 / R_0 + 1} \tag{3.12}$$

Typically x<< R0 which implies vt/R0 << 1

Let us denote this equation as a=√ (1+b)

Recalling binomial theorem we can write

a=√ (1+b2) as 1+b2/2 - b4/8+b6/16---- (3.13)

Since b<<<1 we can consider first order as a=1+b2/2

Using this (3.14) approximation

$$R(t) = R_0 \sqrt{1 + \frac{1/2(vt)^2}{(R_0)^2}} \tag{3.14}$$

$$R(t) = R_0 \sqrt{R_0 + \frac{(vt)^2}{2R_0}} \tag{3.15}$$

Consider the signal transmitted from the beam to be of simple sinusoid form as cos(ω0θ) .This ignores pulse compression but useful in our approximation when target is moving.Let the signal recieved back at the moving beam after reflection from target be cos(ω0(t+t2w)) .As time taken for two way trip is 2w,it is considered as

$$\text{t2w} = \frac{2R(t)}{C} = \frac{2}{C}\sqrt{R_0 + \frac{(vt)^2}{2R_0}} \tag{3.16}$$

The received signal is then

$$\cos(\omega 0t+\omega 0t2w) = \cos[\omega 0t + \omega_0 \frac{2}{C}(R_0 + \frac{(vt)^2}{2R_0})\ ]$$

$$= \cos[\omega 0t + \frac{\omega_0}{C}(2R_0 + \frac{(vt)^2}{R_0})\ ]$$

As $\omega 0 = \frac{2\pi f}{C} = \frac{2\pi}{\lambda}$

So the recieved signal becomes

$$\cos(\omega 0t+\omega 0t2w) = \cos[\omega 0t + \frac{4\pi R_0}{\lambda} + \frac{2\pi v^2 t^2}{\lambda R_0}\ ]$$

$$= \cos[\omega 0t + \phi R(t)]$$

$$= \cos[\phi T(t)] \tag{3.17}$$

where ϕR(t) is the phase delay of the two way travel between the beam and target and ϕT(t) is the total phase angle of the received signal.

If we define instantaneous angular frequency of sinusoid as

$$\omega \text{ then } \omega = \frac{\delta\phi(t)}{\delta(t)} = \omega_0 + \frac{\delta\phi_R(t)}{\delta(t)} \tag{3.18}$$

$$\omega_0 + \frac{4\pi v^2 t}{R_0 \lambda}$$

So $\omega =\qquad = \omega 0 + Bt$ (3.19)

Thus the resultant signal has variation in its frequency variation induced on it as a result of motion towards the beam .The recieved signal therefore appears as received "chirp" or FM modulated signal.
Here B is the doppler rate given as $B=4\pi v2/ R0\ \lambda$ rad/s2 .Hence if B expreseed in terms of frequency

$$B = \frac{2v^2}{R_0\lambda} Hz/S^2 \qquad (3.20)$$

Generally this azimuth cripped signal deals same way as range chripped signal i.e through matched filtering.So in matched filtering frequency bandwidth has inverse relation with pulse width.We also take in to account of visible time of the target towards beam ,which is the total time (tT)the azimuth signal frequency is modulated by doppler.
So the total chrip bandwith is taken as

$$Bc = B\ tT = \frac{BL_{SA}}{v} \qquad (3.21)$$

Now the width time of azimuth is

$$Ta = \frac{1}{B_c}$$

$$Ta = \frac{v}{BL_{SA}} = \left(\frac{vR_0\lambda}{2v^2}\right) \cdot \left(\frac{D_{AT}}{R_0\lambda}\right)$$

$$Ta = \frac{D_{AT}}{2v}$$

So the total time width T of the compressed chrip can be taken in azimuth direction by multiplying it with beam velocity as

$$T = Ta\ v = \frac{D_{AT}}{2} \qquad (3.22)$$

Hence azimuth resolution is achieved via synthetic aperture for fully focussed SAR processing by considering doppler effect and pulse compression techniques and by ignoring burst of unwanted pulses. This is the reason why SAR has a high azimuth resolution with a small size of by considering the half of azimuth direction with the variation of total time width .

