

Estimation of Doppler Centroid Frequency Using SAR Imaging Geometry for RISAT-2

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Abstract- Synthetic Aperture Radar (SAR) is an active microwave sensor which uses coherent imaging techniques to produce high-resolution images of the ground. One of the essential part of SAR Data Processing is the estimation of the Doppler parameters of the received data i.e., Doppler centroid frequency, F_{dc} . The methodology involves sequence of coordinate rotations and translations to get the radar beam's "view vector" into ECI coordinates. With satellite and target positions and velocities expressed in the same coordinate system, the velocities are projected along the beam vector to find the relative velocity, and then calculate Doppler centroid frequency.

The orbit of RISAT-2 is low inclination non-polar, non-sun synchronous orbit and the image data format is different. So, in order to implement the procedure for RISAT-2, the satellite attitude i.e., yaw and pitch are derived from squint angle available in Auxiliary file to arrive at the slant range from the target. A module to calculate the satellite hour angle for both ascending and descending pass has been successfully implemented and integrated into the algorithm which is critical in calculating F_{dc} .

Index Terms: SAR, SAR Geometry, Doppler Centroid Frequency (F_{dc}), Imaging Range, RISAT-2

I. INTRODUCTION

The SAR Processing is an estimation of the Doppler parameters from the received data i.e., the Doppler centroid frequency and the azimuth FM rate. For processing, the average or center Doppler frequency must be known. The Doppler centroid is difficult to estimate accurately for two reasons. First, the satellite system does not have sufficiently accurate attitude measurement or beam pointing knowledge to calculate the centroid from geometry alone. Second, the Doppler estimation result has a considerable dependence on the scene content.

II. SAR IMAGING GEOMETRY

A good insight on SAR data acquisition geometry is vital in order to calculate the Doppler Centroid frequency. A mono static radar system is considered in remote sensing where the same radar antenna is used for transmission and reception.

The corresponding figures explaining the geometry of SAR are shown in Fig2.1.

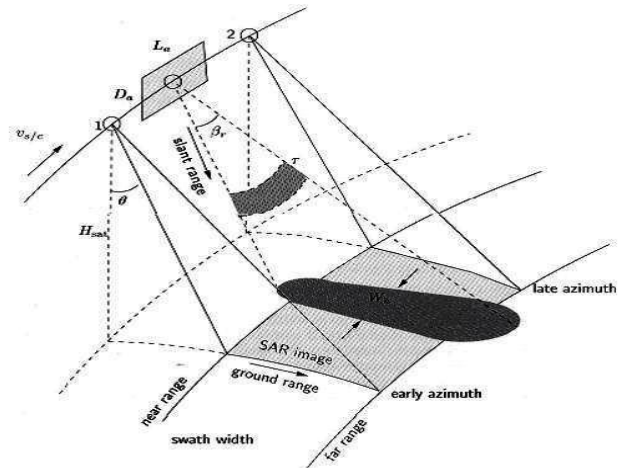


Fig 2.1: SAR Imaging Geometry

In the satellite case, the effect of earth rotation is equivalent to a pure antenna yaw. Pure yaw is a rotation of the antenna around the vertical axis containing the nadir point. The pure yaw is illustrated in Fig 2.2 where equivalent flat-earth geometry is assumed. The beam center line is approximately a straight line on the ground. In the pure yaw case, the beam centerline passes through the nadir point. The yaw angle is identified as the effective yaw angle, the net effect of the antenna yaw and Earth rotation. The squint angle is the angle that the slant range makes with the zero Doppler plane. The variation in yaw angle will have effect the slant range and hence Doppler centroid frequency [3].

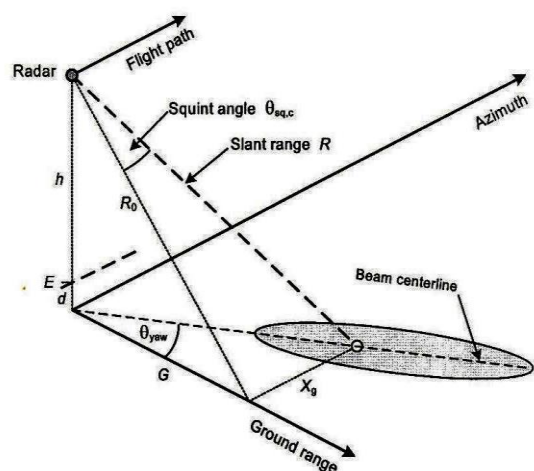


Fig 2.2: Effect of Antenna Yaw

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In contrast, the antenna pitch also affects the Doppler centroid frequency with little variation in slant range as shown in Fig 2.3.

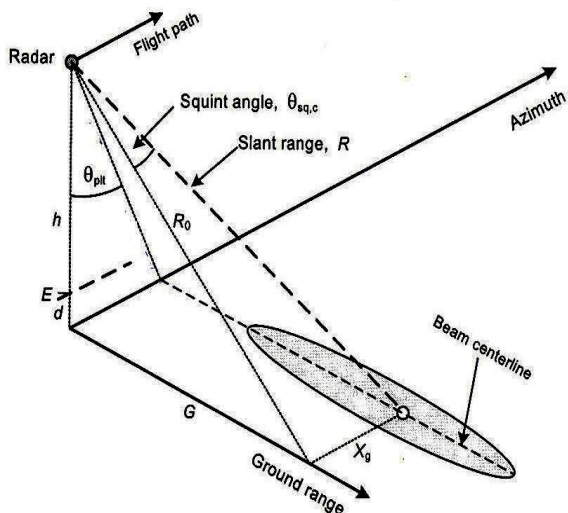


Fig 2.3: Effect of Antenna Pitch

Roll has little effect upon the Doppler centroid, but the roll angle is very important to obtain correct illumination of the desired range swath [7].

