Development of SAR system design and data processing software using MATLAB

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ISRO's MICROWAVE RS PAYLOADS (2010-2021)

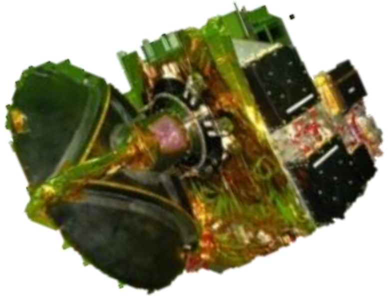
EO TECHNOLOGY DEVELOPMENT

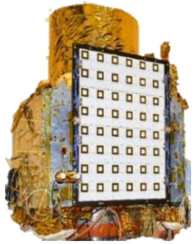
2012

RISAT-1

SCATSAT-1

2015



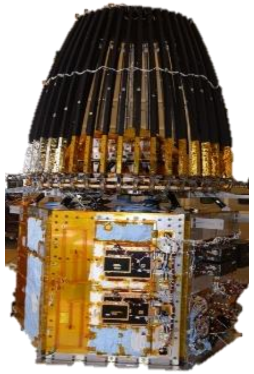


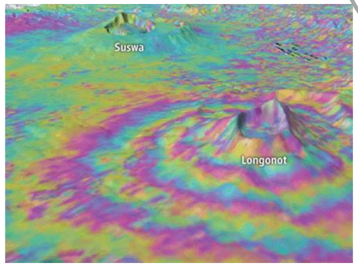
2018

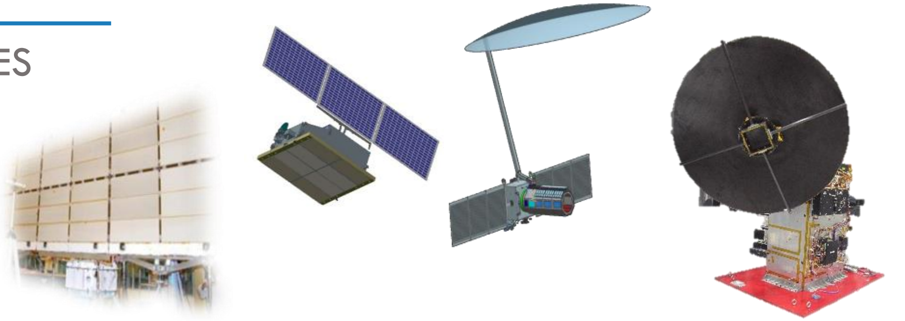
CHANDRAYAAN-2
DUAL FREQUENCY SAR
KA BAND RADAR ALTIMETER

RISAT 2B SERIES
3 X-BAND SARS

2019





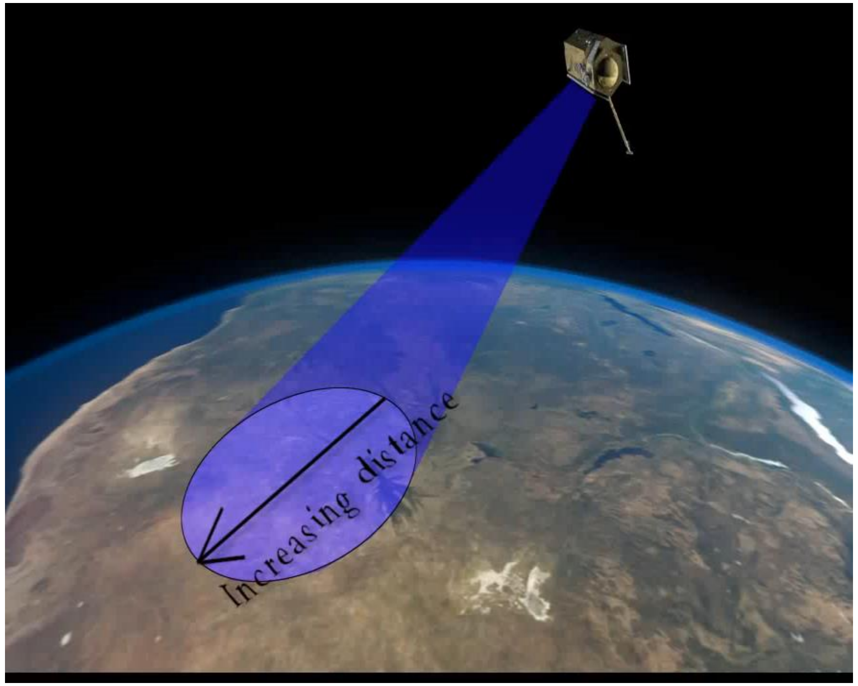


2021 & BEYOND

- FULL-POL
- InSAR
- SWEEPSAR

RISAT 1A &1B
RISAT 2A
NISAR
OCEANSAT-3

Introduction to SAR



- Imaging radars use antennas that have elongated gain patterns that are pointed to the side of radar flight track.
- The pulse sweeps across the antenna beam spot ,creating an echo.
- The resolution in both range and azimuth direction is independent of the distance between antenna and target.
- Range resolution is dependent to the signal bandwidth, while azimuth azimuth resolution is dependent on the Doppler bandwidth generated due to the motion of the spacecraft.

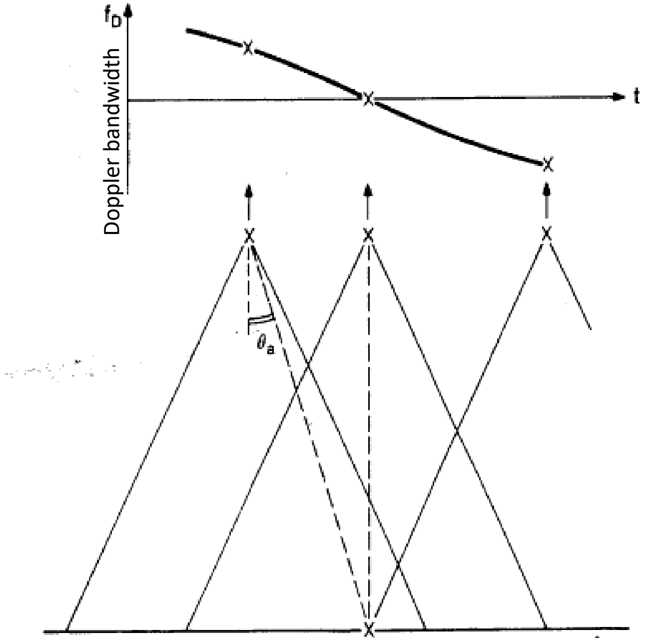
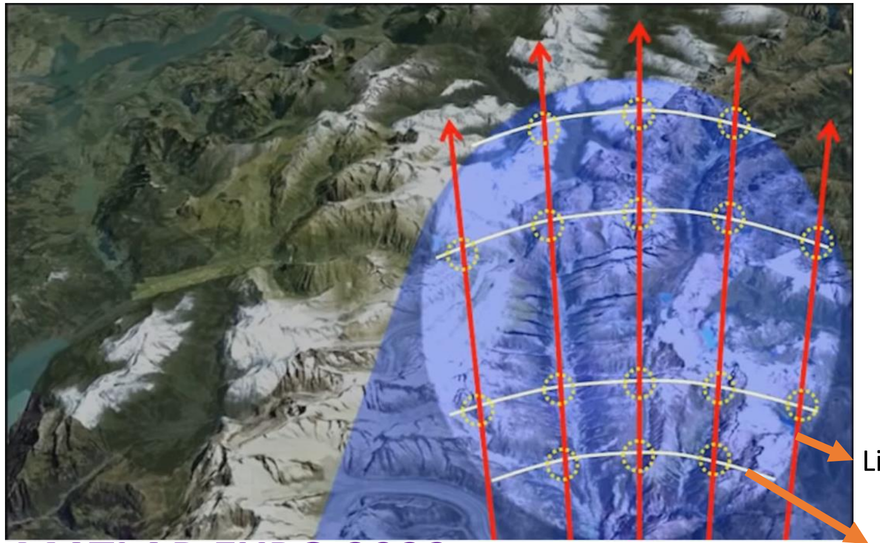


Fig. Doppler shift history of the echo as the sensor passes over it.