IV. COMPONENTS AND TECHNIQUES OF SAR

The azimuth resolution is limited only by the length of the synthetic aperture, not by the size of the antenna carried by the aircraft. However, a constraint on the real (physical) antenna remains: to be capable of keeping the scene of interest within the antenna beam footprint. Appropriate synthetic aperture lengths, which are commonly from several meters to tens of kilometers, are calculated from range, resolution and wavelength. SAR images are more appealing in aesthetic terms when the range resolution is commensurate with that of the finer azimuth resolution. Finer range resolution is achieved by sending a pulse of adequate bandwidth; this can be done either by sending a suitably short pulse or by modulating a pulse so as to yield a narrow autocorrelation function similar to that which characterizes spread spectrum communications. Popular modulation schemes include random phase codes and the linear-frequency- modulated (LFM) chirp signal. Modern SAR systems typically employ pulses that range from several microseconds to sev- eral hundred microseconds in length, with time-bandwidth products that are sometimes in the tens of thousands. The LFM chirp signal is particularly advanta-geous for fine resolution SAR systems in that it can be easily generated; another advantage is that it can be partially processed before the data is digitized. Prior
to sampling, the chirp can effectively be removed from the echo signals via heterodyning. The resulting video signal has reduced bandwidth, in which a constant frequency maps to a constant relative delay (range) The azimuth resolution is limited only by the length of the synthetic aperture, not by the size of the antenna carried by the aircraft. However, a constraint on the real (physical) antenna remains: to be capable of keeping the scene of interest within the antenna beam footprint. Appropriate synthetic aperture lengths, which are commonly from several meters to tens of kilometers, are calculated from range, resolution and wavelength. SAR images are more appealing in aesthetic terms when the range resolution is commensurate with that of the finer azimuth resolution. Finer range resolution is achieved by sending a pulse of adequate bandwidth; this can be done either by sending a suitably short pulse or by modulating a pulse so as to yield a narrow autocorrelation function similar to that which characterizes spread-spectrum communications. Popular modulation schemes include random phase codes and the linear-frequency-

modulated (LFM) chirp signal. Modern SAR systems typically employ pulses that range from several microseconds to several hundred microseconds in length, with time-bandwidth products that are sometimes in the tens of thousands. The LFM chirp signal is particularly advantageous for fine resolution SAR systems in that it can be easily generated; another advantage is that it can be partially processed before the data is digitized. Prior to sampling, the chirp can effectively be removed from the echo signals via heterodyning. The resulting video signal has reduced bandwidth, in which a constant frequency maps to a constant relative delay (range)

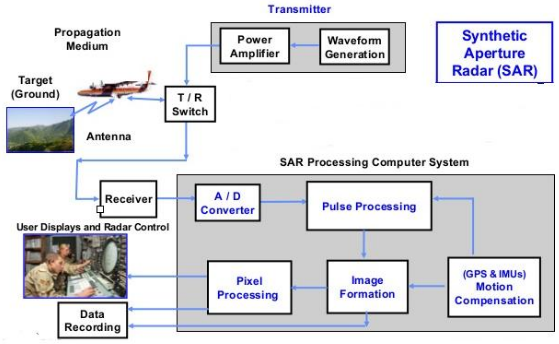


Figure 4.1: Block diagram of SAR system

Transmitter-Power amplifier: The main functions of the transmitter are to generate the desired waveform, amplify it and transmit via an antenna. STALO is used as reference signal for chirp or waveform generator and other local oscillator (LO) to maintain the coherence of SAR system. The modulation circuit provides proper pulse modulation (PM) to the chirp mode gate and the power amplifier. Major portion of the signal is routed to a solid state high power amplifier with 40-dB gain. The amplified signal is then radiated through the antenna via a circulator.

4.1 High Resolution of SAR by means of low profile antenna

The SAR processing can be achieved by utilising the Doppler effect (frequency shift) of the echo signal.The instantaneous frequency for the two targets, p1 and p2 , both at a distance of Ro but separated in azimuth by a distance, D/2, will

$$f_o + \frac{2v}{\lambda}\cos\theta_o \text{ and } f_o + \frac{2v}{\lambda}\cos\theta_o - \frac{vD}{R_o\lambda}\sin\theta_o \tag{4.1}$$

since the time to fly the distance between them is

t = D sin θo/2v and the observed differential frequency shift Δfi will be

$$\Delta f_i = \frac{vD}{R_o\lambda}\sin\theta_o \tag{4.2}$$

High resolution can be obtained by considering the antenna illumination coverage on the ground should be greater than the equivalent antenna array length independent of range, wavelength and pointing[7]. Using the antenna beamwidth relationships, we get array length on the ground.