III. DOPPLER CENTROID FREQUENCY (FDC)

An essential part of SAR Processing is the estimation of the Doppler parameters from the received data is the Doppler centroid frequency and the azimuth FM rate. For processing, the average or centre Doppler frequency must be known, which is referred to as Doppler centroid frequency or simply Doppler centroid. Despite many advances in SAR processing and data handling, many production SAR processing systems for satellite SAR data tend to suffer from unreliability. Doppler centroid estimates in a number of the scenes processed. Poor estimates affect the registration and focusing, and raise the noise and ambiguity levels in the processed image, sometimes to the point of seriously affecting image quality.

The Doppler centroid is difficult to estimate accurately for two reasons. First, the satellite system does not have sufficiently accurate attitude measurement or beam pointing knowledge to calculate the centroid from geometry alone. Second, the Doppler estimation result has a considerable dependence on the scene content.

The system factors that affect the Doppler frequency can be examined through a model of the geometry of the satellite orbit, the radar beam pointing direction, and the intersection of the beam with the rotating Earth's surface. The satellite positions and velocity (the satellite ephemeris) is described by state vectors. These quantities are estimated by satellite tracking and control stations, and are included as engineering data in the SAR signal records and auxiliary data. State vectors are usually given for a set of coarse time intervals, for example, 30 seconds intervals. The satellite position and velocity can be calculated for arbitrary intermediate times using interpolation techniques.

After specifying the orbit, the beam pointing direction must also be given. This requires knowledge of the satellite attitude, the local vertical, and the beam off-nadir angle. With a given pointing direction, the intersection of the beam center with the Earth's surface can be calculated for a variety of off-nadir angles corresponding to the slant ranges of interest.

The Doppler frequency can be then found as a function of range. The Doppler frequency mainly depends on the yaw and pitch of the satellite (the roll angle has little effect), and attitude rates and accelerations can be used to define how the Doppler centroid changes with time.

The sketch of the geometry of the radar beam and its intersection with earth's surface is well understood in Fig 3.1 [7]. The radar position is at point P1 at the time when the target is illuminated by the centre of the radar beam.

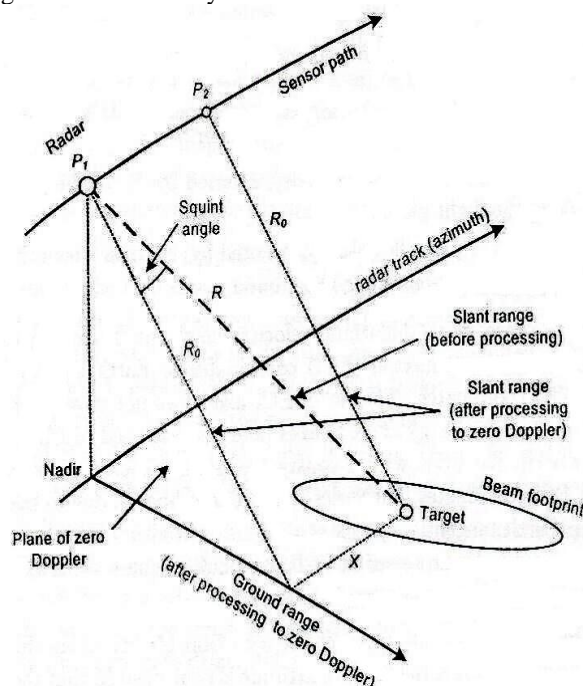


Fig 3.1: Radar Data Acquisition Geometry

Another significant sensor location is point P2, which is the position of the radar when the zero Doppler plane crosses the target. As the beam is pointed forward in this figure for example, point P2 is reached after point P1. The squint angle is the angle that the slant range makes with the zero Doppler plane, and is important component in the description of the beam pointing direction. It is measured in the slant range plane. The squint angle depends upon the target's range, R_0 , for a given beam pointing direction [7].

IV. CALCULATION OF DOPPLER CENTROID FREQUENCY

The Doppler frequency is given by

$$F_{dc} = -2V_{rel} / \lambda \quad (4.1)$$

Where λ is the radar wavelength and V_{rel} is the relative velocity between the sensor and beam center target on the Earth's surface [1].

V. ESTIMATION OF DOPPLER CENTROID FREQUENCY

The flow chart of the calculation procedure is shown in the Fig 1 which uses the following steps [1]:

- Step 1:** Define the Earth and Satellite orbit parameters
- Step 2:** Select an orbit time to calculate the Doppler Centroid, and specify the satellite yaw and pitch at this time



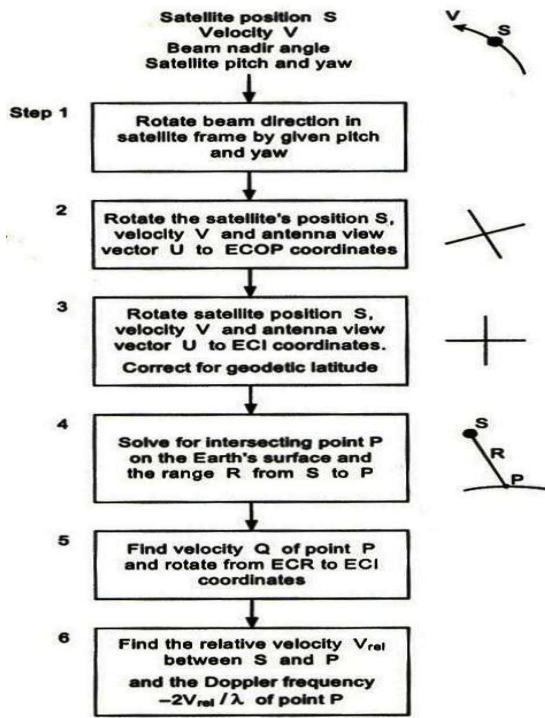


Fig 5.1: Flow chart of Doppler Centroid Calculations.