Lines of Equi-Doppler

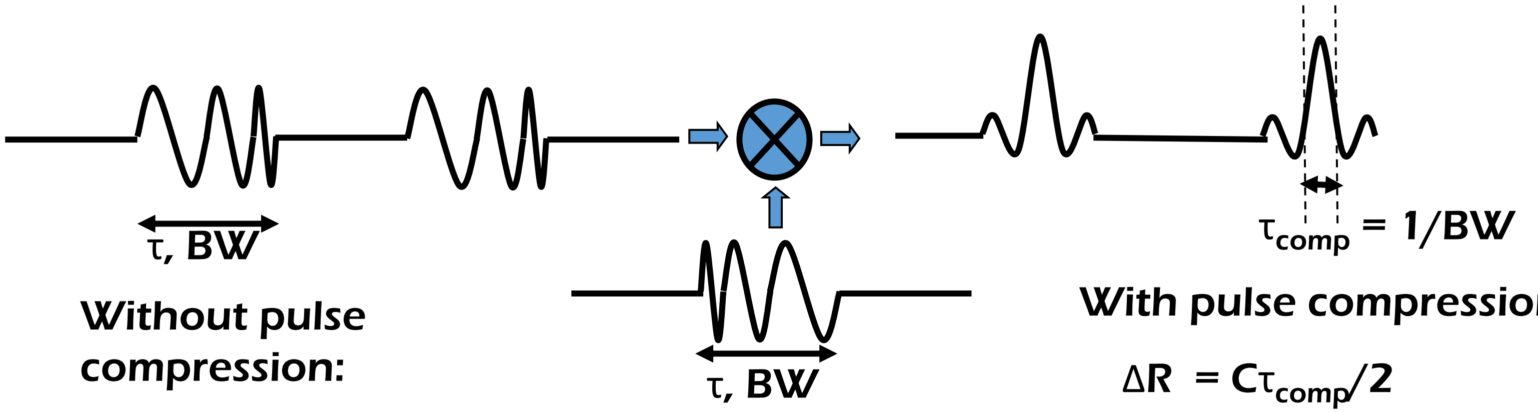
Lines of Equidistance .

Enhancement of Range Resolution using Pulse Compression

•Without pulse compression , range resolution is directly proportional to pulse width creating a trade-off between resolution and mean transmitted power.

•To take care of this SAR sensors employ modulation techniques like linear frequency modulation (chirp, most-oft used) or barker codes during transmission.

•After reception, the echoes are compressed using matched-filtering technique, so that the resolution is improved. this is pulse / range compression.



Without pulse compression:

$\Delta R = C\tau/2$

With pulse compression:

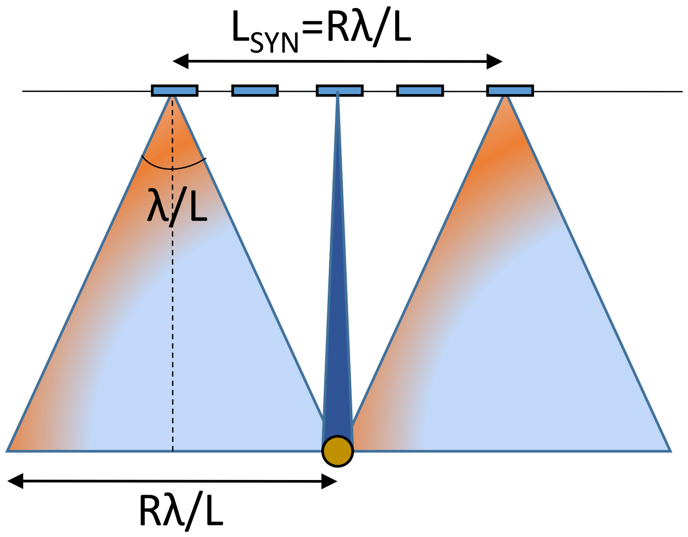
$\Delta R = C\tau_{comp}/2$

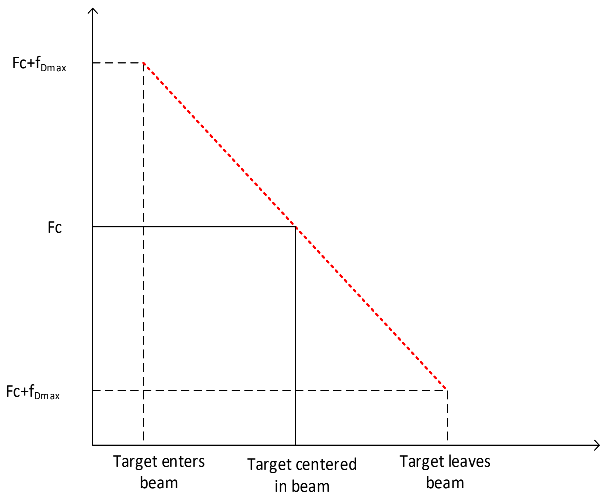
$= C/(2.BW)$

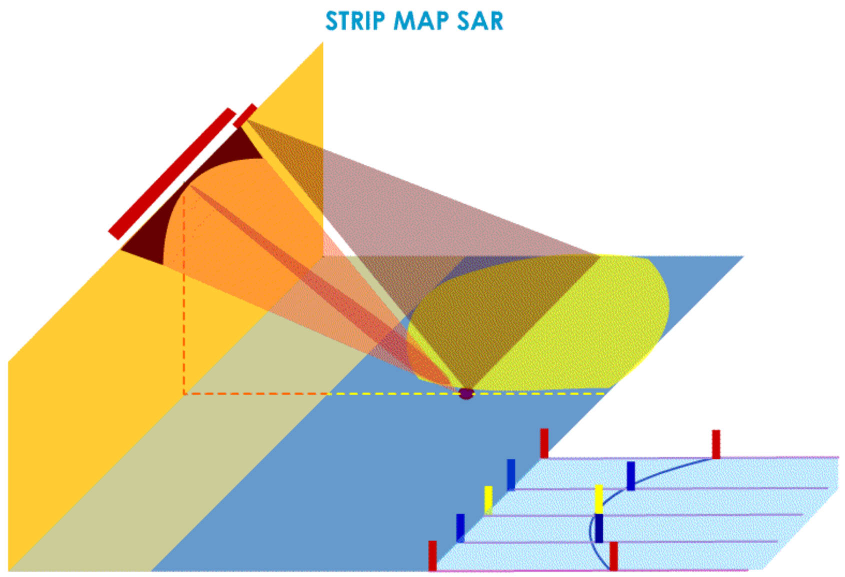
WITH THIS RESOLUTION IS IMPROVED IN RANGE DIRECTION,
BUT WHAT ABOUT AZIMUTH??

Enhancement of Range Resolution by SYNTHESIS OF LONGER APERTURE

- MAKES USE OF DOPPLER VARIATION BETWEEN SENSOR AND TARGET
- PERIODIC PULSE TRANSMISSION SIMULATES PHASED-ARRAY
- LENGTH OF THE SIMULATED ANTENNA LIMITED BY THE AZIMUTH BEAM FOOTPRINT