$$\frac{R_o\lambda}{\ell} > L = \frac{\lambda R}{D\sin\theta_o} \tag{4.3}$$

Noting that ρa = D/2 for θo = 90◦ results

$$\rho_a \geq \frac{\ell}{2} \tag{4.4}$$

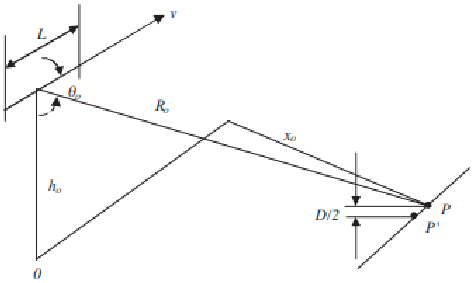
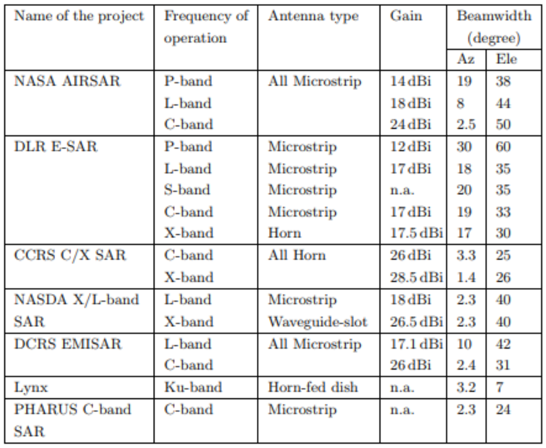


Figure 4.2: Azimuth resolution of SAR with low profile antenna

So from the above approximations and considering the illustrations of section 3.1 and 3.2 it is implied that smaller antenna can also obtain better and high resolution with SAR. A possible solution for building the gap between high azimuth resolution and the fast processing is analyzed .A proposal for processing special target scenes made before the parts of the image where an aim is detected with azimuth stacking algorithm or range resolution algorithm[12].

Table 4.1shows a summary of some SAR systems. SAR system generally operate in L- Cand X-band, where slotted-waveguide and patch antennas having low profile provide the bestperformance for high resolution for spaced-based synthetic aperture radar (SAR) applications.



Name of the project	Frequency of operation	Antenna type	Gain	Beamwidth (degree)	
				Az	Ele
NASA AIRSAR	P-band	All Microstrip	14 dBi	19	38
	L-band		18 dBi	8	44
	C-band		24 dBi	2.5	50
DLR E-SAR	P-band	Microstrip	12 dBi	30	60
	L-band	Microstrip	17 dBi	18	35
	S-band	Microstrip	n.a.	20	35
	C-band	Microstrip	17 dBi	19	33
	X-band	Horn	17.5 dBi	17	30
CCRS C/X SAR	C-band	All Horn	26 dBi	3.3	25
	X-band		28.5 dBi	1.4	26
NASDA X/L-band SAR	L-band	Microstrip	18 dBi	2.3	40
	X-band	Waveguide-slot	26.5 dBi	2.3	40
DCRS EMISAR	L-band	All Microstrip	17.1 dBi	10	42
	C-band		26 dBi	2.4	31
Lynx	Ku-band	Horn-fed dish	n.a.	3.2	7
PHARUS C-band SAR	C-band	Microstrip	n.a.	2.3	24

Table 4.1: Comparison of antenna parameters between SAR system

Image Formation :For using the SAR system for nearly real-time image processing, due to actual processor capabilities the biggest issue is to find a way between sufficient contrast and short processing time by maintaining high azimuth and range resolution. Since there are no smooth transitions between and algorithms mainly focus on one of both sides respectively, one cannot do a compromise. The sum of the resulting vector from SAR data yields the reflectivity of the pixel. This way even a translational motion of the antenna can be compensated.

Pixel Processing: To achieve range resolution with range stacking the results for different frequencies are calculated and added each time[11]. In both 2-D dimensions the processing is substituted by a summation. For each range line, each pixel is processed concerning its reflectivity. Each range line has to be processed for each frequency. This results for one range line are summed up vectorially and picture is reconstructed and the corresponding data is recorded. An estimation of the processing time can be done. Therefore a reference processing time have to be defined using equation (3.22).

V. ANALYSIS OF SAR IMAGE PROCESSING ALGORITHMS

The main goal of SAR data processing is the determination of the range and azimuth coordinates of the targets lying in the strip- map[11]. Generally there are two approaches for SAR processing, namely azimuth stacking Algorithm and Range Doppler Processing Algorithm.