Step 3: Define a set of beam off nadir angles, which specify a set of target positions along the beam center line. Perform steps 4 and 5 for each nadir angle.

Step 4: Using the beam pointing angle, find the target location by calculating the intersection of the beam pointing vector with Earth's surface.

Step 5: Calculate the range to the target, the relative satellite/ target velocity and the Doppler frequency to the target [1].

The flow chart of the Doppler frequency calculations has been given in the fig 5.1

VI. METHODOLOGY FOR ESTIMATING DOPPLER CENTROID FREQUENCY (FDC)

The estimate of Fdc can be made from geometry models and their related measurements, and from measurements on the received data. The calculation of the Doppler centroid from the satellite orbit model and attitude measurements are outlined in this chapter along with relevant mathematical details [1].

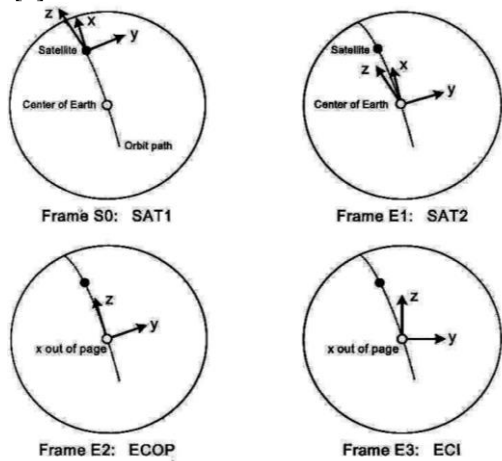


Fig 6.1: Frames of Reference used in Transformation.

Table 6.1: Centre and Orientation of Frames of Reference

Frame	Name	Origin of Frame	Orientation of Frame
S0	SAT1	On the Satellite	Satellite forward up
E1	SAT2	Earth Center	Same as Frame S0
E2	ECOP	Earth Center	Orbit plane at ascending node
E3	ECI	Earth Center	Equator at ascending node

The frames of reference used in the mathematical development are listed in the table 6.1, where ascending node is assumed to be at the Greenwich meridian. The frames are sketched in the fig 6.1, where all "views" are towards the Earth's center from the equator at the Greenwich meridian.

1. Detailed description to calculate Fdc:

Step1: Rotate Beam by the satellite pitch and Yaw and Translate to the Earth Center (to Frame E1).

The geometric development begins in the satellite centered frame of reference referred to as Frame S0, in which the x point up, away from the earth's center, z points 'ahead' in the plane of the satellite orbit, perpendicular to x and y points to the right, completing the orthogonal, right handed frame.

For illustration purposes [1], a circular orbit is assumed, and satellite position and velocity state vectors are

$$S_0 = [0 \ 0 \ 0]^T \text{ position} \quad (6.1)$$

$$V_0 = [0 \ 0 \ V_{\text{sat}}]^T \text{ velocity} \quad (6.2)$$

Where $V_{\text{sat}} = \sqrt{(\mu_e/R_s)}$ is the scalar value of the satellite velocity for an orbit of radius R_s , $\mu_e = 3.987 \times 10^{14} \text{ m}^3/\text{s}^2$ is the gravitational constant of the Earth, and $[\cdot]^T$ denotes transpose.

It is assumed that the radar antenna is attached to the satellite body in such a way that the azimuth bore sight lies in the x, y plane for all elevation angles and the specific pointing angle under consideration is defined by the unit view vector.

$$U_0 = [-\cos(\alpha) \ \sin(\alpha) \ 0]^T \text{ view vector} \quad (6.3)$$

Where α is the 'nadir' angle between the local vertical and the beam direction, positive for right pointing antennas. Now assume that the satellite is subject to an arbitrary Yaw, ϕ and pitch, ψ . The beam view vector must be rotated clockwise around the positive y -axis by the *pitch angle* ψ , using Euler transformation matrix [4].

$$T_y \psi = \begin{bmatrix} \cos(\psi) & 0 & \sin(\psi) \\ 0 & 1 & 0 \\ -\sin(\psi) & 0 & \cos(\psi) \end{bmatrix} \text{ Nose up} \quad (6.4)$$

Then the view vector is rotated clockwise around the positive x -axis by the *yaw angle*, ϕ , using the transformation.

$$T_x \phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix} \text{ Nose left} \quad (6.5)$$

So the unit vector becomes

$$U_0 = T_x \phi \cdot T_y \psi \cdot U_{0f} \quad (6.6)$$



In the frame S0.Finally, the satellite-centered frame is translated to the parallel, Earth centered frame E1

$$S1=s0+ [Rs \ 0 \ 0]' \text{ position} \quad (6.7)$$

$$V1=V0 \text{ velocity} \quad (6.8)$$

$$U1=U0 \text{ ViewVector} \quad (6.9)$$

Step 2: Rotate to ECOP Coordinates (to Frame E2)

Although centers on the Earth, the orientation of the frame E1 is aligned with the satellite ‘zero attitude’ direction. As a first step in moving into the earth centered Inertial Reference (ECI) frame .Frame E1 is rotated ‘back around the orbit’ to the ascending node. The resulting reference system is called the Earth Centered Orbital Plane (ECOP),or Frame E2.If λ_h is the satellite Hour Angle measured from the ascending node crossing, the rotation is clockwise about the y-axis for positive λ_h and is achieved by the transformation matrix

$$T_{12} = \begin{bmatrix} \cos(\lambda) & 0 & -\sin(\lambda) \\ 0 & 1 & 0 \\ \sin(\lambda) & 0 & \cos(\lambda) \end{bmatrix} \quad (6.10)$$

Step 2.1: Satellite Hour Angle

The satellite Hour angle is measured from the ascending node crossing the rotation is clockwise and about y-axis for positive λ_h is achieved by the transformation matrix [2] [6].