SYNTHESIZED BEAMWIDTH: λ/2LSYN

RESOLUTION: Rλ/2LSYN = L/2

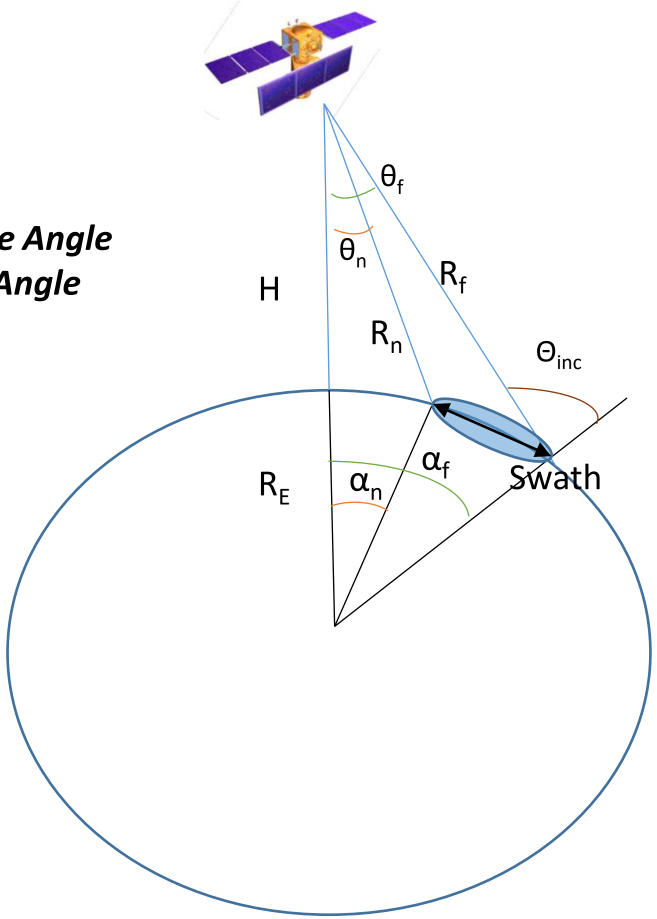
SAR RESOLUTION INDEPENDENT OF RANGE

AZIMUTH RESOLUTION FOR C-BAND FREQ (λ ~ 6cm), L OF 6m AND R OF 600KM ?

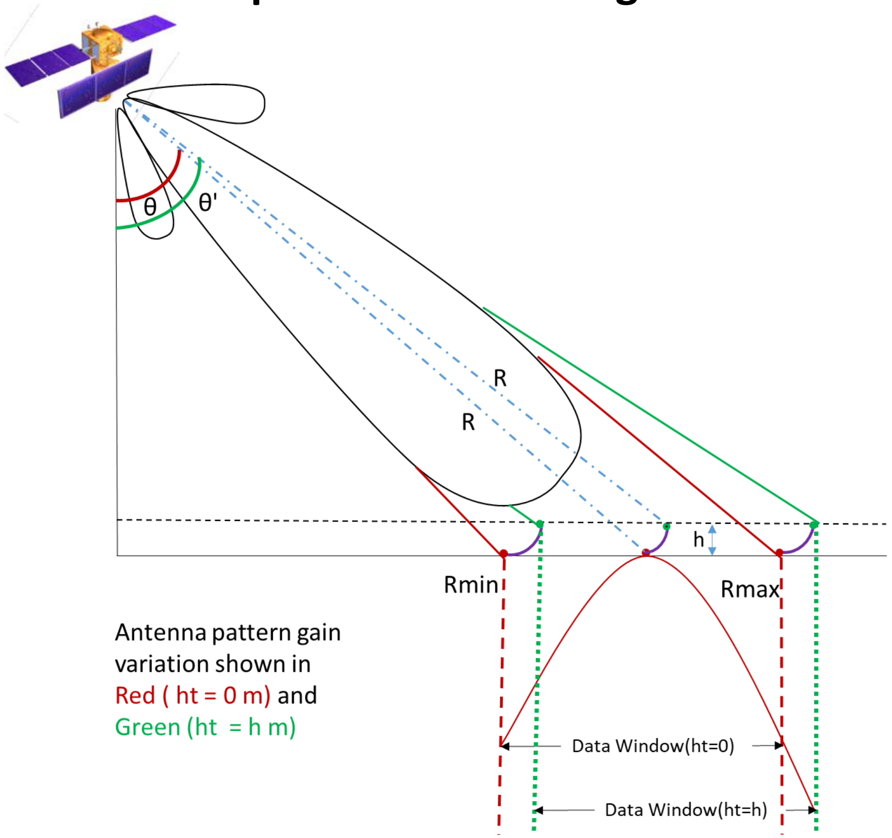
User Requirements ,Imaging Geometry and Platform Parameters

Satellite Orbital Geometry

- **H : *Height***
- **R_E : *Radius of Earth***
- **R_n : *Near Range***
- **R_f : *Far Range***
- **α_n: *Near Earth Centre Angle***
- **α_f: *Far Earth Centre Angle***
- **Θ_n: *Near Look Angle***
- **Θ_f : *Far Look Angle***

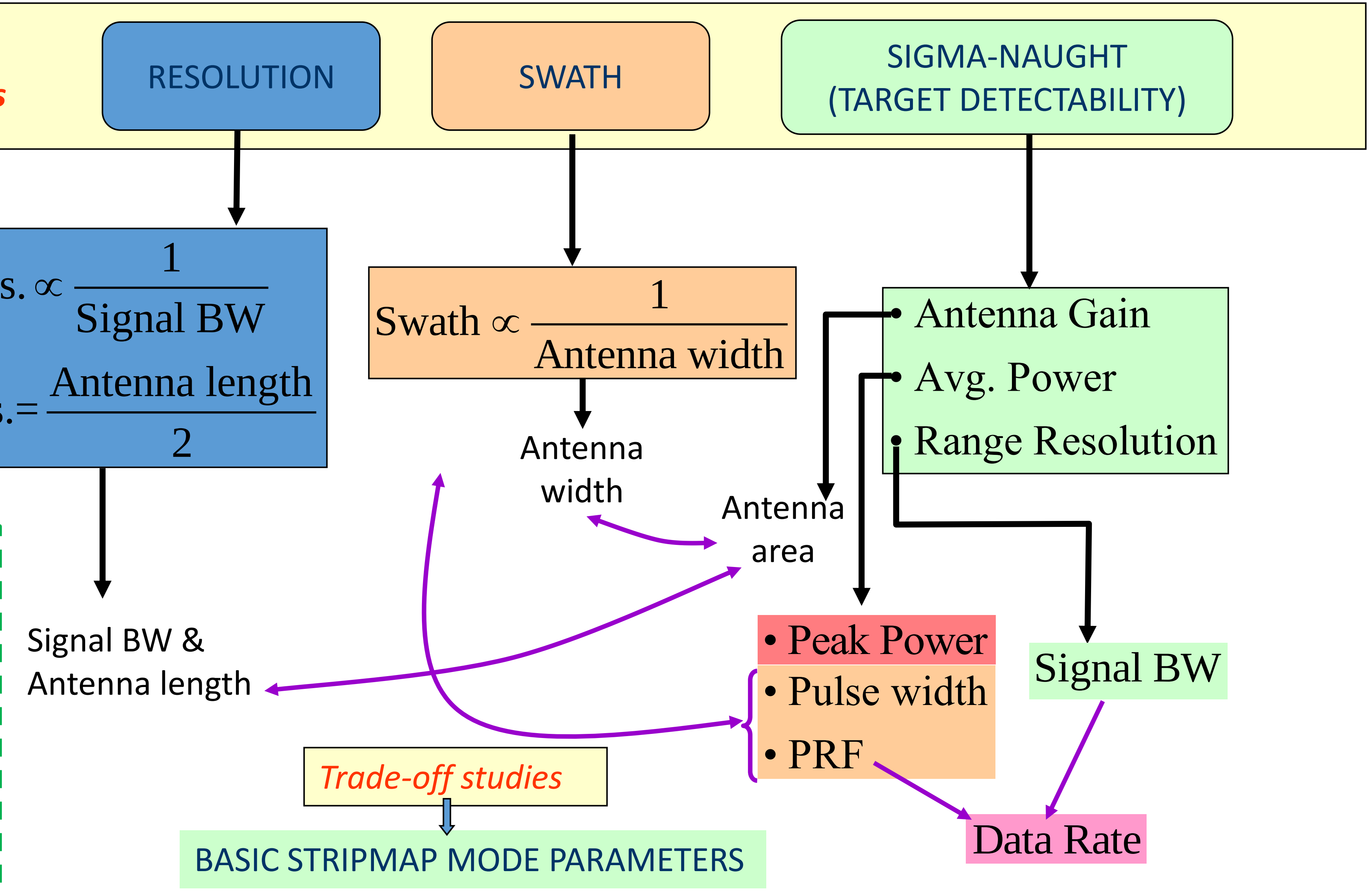


Impact of surface height



Antenna pattern gain variation shown in Red (ht = 0 m) and Green (ht = h m)