Receiver: The function of a radar receiver is to amplify the echoes of the radar transmission and to filter them in a manner that will provide the maximum discrimination between desired echoes (ground) and undesired interference. The front-end circuitry of the receiver selects the input frequency band and amplifies the incoming signal to a proper level for the detector and subsequent low frequency circuitry.The LNA amplifies the received echo from the antenna by 30 dB and improves the sensitivity of the system. A combline band-pass filter is inserted at the receiver to reject any unwanted signal outside the passband. This signal is then down-converted to IF by a quadrature mixer and produces full-phase IF signals (I and Q) [10].

Ato D converter: A high-speed analog-to digital converter (ADC) is used to digitize the down-converted signal to data stream and stored in a high-density digital recorder.

Motion compensation: To reconstruct a recorded scene correctly, the main postulation to an SAR system is, that its trajectory has to be known using image formation with the help of pixel processing. For this purpose different algorithms are recommended in literature to detect the deviation either by inertial measurement supported by GPS and IMUs or by analyzing the received signal[10]. Afterwards the received data is manipulated, what means that the phase and the amplitude are corrected.

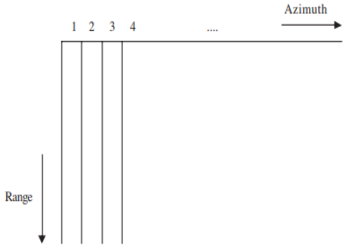


Figure4.3: Two-dimensional SAR data space.

From figure 4.3 a Two-dimension Algorithm processes the range and azimuth data simultaneously,whereas the Range Doppler Processing algorithm implements range compression processing followed by azimuth compression processing[8].

5.1 The Azimuth Stacking Algorithm

The radar radiation pattern and the limitations of different SAR will not be included in this analysis. Because only phase information matters for focusing SAR signal, while the antenna radiation pattern and mode selection only affects the focusing pattern. Then, evaluating, the 2D SAR spectrum (range compressed) of a point scatterer located at (x, r) can be given as

$$S(k_u, \omega) = \exp\left\{ -j\sqrt{(2k)^2 - k_u^2}\,r - jk_u x \right\}, \quad (5.1)$$

in which the insignificant slowly varying amplitude terms and constants are suppressed. Where, ku is the wave number variable corresponding to the azimuth (antenna illuminating) position 'u'. where kr is the frequency domain after the mapping.ω the angular velocity of the transmitted pulse, and 'k ≡ wc' the corresponding wave number variable.

Based on the SAR 2D spectrum ,the proposed azimuth stacking algorithm will be discussed in this section. This mainly consists of three parts: Doppler domain mapping, frequency domain mapping, and azimuth stacking. The two consecutive mappings will change the conventional range dependent SAR transfer function (or 2D spectrum) into azimuth-dependent[12].

According to the above derivations, the proposed azimuth stacking algorithm with reference to Azimuth Stacking Algorithm for Synthetic Aperture Radar Imaging can be given by following steps :

[1] Range compression without IFFT
[2] Azimuth FFT to obtain SAR 2D spectrum
[3] Doppler domain mapping
[4] Frequency domain mapping
[5] Phase multiplication of diferent signals S(ku, kr) by there corresponding phase values φ(ku, kr ;xi) is done in this step,which corresponding to filtering the data for each azimuth position.
[6] Integrating (summing) the multiplication result over the Doppler domain ku to give targets function γ(xi, r) at azimuth position x.
[7] Inverse Fourier transform of γ(xi, kr) to generate the reflectivity image γ(xi, r) at azimuth position xi.
[8] Iterating step 4) to step 6) for all azimuth positions
[9] Combing γ(xi, r) along azimuth direction to yield 2D SAR image.

It should be noted that since the Doppler domain mapping and frequency domain mapping are linear mappings, they can be efficiently implemented suffering from the interpolation truncation error.

VI. DESIGN CONSIDERATIONS

The design parameters can be used as the basic guideline to select the suitable image processing algorithm along with microwave system parameters to obtain high resolution performance along with low profile antenna for different microwave frequencies. Basically, the system hardware consists of the microwave components such as antenna, oscillator, mixer, power amplifier and circulator. The design of the microwave subsystem is generally more difficult to handle. Therefore, the microwave subsystem was given more attention in the initial stage of the design.