Step 2.1.1: Satellite Conversion - Orbit plane to Equatorial plane

The transformation from the orbit plane to equatorial plane corresponds to a rotation about the X-axis through an angle α , so that

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha \\ 0 & \sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} \quad (6E.1)$$

Expressing the rectangular coordinates in the equivalent spherical polar coordinates we have

$$\begin{pmatrix} r \cos \lambda_s \cos \psi_s \\ r \cos \lambda_s \sin \psi_s \\ r \sin \lambda_s \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha \\ 0 & \sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} r \cos \theta \\ r \sin \theta \\ 0 \end{pmatrix} \quad (6E.2)$$

$\Psi_s(t)$ = Longitude angle of satellite eastward from X- Axis
 $\lambda_s(t)$ = latitude angle of satellite northward from equator and λ_h is denoted as θ

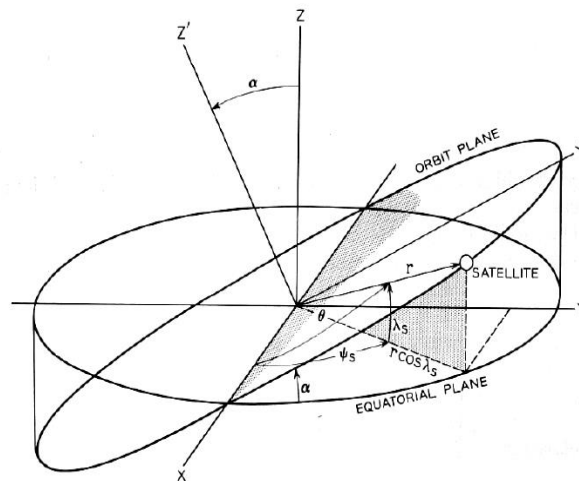


Fig 6.3: Satellite Hour Angle

The rectangular coordinates (xyz) are located with the origin at the antenna site as shown in the Fig 6.3, with the + x-axis pointing northward. The notation used here is as follows: r = radius of the earth (assumed constant) Ψ = longitude angle of antenna site, measured eastward from X-axis λ = latitude angle of antenna site, measured northward from equator. From 6E.1 and 6E.2, we find the value of θ (λ_h) which is the satellite hour angle which is critical in this methodology for **RISAT-2** SAR system.

The ECOP frame corresponds to the view from the equator at Greenwich meridian,looking into the center of the Earth in the direction of the negative x-axis .The z-axis lies in the orbit plane and the y-axis points to the right,perpendicular to the orbit phase. The z-axis is coincident with the satellite’s velocity vector at $t=0$,if the orbit is circular.The z-axis is inclined at from north by the angle k ,which is the inclination angle of the satellite orbit plane ,minus $\pi/2$.

The transformation of the vectors of interest from Frame E1 to the ECOP Frame E2 is done by the matrix multiplications.

$$S2=T12. S1 \text{ Satellite Position} \quad (6.11)$$

$$V2= T12. V1 \text{ Satellite Velocity} \quad (6.12)$$

$$U2= T12 U1 \text{ View Vector} \quad (6.13)$$

Step 3: Rotate to ECI Coordinates (To Frame E3)

There are two parts in this step. The first is the rotation, and the second is the compensation of the view vector for the geodetic latitude.

Step 3.1: Rotation

The second step in transforming to the ECI frame of reference is to rotate the ECOP frame counter clockwise around the x-axis by the angle k . This is achieved by transformation ([4]).

$$T_{23} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(k) & -\sin(k) \\ 0 & \sin(k) & \cos(k) \end{bmatrix} \quad (6.14)$$

To obtain

$$S3= T23 .S2 \text{ satellite position} \quad (6.15)$$



$$V_3 = T_{23} \cdot V_2 \quad \text{satellite velocity} \quad (6.16)$$

$$U_3 = T_{23} \cdot U_2 \quad \text{view vector} \quad (6.17)$$

In frame E3. This frame corresponds to a ‘conventional’ view of the earth with z pointing north, y pointing east and x pointing from the earth’s center to the equator at the Greenwich meridian. The two vectors (S3, V3) represent the satellite’s state vector, assuming it is expressed in ECI coordinates.

Step 3.2: Compensation of the View Vector for the Geodetic Latitude

The satellite attitude is often expressed in the frame of reference in which the local vertical is normal to the earth’s ellipsoid (geodetic reference), rather than pointing to the earth’s center (geocentric reference). The geodetic reference is not used in the current development, but if the satellite attitude is expressed in the geodetic coordinates, then the unit vector can be compensated at this point in the transformations. The difference in viewing angle definitions is illustrated in the Fig6.4.

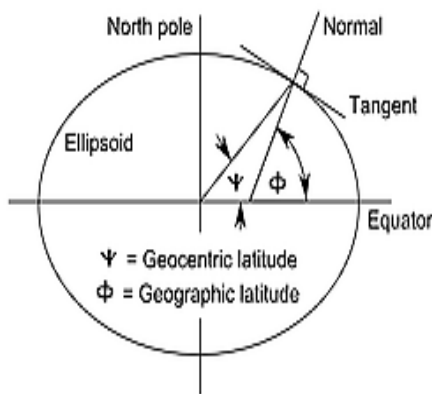


Fig 6.4: Comparison of View Vectors Expressed in Geodetic and Geocentric Latitude

If V_{sat_lat} and V_{sat_long} are the latitude and longitude of the satellite, this compensation can be achieved by first rotating the ECI coordinates clockwise around the z-axis to the satellite’s longitude using

$$T_{Z3} = \begin{bmatrix} \cos(V_{sat_long}) & \sin(V_{sat_long}) & 0 \\ -\sin(V_{sat_long}) & \cos(V_{sat_long}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (6.18)$$

The beam is then tilted slightly towards the equator by the angle

$$\Phi_g = V_{lat_geodetic} - V_{lat_geocentric} \quad (6.19)$$

Using the transformation

$$T_{y3} = \begin{bmatrix} \cos(\Phi_g) & 0 & -\sin(\Phi_g) \\ 0 & 1 & 0 \\ \sin(\Phi_g) & 0 & \cos(\Phi_g) \end{bmatrix} \quad (6.20)$$

Finally, the beam is rotated back around the z-axis to the ECI Coordinates using T_{y3}^{-1} . The net result is

$$U_{3g} = T_{z3} \cdot T_{y3} \cdot U_3 \quad \text{view vector} \quad (6.21)$$

Note the geodetic compensation angle Φ_g , is zero at the equator and the poles, and has a maximum of 0.194 at $\pm 45^\circ$ latitude.