TYPICAL SAR SYSTEM DESIGN FLOW



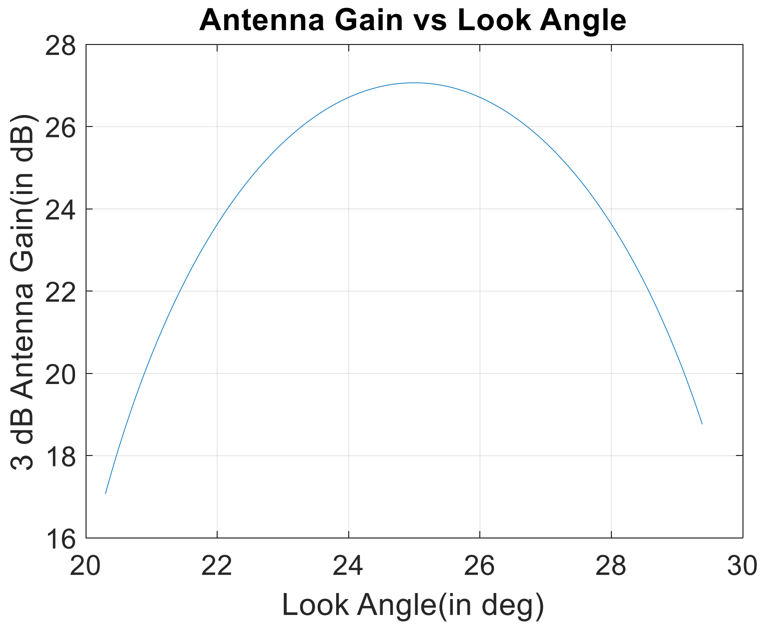
- Custom scripts
- Antenna systems toolbox
- Phased array toolbox
- MATLAB toolbox
- Symbolic math toolbox
- Signal processing toolbox

…. TYPICAL SAR SYSTEM DESIGN FLOW

Requirements

HIGHER RESOLUTION THAN IN STRIPMAP	LARGER SWATH THAN IN STRIPMAP	LARGER SWATH ALONG WITH HIGH RESOLUTION
SPOTLIGHT MODE	SCANSAR MODE	SWEEPSAR MODE
BETTER RESOLUTION AT THE COST OF SWATH/ AZIMUTH COVERAGE	LARGER SWATH AT THE COST OF RESOLUTION	LARGER SWATH ALONG WITH HIGH RESOLUTION IS POSSIBLE BUT REQUIRES HIGH DATA RATE AND ADVANCED TECHNOLOGIES LIKE DIGITAL BEAM FORMING

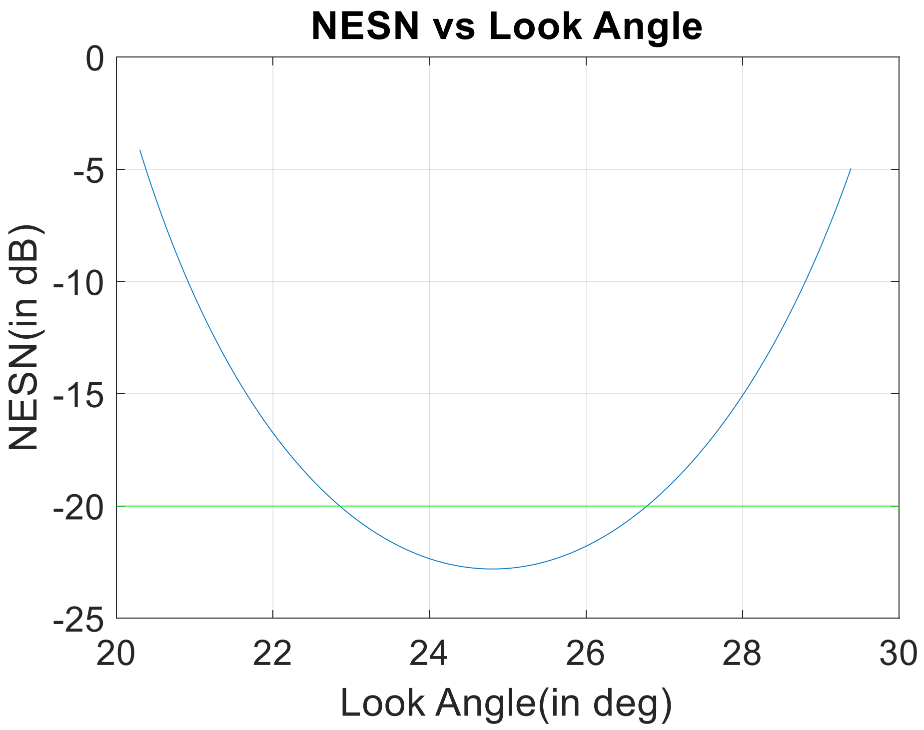
Antenna pattern generation



- Antenna peak gain(G_0)
- Antenna width(W_{eff})
- Pointing angle of peak antenna gain(α_0)
- Wavelength( )

$$G = G_0 \frac{\sin\left(\dfrac{\pi W_{eff} \sin(\alpha - \alpha_0)}{\lambda}\right)}{\dfrac{\pi W_{eff} \sin(\alpha - \alpha_0)}{\lambda}}$$

Noise equivalent sigma naught (NESO) or minimum sensitivity level



$$\sigma_0 = \frac{(4\pi)^3 R^3 (KT_0 LF) 2V \sin\theta}{P_{avg} G^2 \lambda^3 \delta_r}$$

where, P_{avg} is the average transmitted power given by $P_T \tau.PRF$,

- P_T is the transmitted peak power,
- PRF is the optimum PRF determined earlier,
- τ is the pulse width,
- G is the antenna gain at the point of evaluation (depending on off-nadir distance)
- δ_r is the slant range resolution
- θ is the incidence angle
- R is the slant range
- V is the satellite velocity
- F is the receiver noise factor
- T_0 is the system temperature, assumed to be 290 K.
- K is the Boltzmann's constant = 1.38×10^{-23} J/K
- L is the system losses which includes Transmitter, Receiver and mismatch losses

PRF OPERATION RANGE

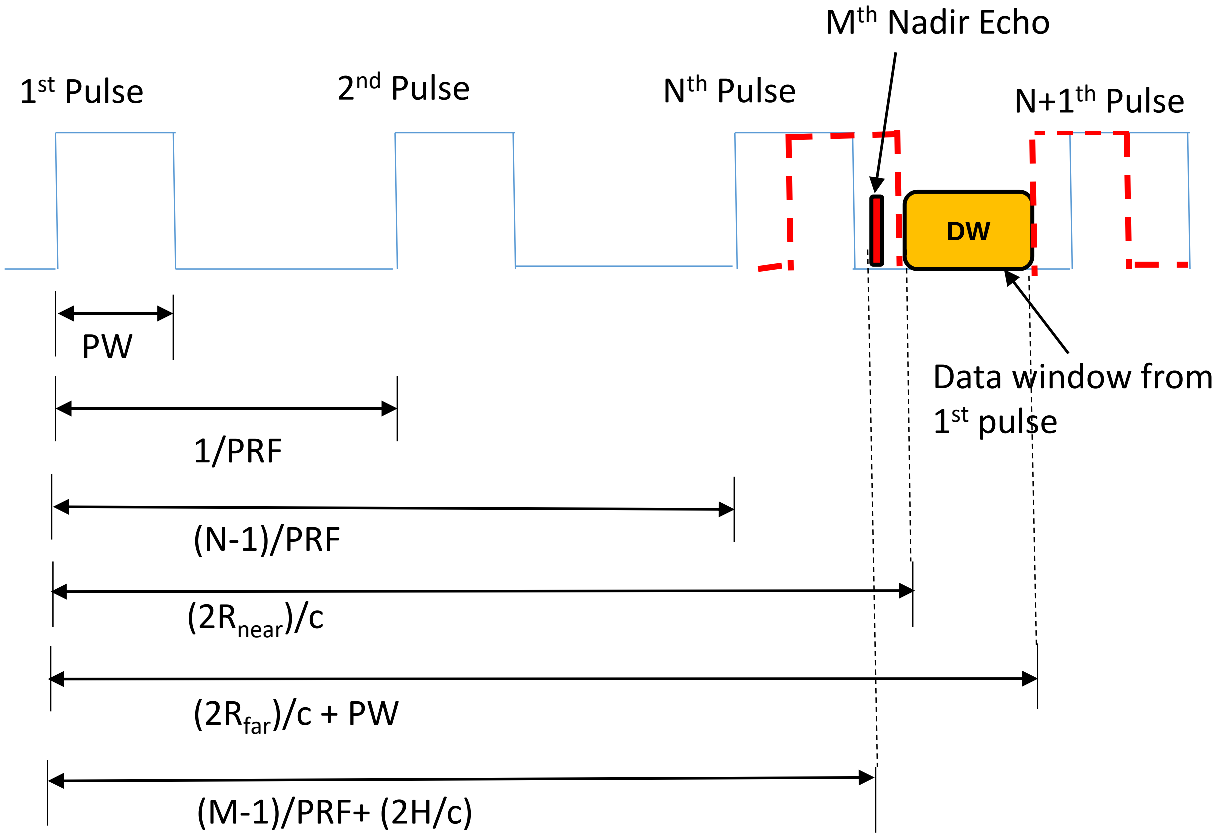
- PRF has to be selected to avoid eclipsing between :
  - i. Data Window and Pulse Width
  - ii. Nadir Return and Data Window