VII. COMPARATIVE STUDY AND FUTURE WORK

Comparison of SAR image processing techniques helps to determine the range and azimuth coordinates of the targets lying in the strip-map to reconstruct a radar image .Synthetic Aperture Radar is useful future technology for Military endeavors and Environmental monitoring and plays important role in surveillance, reconnaissance, mapping, monitoring and resource management. As this study helps to determine the salient features of SAR which

- Achieves range resolution by utilizing the change in the platform position with respect to the target where resolution is determined by the Doppler bandwidth.
- Measurement of its Doppler frequency shift fd allows us to associate it with an azimuth coordinate for better resolution is using smaller antenna which greatly increases the computational processing
- If a region of the scene is disturbed between the time slots with time span in which the two images are plotted, then the speckle coherence for that region is destroyed. Pixel-by-pixel coherence measurement and mapping for the two images will display the destroyed coherence and distinguish it from its surroundings. This technique is called coherent change detection used to ermine the individual SAR images .
- Areas of current research and development include foliage penetration, ground penetration, imaging moving vehicles, bistatic imaging (transmitting and receiving antenna on separate vehicles) and techniques for improved image quality, particularly at long ranges, fine resolution and for large scenes.
- In near future modern high-performance SAR systems, with their multiple modes and unique capabilities, are increasingly being turned to as indispensable imaging tools.

VIII. CONCLUSION

A comparative study on SAR serves how multiple images can produce a comparable resolution of an image by necessary signal processing algorithm like azimuth stacking algorithm which takes the advantage of radar motion to synthesize a large antenna aperture using small antenna. This paper will be useful to introduce high resolution of images by achieving fine azimuth resolution with doppler shift using low profile antennas and fine range resolution is achieved by sending a pulse of adequate bandwidth, in general for space applications mainly for flying objects. Future SAR systems may have capability of huge simultaneous access using different mechanisms with single monitoring system, particularly for better understanding which may lead to conventional technique with low risk.

IX. REFERENCES:

[1] A Tutorial on Synthetic Aperture Radar published in ieee Geoscience and remote sensing magazine,april 2013

[2] An Introduction to Synthetic Aperture Radar Imaging published in the Official Magazine of the Oceanography society.Thomas P. Ager,ne: October 2, 2015

[3] Birk, R., W. Camus, E. Valenti, and W. J. McCandles, “Synthetic aperture radar imaging systems,” IEEE Aerospace and Electronic Systems Magazine, Vol. 10, No. 11, 15–23, 1995. 16.

[4] Way, J. and E. A. Smith, “The evolution of synthetic aperture radar systems and their progression to the EOS SAR,” IEEE Transactions on Geoscience and Remote Sensing, Vol. 29, Issue 6, 962–985, 1991

[5] John C. Curlander and Robert N. McDonough, Synthetic Aperture Radar, Signal Processing, John Wiley & Sons, Inc., 1991.

[6] SAR Processing Cumming, Ian and Frank Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2005

[7] Franceschetti G. und R. Lanari.: Synthetic Aperture Radar Processing. CRC Press, USA, 1999 Li, F.K., Croft, C., Held,D. Comparison of Several Techniques to Obtain Multiple-Look SAR Imagery. In: IEEE

[8] Trans. Geoscience and Remote Sensing, Vol. 21, No. 3, Juli 1983. Moreira, A., Mittermayer, J., Scheiber, R.: Extended Chirp Scaling Algorithm for Air- and Spaceborne SAR Data Processing in Stripmap and ScanSAR Imaging Modes.

[9] Wang, Y.; Liu, Y.Y.; Li, Z.F.; Suo, Z.Y.; Fang, C.; Chen, J.L. High- resolution wide-swath imaging of spaceborne multichannel bistatic SAR with inclined geosynchronous illuminator. IEEE Geosci. Remote Sens. Lett. 2017, 14, 2380–2384. [CrossRef]

[10] Curlander, John C. and Robert N. McDonough (1991). Synthetic Aperture Radar: Systems and Signal Processing. Chapter 4. John Wiley & Sons

[11] Soumek, M., Synthetic Aperture Radar Signal Processing with MATLAB Algorithms, Wiley, NewYork and N.Y. [etc.], 1999.

[12] Progress In Electromagnetics Research, Vol. 144, 103–114, 2014 Azimuth Stacking Algorithm for Synthetic Aperture Radar Imaging Zhe Li1, *, Tian Jin2, Junjie Wu3, Jian Wang1, and Qing Huo Liu4