The effect of the transformation is to rotate the view vector so that the satellite pitch and yaw, which are originally specified with respect to the local horizontal, are corrected in the ECI frame.

Step 4: Solve for the Target Location

The next step is to locate the target on the Earth’s surface. The satellite position is represented by the vector, S3 from and the beam range vector by R3. U_{3g} , where R3 is unknown range to the target. The target position is given by the sum of these vectors

$$P_3 = S_3 + R_3 \cdot U_{3g} \quad \text{target position} \quad (6.22)$$

And is found by solving for the intersection of the beam range vector with the Earth ellipsoid

$$\frac{P_3(x)^2}{Ae^2} + \frac{P_3(y)^2}{Ae^2} + \frac{P_3(z)^2}{Be^2} = 1 \quad (6.23)$$

Where $Ae = 6,378,137.0m$ and $Be = 6,356,752.3142m$ are the equatorial and polar radii in meters of the WGS-84 ellipsoid.

Because the ellipsoid is quadratic, the intersection is solved by finding the smallest root of the quadratic equation

$$R_3^2 + 2F \cdot R_3 + G = 0 \quad (6.24)$$

With the coefficients

$$F = S_3 \cdot U_{3g} + \epsilon \cdot S_3(z) \cdot U_{3g}(z) \quad (6.25)$$

$$G = \frac{S_3^2 + \epsilon \cdot S_3^2(z)}{1 + \epsilon \cdot U_{3g}^2(z)} \quad (6.26)$$

Where \cdot is the dot product, and $S_3(z)$ is the Z-component of S3. The parameters, ϵ is defined for WGS-84 ellipsoid as

$$\epsilon = \frac{e^2}{1 - e^2} = 0.0067395 \quad (6.27)$$

Where, e is the eccentricity of the ellipsoid.

The scalar variable, R3, is the range from the satellite to the target in the Earth’s surface, and is solved using 6.28 to obtain

$$R_3 = -F - \sqrt{F^2 - G} \quad \text{slant range to the target} \quad (6.28)$$

Having found out the range to the target, the location of the target in ECI coordinates, P3, can be found by extrapolating by this distance along the view vector, U_{3g} , starting from the satellite position, S3



Step 5: Find the Target Velocity

The target’s velocity must now be found in the ECI coordinates .The target is assumed to be stationary with respect to the Earth’s surface, but if it is not stationary, a suitable component can be included in (6.30). The magnitude of the velocity is a function of the target’s latitude and the direction of the velocity is a function of the target’s longitude. The rotates with the Earth around the polar axis, with a radius

$$D3= \sqrt{(P3^2(x) + P3^2(y))} \tag{6.29}$$

So that the target’s velocity vector is

$$Q4= [0 \quad D3. \omega e \quad 0]’ \tag{6.30}$$

When it is at longitude zero, that is, at y=0.

The variable $\omega e = 7.2921 \times 10^{-3}$ is the Earth’s rotation rate in an inertial reference frame. To get the target velocity into the ECI coordinates of the satellite, its velocity vector must be rotated about the polar axis, by the target’s ECI east longitude.

$$V_{tar_long} = \arctan \{P3(y), P3(x)\} \tag{6.31}$$

Using the transformation

$$T_{Z43} = \begin{bmatrix} \cos(v_{tar_long}) & -\sin(v_{tar_long}) & 0 \\ \sin(v_{tar_long}) & \cos(v_{tar_long}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6.32}$$

This give the target velocity vector in ECI coordinates

$$Q3 = T_{Z43} \cdot Q4 \quad \text{target velocity} \tag{6.33}$$

$$= D3. \omega e [-\sin(V_{tar_long}) \quad \cos(V_{tar_long}) \quad 0]’ \tag{6.32}$$

Step 6: Calculating the Doppler frequency

To calculate the target’s Doppler frequency .the relative velocity of the satellite, with respect to the target, must be found. This is done by projecting each of the velocities along the radar view vector, and subtracting them. This projection can be done in either the ECI or ECR frames.

In the ECI frame, the relative velocity is obtained from

$$V_{rel} = V3 \cdot U_{3g} - Q3 \cdot U_{3g} = (V3 - Q3) \cdot U_{3g} \tag{6.34}$$

The Doppler frequency of the target in the center of the beam (the Doppler centroid) is then

$$F_d = - 2V_{rel} / \lambda \tag{6.35}$$

Where λ is the radar wave length. Thus the Doppler centroid can be obtained geometrically from attitude measurements.

2. Input Data Sets For Estimating FDC

The datasets corresponding to RISAT-2 are considered for calculating Fdc in this paper.



RISAT 2

RISAT2 system is a space-borne near real time Synthetic Aperture Radar (SAR) operating in X-Band having multiple high resolution imaging modes with agility. RISAT-2 has been successfully launched on 20th April 2009 from Shriharikota by Indian Space Research Organisation and the satellite has been finally placed in to 556 x 450 km with 41.2 deg inclination. RISAT-2 is an agile system capable of imaging multiple targets in different operational modes, within a pass, with various look angles and squint angles. RISAT-2 Imaging has been done over various parts of the globe, but more specifically over Indian Region, using Spot A ML4 / ML3/ ML2, SpotB ML4, Strip, Super Strip, Wide Coverage, Mosaic-1 and Mosaic-3 modes in different look

angles, squint angles and swaths. Some of the RISAT-2 images used are shown in the figures below.