- The selected PRF will be a function of :
  - i. Look Angle
  - ii. Incidence Angle
  - iii. Swath
  - iv. Pulse Width

- Selected PRF needs to satisfy the ambiguity levels.

- Azimuth ambiguity defines the lower limit of PRF.

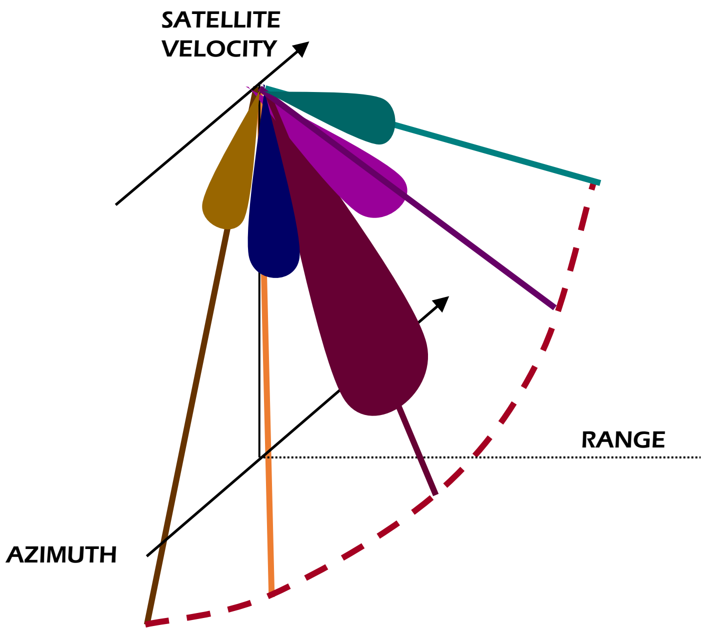
- Range Ambiguity defines the upper limit of the PRF.

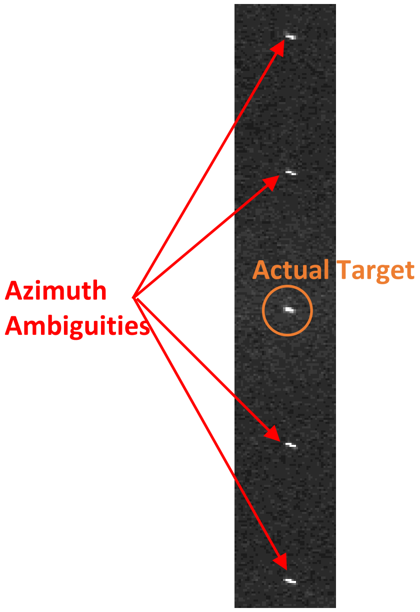


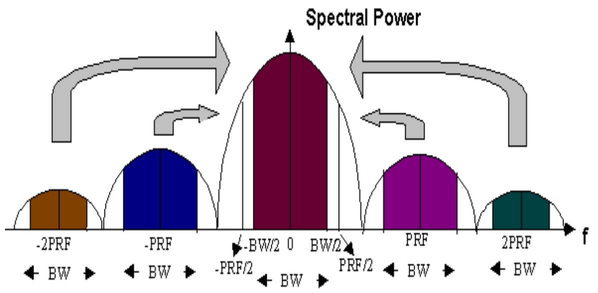
AMBIGUITY CALCULATIONS

AZIMUTH AMBIGUITY

- Azimuth ambiguity defines the lower limit of PRF
- PRF > Doppler Bandwidth to avoid azimuth ambiguities.

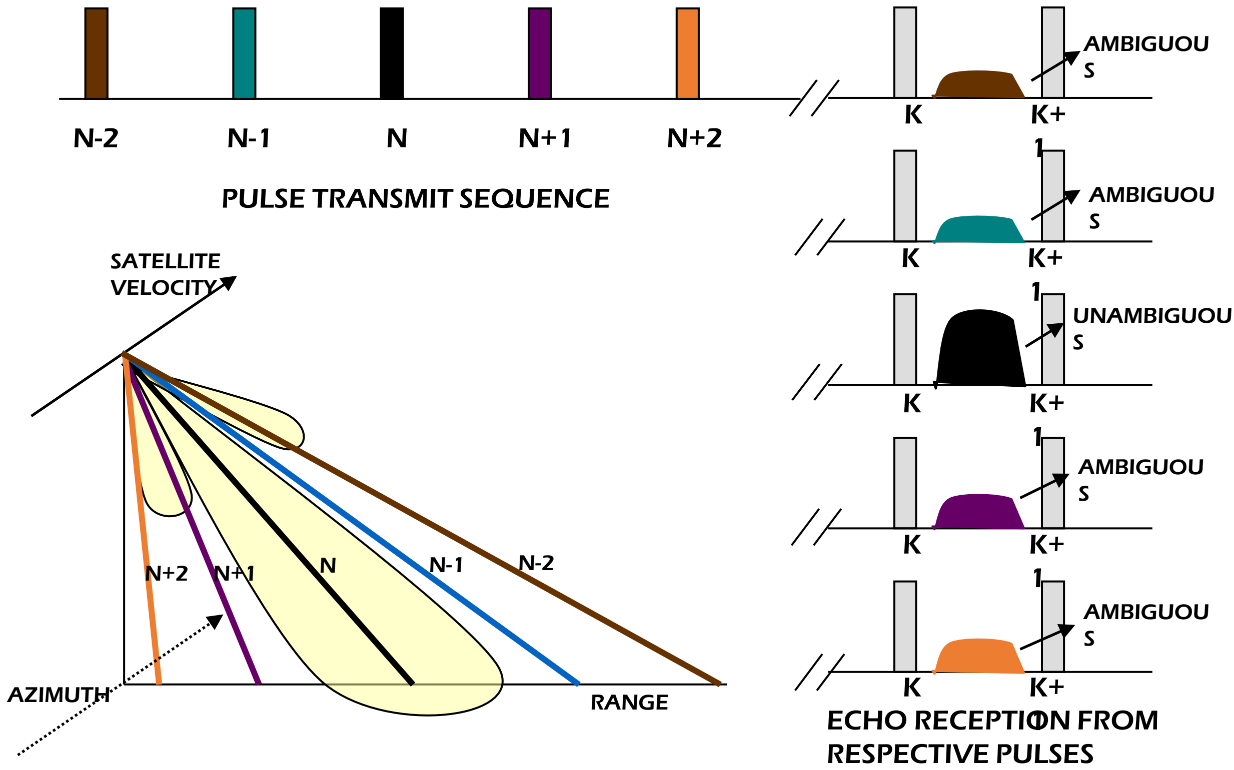






RANGE AMBIGUITY

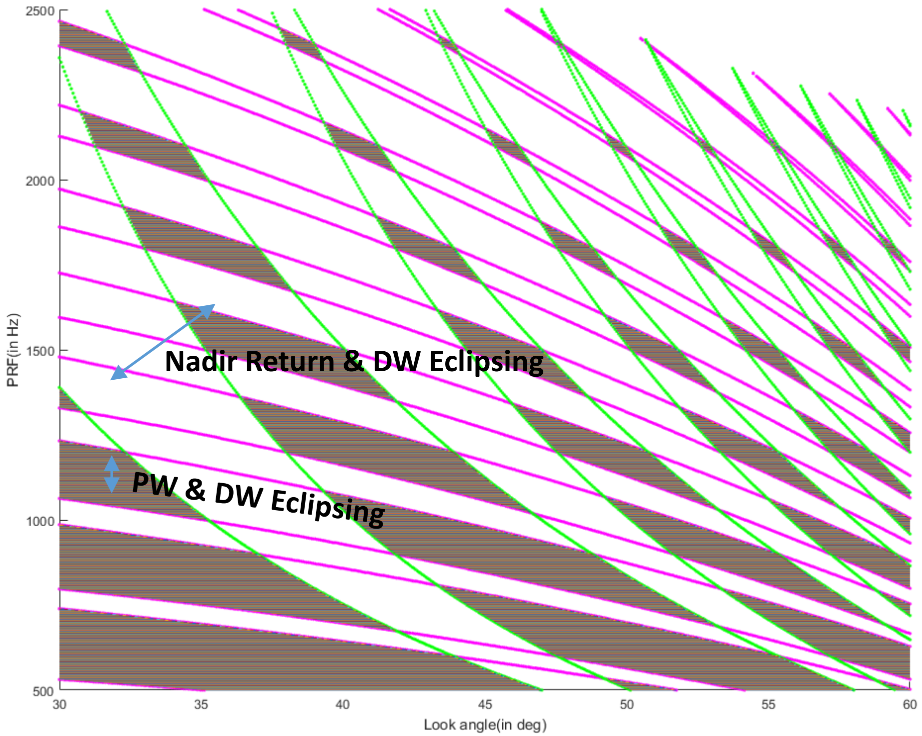
- Range Ambiguity defines the upper limit of the PRF.



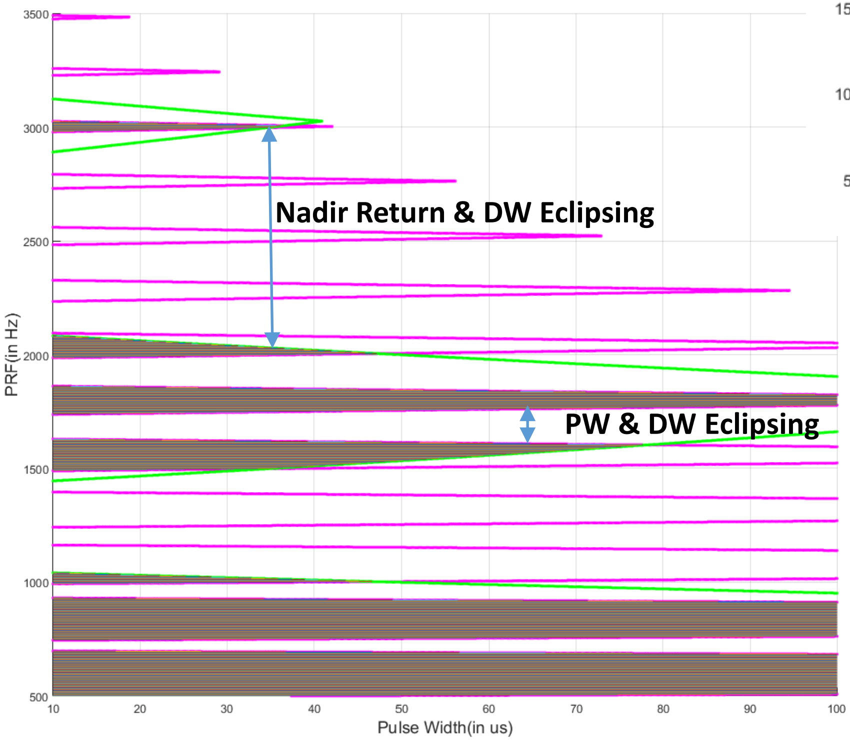
Ambiguity Ratio = Total Ambiguous Power/ Unambiguous Power