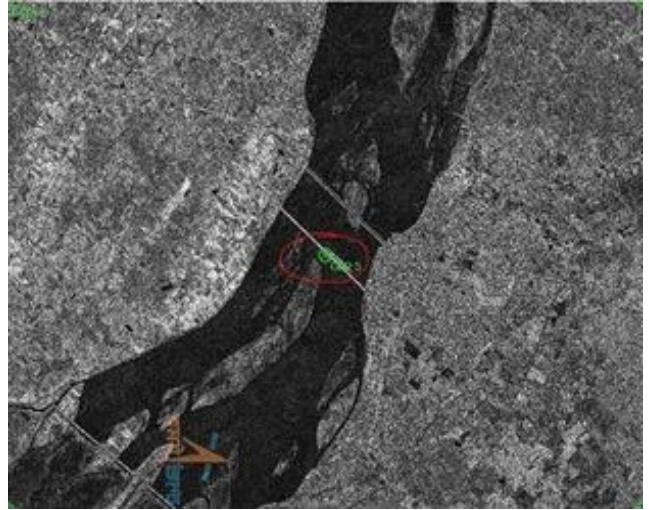


Fig6.5: \\grsipsstrg\SIP\IPS\TARGET\AUTOMATIC\ts3_gr s_00266_00055_1\RS2_GRS_00266_00266_00010_1_04_0 01_00001_001(IMG_RJM)

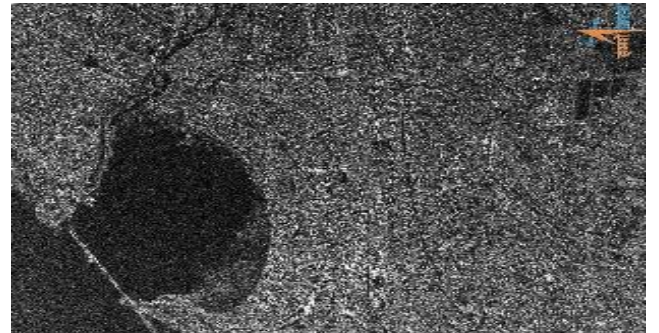


Fig 6.6: RISAT2-SAR Bandra Worli Sea Link, Mumbai, IN (IMTG_110086Strip)

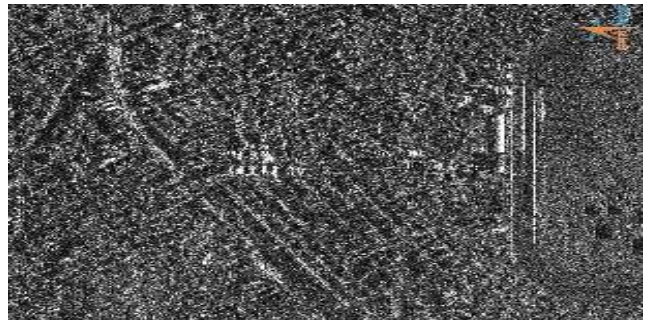


Fig 6.7: RISAT2 SAR Image of Hyderabad International Airport , HYD, AP, IN (IMG_068017)



Fig 6.8: RISAT2 SAR Image (IMG_05712)



VII. RESULTS

The data is operationally acquired at *National Remote Sensing Centre, Indian Space Research Organisation*, Hyderabad, Andhra Pradesh, India.

The methodology used for estimating Fdc using SAR Geometrical model and attitude information is a well-established theory for RADARSAT-1, Canada Space Agency, Canada. This methodology was verified with an existing RADARSAT-1 Data to calculate the slant range from sensor to target and then Doppler centroid frequency. The results were compared with Leader file given in CEOS format.

In this paper, the RADARSAT-1 methodology has been extended and modified to derive required results for RISAT2. RISAT-2 uses X-band and the data is operationally acquired at NRSC and processed to cater to various data users. Unlike the orbit of RADARSAT-1, the orbit of RISAT-2 is low inclination non-polar, non-sun synchronous orbit and the image data formats are different [8].

So, in order to implement the modified procedure for RISAT-2, the satellite attitude i.e., yaw and pitch are derived from squint angle available in Auxiliary file to arrive at the slant range from the target. A module to calculate the satellite hour angle for both ascending and descending pass has been successfully implemented and integrated into the algorithm which is critical in calculating Fdc.

The proposed approach to calculate Fdc from SAR geometry for RISAT2 is tested on real SAR data. Many datasets corresponding to RISAT2 are considered in estimating Fdc.

The main goal of this report was to propose novel techniques in the Doppler Centroid Estimation from processed SAR data of RISAT-2. The following tables 7.1 and 7.2 discuss the effectiveness of the algorithm used in the paper.

S No	Image Name	Entity	Processed Values as given in AUX file	Derived Values
1	IMG_RJM	Fdc	118874.625 Hz	128223.732 Hz
2	IMG_RJM	Imaging Range	737906.548 m	730859.802 m
3	IMTG_110086 Strip	Fdc	-2050.057 HZ	-2194.611 Hz
4	IMTG_110086 Strip	Imaging Range	510419.675 m	554803.994 m
5	IMG_068017	Fdc	57360.900 Hz	57360.397 Hz
6	IMG_068017	Imaging Range	657850.499 m	618971.535 m
7	IMG_05712	Fdc	-19574.873 Hz	-19574.938 Hz
8	IMG_05712	Imaging Range	563223.030 m	574717.377 m