TRADE OFF ANALYSIS TO SELECT THE PRF

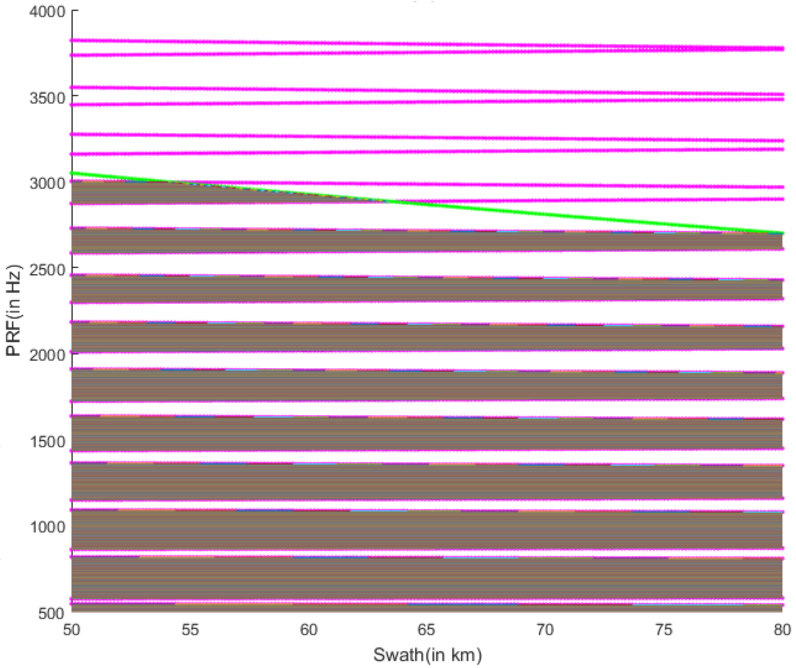
PRF VS LOOK ANGLE



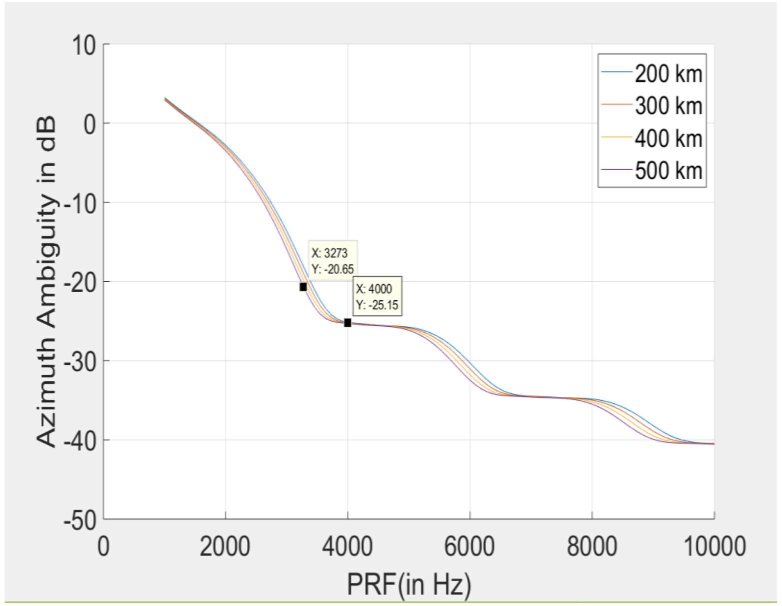
PRF VS PULSEWIDTH

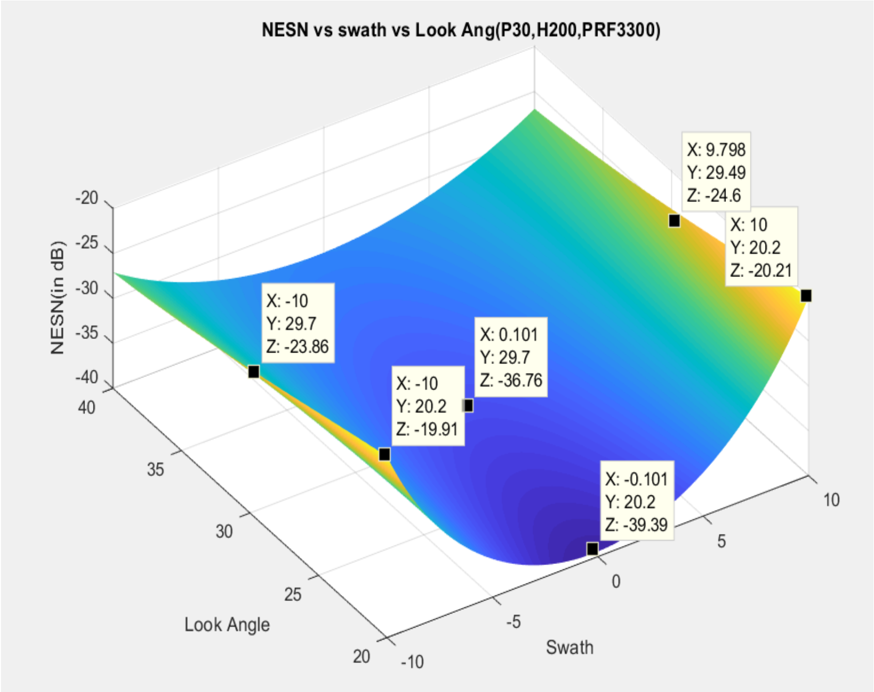


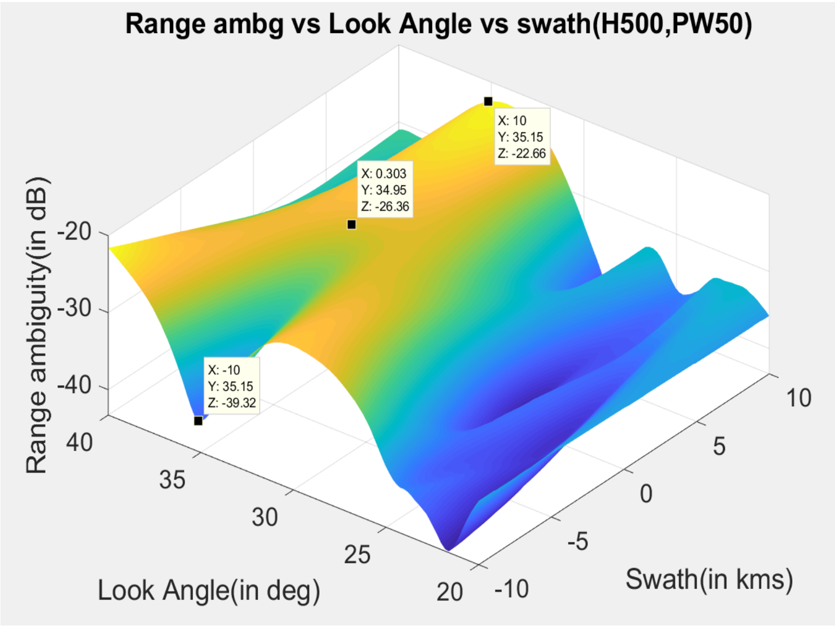
PRF VS SWATH



System Design Results





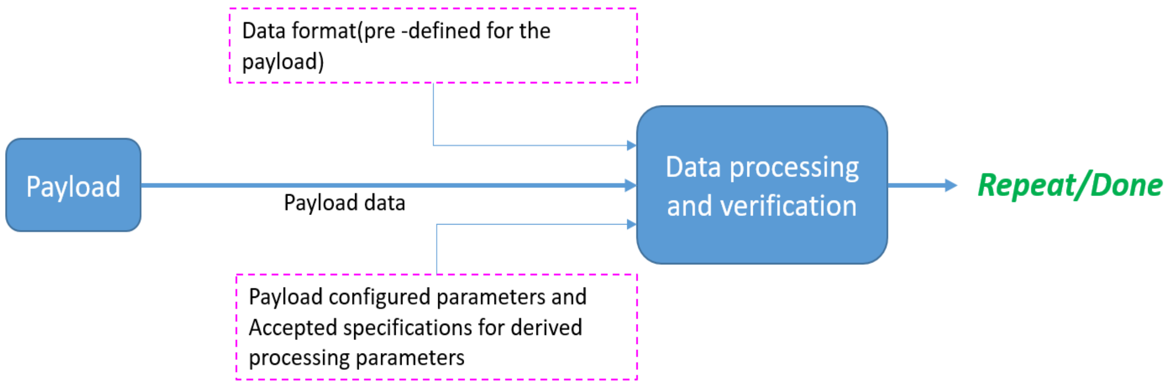


MATLAB toolbox used

- custom scripts
- Antenna toolbox
- Phased array toolbox
- Radar toolbox

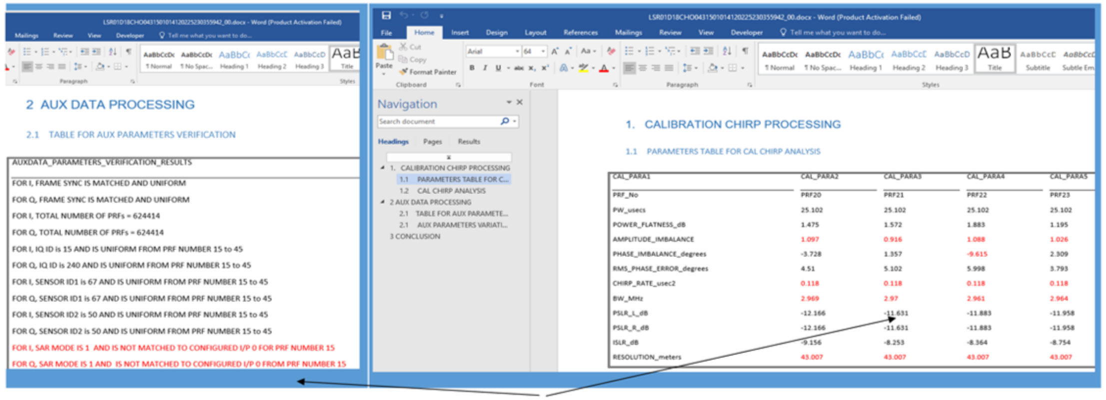
Data processing Software requirement and overview

- **Software was required to process and verify the payload data as a part of Ground Checkout activity of the payload.**
  1. **Requirement for verification of payload configuration parameters in the payload data.**
  2. **Requirement for Verification of derived processing parameters from payload data w.r.t. accepted specifications.**
- **Requirement for scope of Automization of software to reduce data processing and verification time and to minimize human interference.**



General Payload Data processing and verification flow diagram

PDF ERROR REPORT



Extracted Aux(Left) and chirp characterization parameters(Right) error(SHOWS RED) with respect to commanded parameters/accepted specifications

Generated final PDF error report

- *MATLAB toolbox*
- *Symbolic Math Toolbox*
- *Signal processing toolbox*
- *MATLAB report generator toolbox*

Payload data constituents and derived processing parameters

Payload data file(.bin)

Auxillary data

- Contains payload configuration information Like pulse width, Bandwidth, Imaging duration, Sampling frequency etc.

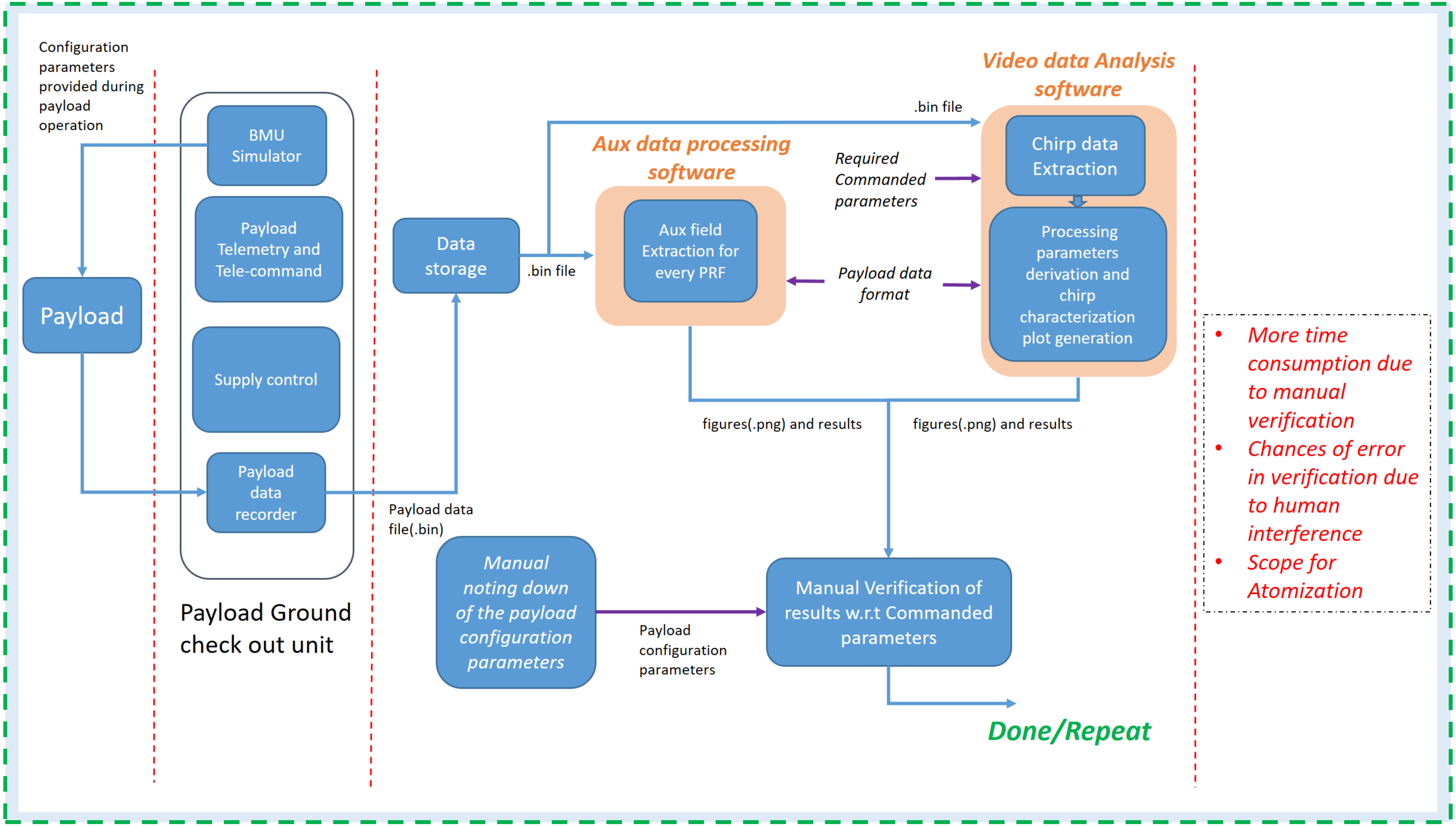
Vedio data

- Contains payload internal calibration and return signal(Chirp) information.
- Derivation of chirp characterization and radar performance parameters after the video data processing.
- Chirp characterization parameters are Pulse width, Bandwidth, Amplitude Droop, Amplitude and Phase imbalance between I and Q, RMS phase error of unwrapped phase of chirp signal, Chirp rate.
- Radar performance parameters are PSLR(peak side lobe ratio), ISLR(integrated side lobe ratio), Resolution.

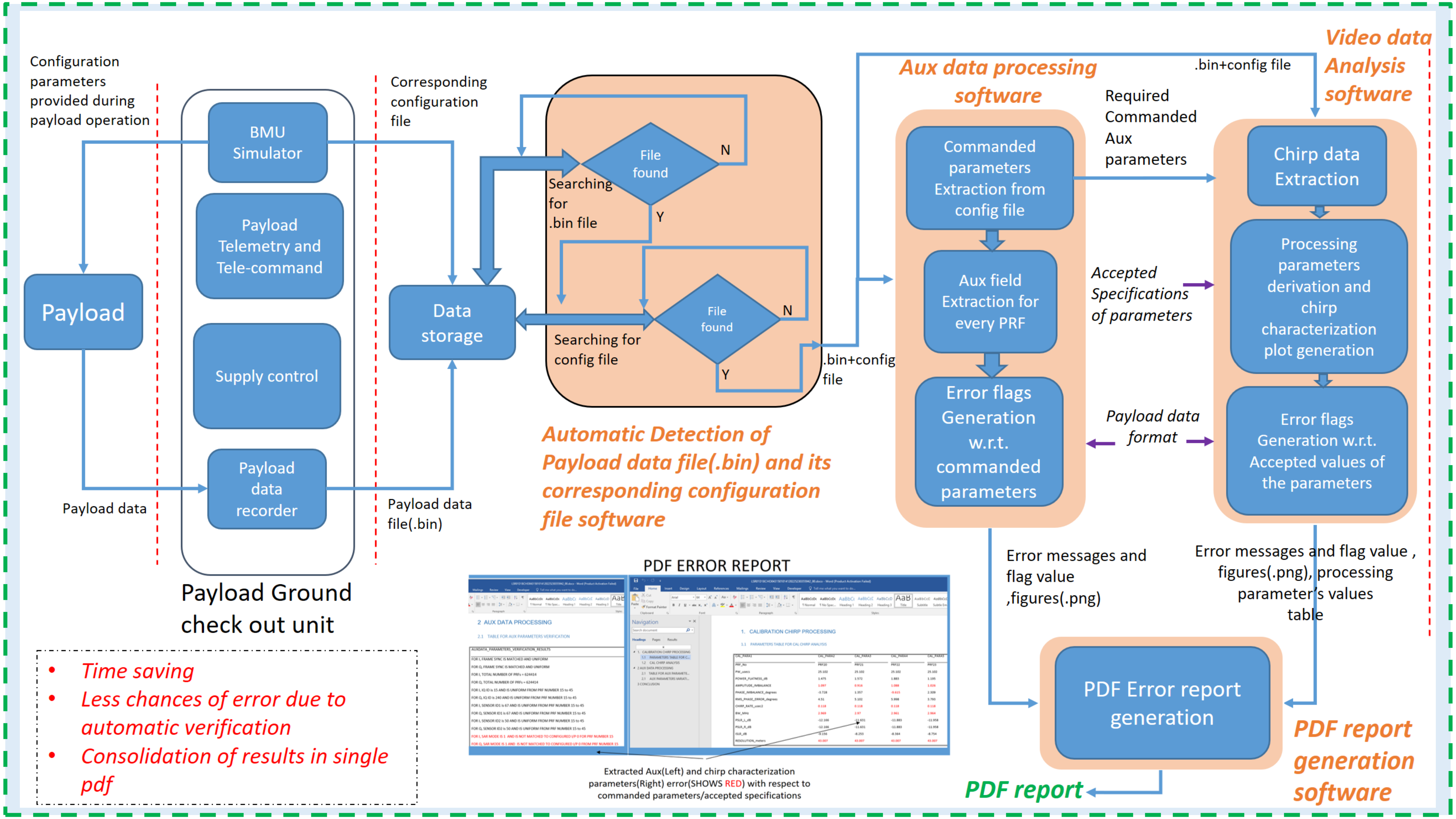
Configuration file(.csv)

- Contains payload configuration information Like Pulse width, Bandwidth, Imaging duration, Sampling frequency etc.

Conventional data processing software flow diagram



Automated data processing software flow diagram



Summary

- SAR payload data was processed and verified using automated data processing software.
- Usage of automated data processing software was found to be time saving and verification error free as compared to conventional data processing software.

Future scope

- Integrating terrain information and Earth oblateness for imaging geometry simulations
- Raw data generation for different SAR modes
- MATLAB based processing to generate Quick Look SAR Image
- Designing a digital twin SAR sensor by integration with physics-based engines

Acknowledgement

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Thank you