Table 7.1: Results

S. No	Image Name	Entity	Error in %
1.	IMG_RJM	Fdc	7.864
2.	IMG_RJM	Imaging Range	0.934
3.	IMTG_110086_Strip	Fdc	7.051

4.	IMTG_110086_Strip	Imaging Range	8.103
5.	IMG_068017	Fdc	0.087
6.	IMG_068017	Imaging Range	2.945
7.	IMG_05712	Fdc	0.0003
8.	IMG_05712	Imaging Range	2.000

Table 7.2: Error in Percentages

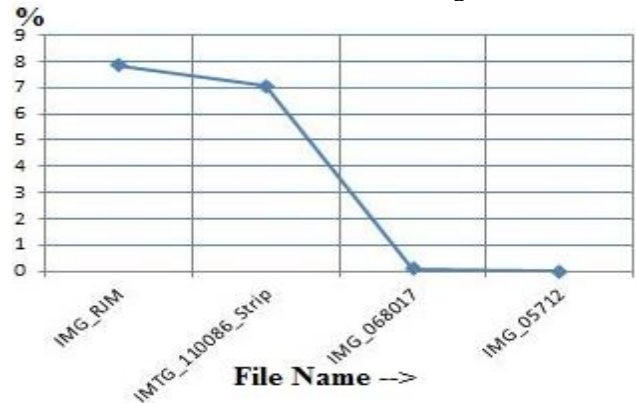


Fig 7.1: Error in Percentage- Fdc

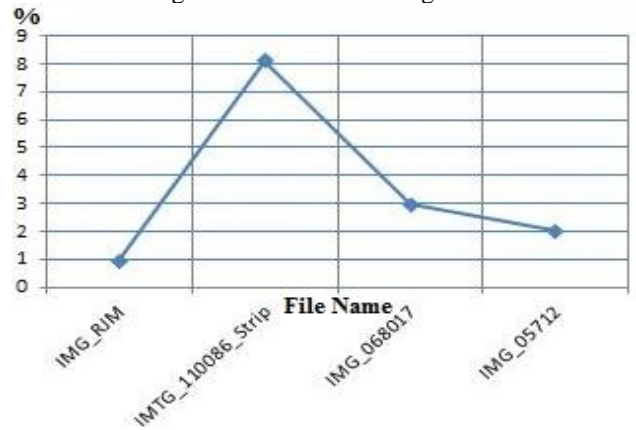


Fig 7.2: Error in Percentage- Imaging Range

VIII. CONCLUSIONS AND FUTURE WORK

In this paper an approach to estimate Doppler Centroid frequency using satellite attitude parameters is presented. The analysis with real data showed the efficiency and capability of this technique. Further work will focus on improving accuracy on various parameters as well utilizing the derived parameter to estimate velocity of the targets based on the concept of Doppler Shift.

IX. ACKNOWLEDGMENTS

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Appendix: Matlab Code for Estimating FDC:

```

1 %Rotate beam by satellite pitch and yaw and translate
to earth center(toframe E1)
2 clc 3 %Format is set to long for accuracy
4 format long
5 %Orientation of the satellite
6 7 disp('FRAME S0:SAT1-ON THE SATELLITE'); 9
disp('ORIENTATION OF
FRAME:Satellite,Zforward,X-Up');
10 x=0; 11 y=0; 12 z=0;
13 So=[x y z]';
14 Rs= input ('*Enter the value the radius of the orbit of
Sensor:');
15 disp('The radius of the orbit of Satellite :');
16 disp(Rs)
17 Ue=3.987*10^14;
18 %Input all the values of the satellite velocity
parameters
19 20 v1=input('Enter the velocity of the Sensor in x:');
21 v2=input('Enter the velocity of the Sensor in y:');
22 v3=input('Enter the velocity of the Sensor in z:');
23 Vsat=((v1^2)+(v2^2)+(v3^2))^(0.5);
24 disp(Vsat)
25 Vo=[0 0 Vsat]';
33 lam=input('Enter the Sensor Latitude Angle :');
34 sye=input('Enter the Sensor Longitude Angle :');
35 36 ga=input('Grazing Angle: ');
37 alp=90-ga;
38 39 %calculating theta:satellite hour angle
40 s=Rs*cosd(lam)*cos(sye);
41 t=Rs*cosd(lam)*cos(sye);
42 u=Rs*sind(lam);
43 v=[1 0 0;0 cosd(alp) -sind(alp);0 sind(alp)
cosd(alp)];
44 w=inv(v);
45 x=[s;t;u];
46 y=w\x;
47 aa=y*[1 0 0]';
48 theta=acosd(aa/Rs);
49 disp('The satellite Hour Angle{For Ascending
Pass}:');
50 disp(theta);
51 disp('The satellite Hour Angle{For Descending
Pass}:');
52 desc_theta=180-theta;
53 disp(desc_theta);

```

```

54 alpha=90-ga;
55 disp('Off Nadir Angle(Look Angle): ')
56 disp(alpha)
57 disp('The azimuth bore sight lies in x,y plane for all
the elevation angles and the specific pointing angle
which is defined by the unit view vector ')
58 disp(alpha)
59 disp('the unit view vector=[-cos(alpha) sin(alpha)
0]''')
60 Uof=[-cosd(alpha) sind(alpha) 0]
61 %Input Squint,Obtain yaw,pitch from squint
62 squint1=input('Please enter the squint angle:');
63 squint=squint1;
64 disp('The user entered squint angle is:');
65 disp(squint)
66 look=alpha;
67 a=tand(squint);
68 b=cosd(look);
69 c=sind(look);
70 sye=(atand(a/b));
71 disp('Pitch angle:')
72 disp(sye)
73 phi=(atand(-a/c));
74 disp('yaw angle:')
75 disp(phi)
76 77 78 %Calculations from user entered values
79 Tysye=[cosd(sye) 0 sind(sye) ; 0 1 0 ; -sind(sye) 0
cosd(sye)];
80 disp('sye:');
81 disp(sye);
82 disp('phi:');
83 disp(phi);
84 disp('The view vector is rotated clockwise around the
positive y-axis by the pitch angle sye,85 disp(Tysye)
86 87 88 Txphi=[1 0 0 ; 0 cosd(phi) -sind(phi) ; 0 sind(phi)
cosd(phi)];
89 90 disp('The view vector is rotated clockwise around the
positive x-axis by the yaw angle sye,using
91 disp(Txphi)
92 93 disp('the unit vector after transformation becomes:');
94 Uo=Txphi*Tysye*Uof
95 96 disp('The satellite centered frame is translated to
parallel,earth-centred frame E1');
97 S1=So+[Rs 0 0]';
98 Position=S1
99 V1=Vo;
100 velocity=V1
101 U1=Uo;
102 ViewVector=Uo
103 104 disp('Rotate to ECOP Co-ordinates(To frame E2)');
105 lamda_h=input('Enter the satellite Hour Angle');
106 107 disp('The transformed co-ordinates into Earth
Centered Orbit Plane');
108 T12=[cosd(lamda_h) 0 -sind(lamda_h); 0 1 0 ;
sind(lamda_h) 0 cosd(lamda_h)]
109 disp('if the orbit is circular,Ws is the satellite"s angular
rate around its orbit and if the 110 disp('the hour
angle,Lamda_h=Ws*Ts" 111
112 disp('the transformation of the vectors of the interest from
frame E1 to ECOP frame E2 is is done')
113. disp(""); 114
115 S2=T12*S1;
116 117 SatellitePosition=S2
118 119 V2=T12*V1;
120 SatelliteVelocity=V2

```



```

121 122 U2=T12*U1;
123 ViewVector=U2
124 disp('_');
125 126 disp('Step 3:Rotation to ECI Co-Ordinates');
127 K=alp;
128 T23=[1 0 0;0 cosd(K) -sind(K);0 sind(K) cosd(K)]
129 130 S3=T23*S2;
131 satellitePosition=S3
132 133 V3=T23*V2;
134 SatelliteVelocity=T23*V2
135 136 U3=T23*U2;
137 viewvector=U3
138 139 disp('COMPENSATION OF VIEW VECTOR FOR
GEODETIC LATITUDE ');
140 disp('If SAT_LONG is the longitude of the satellite and
SAT_LAT is the latitude of the satellite 141
142 SAT_LAT=input('Enter the value of the latitude of the
satellite: ');
143 SAT_LONG=input('Enter the value of the longitude of
the satellite: ');
144 145 Tz3=[cosd(SAT_LAT) sind(SAT_LAT) 0;
-sind(SAT_LAT) cosd(SAT_LAT) 0; 0 0 1]
146 147 disp('The beam is tilted slightly towards the equator
by the angle:Phi_G')
148 149 %Geo Latitude Calculations
150 geodetic_lat=input ('Please Enter the Geodetic
Latitude'); % Error Calculations
151 e=0.0067395;
152 new1= 1-(e^2);
153 new2=tand(geodetic_lat);
154 new3=(new1)*(new2);
155 geocentric_lat=atand(new3);
158 Phi_G=(geodetic_lat-geocentric_lat);
159 160 Ty3=[cosd(Phi_G) 0 -sind(Phi_G);0 1
0;sind(Phi_G) 0 cosd(Phi_G)];
161 disp('Transformed ECI co-ordinates: ')
162 disp(Ty3)
163 164 U3g=inv(Tz3)*Ty3*Tz3*U3;
165 disp(U3g);
166 167 disp('TARGET LOCATION: ');
168 e=0.0067395;
169 A=6378137.0;
170 B=6356752.3142;
171 172 satzcoordinate=S3*[0 0 1]';
173 viewzcoordinate=U3g*[0 0 1]';
174175
F=(dot(S3,U3g)+e*(satzcoordinate)*(viewzcoordinate))/1+
e*(viewzcoordinate^2);
176177
G=(dot(S3,S3)-(A^2)+e*(satzcoordinate^2))/1+e*(viewzcoo
rdinate^2);
178 179 disp('Slant Range to the Target: 180 R3=
(-F-sqrt(F^2-G));
181 R3=real(R3);
182 disp(R3);
183 184 disp('TARGET LOCATION: ');
185 P3=S3+R3*U3g;
186 TargetPosition=P3
187 188 disp('Step 5:Find the target velocity ')
189 disp('TARGET VELOCITY: ');
190 P3y=P3*[0 1 0]' 191 P3x=P3*[1 0 0]' 192 193 194
TARGET_LONG=atand(P3y/P3x);
195 196 197 D3=sqrt((P3y^2)+(P3x^2));
198 199 We=7.2921*(10^-5);

```

```

201 Q4=[0 D3*We 0]';
205 disp('ECI Co-Ordinates: ');
207Tz43=[cosd(TARGET_LONG) -sind(TARGET_LONG)
0; sind(TARGET_LONG) cosd(TARGET_LONG) 0;0 0 1];
209 disp(Tz43);
211 disp('Target Velocity: ');
212 Q3=Tz43*Q4;
213 disp(Q3);
214 215 disp('Step 6');
216 disp('Calculating the Doppler Frequency: ');
217 Vrel=dot(V3,U3g)-dot(Q3,U3g);
218 Vreln=dot((V3-Q3),U3g);
219 220 if Vrel==Vreln
221 disp(Vreln)
222 end 223
224 disp ('THE DOPPLER FREQUENCY OF THE
TARGET IN THE CENTRE OF THE BEAM(THE
DOPPLER CENTROID
225 L=input ('Enter the value of the Radar wavelength: ');
226 Fd=(-2*Vrel)/L;
227 disp('The Doppler frequency of the target in the center of
the beam is : ');
228 disp('Doppler Centroid Estimation Developed by Phani
Madhav Yannam, Trainee, NRSC,ISRO, DOS, IN');

```



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