RFI Suppression in P Band SAR

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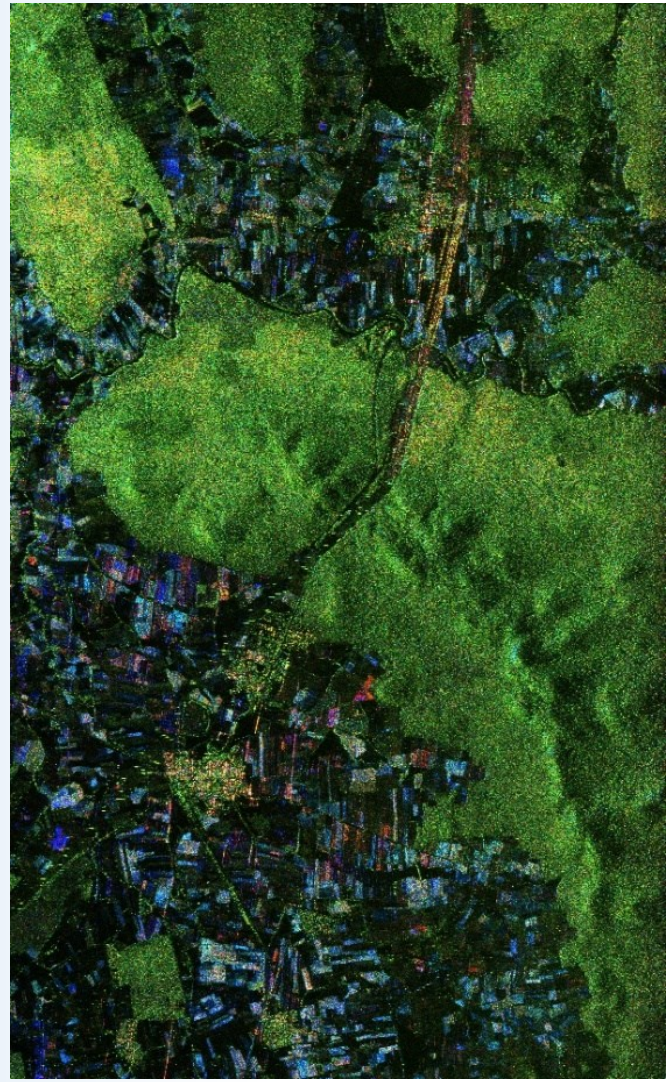
Dated 13/11/2024



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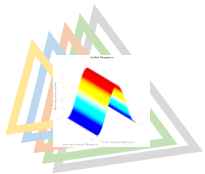


Sources of RFI

L-band* 1.215 GHz -1.3 GHz is most susceptible to RFI by aviation radars, military radars and RNSS systems.

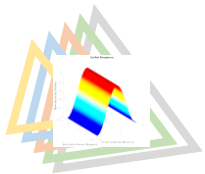
S-band* 3.1GHz – 3.3 GHz vulnerable to RFI due to 4G LTE, WIFI frequencies in S band.

C-band* 5.25 – 5.57 GHz could be affected by RFI due to Weather radar operating within this band or by any other military radar. Allocation of 5350-5470 MHz to RLAN is a potential source for RFI in C-band.

X-band* 9.3 GHz – 9.8 GHz, Doppler Weather radar is a potential source of RFI

P-band* 432-438 MHz could be affected by RFI due to UHF amateur radio, radiocommunication services, DVB-T , space object tracking radars etc.

*for spaceborne SAR as per ITU-R RS.577-7



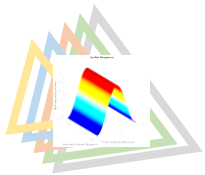
RFI Observations In SAR Data

- RFI in SAR data is caused by radio frequency sources operating in the same frequency band as SAR instrument.
- RFI are electromagnetic interference signals that affects the SAR echo data and appears as various kind of bright linear features in azimuth time range frequency diagram.
- RFI can broadly be classified as,
    1. *TVWB (Time varying wide bandwidth) RFI*: TVWB represents the RFI whose bandwidth is wide and centre frequency varies with respect to azimuth time.
    2. *TSNB (Time stationary narrow band) RFI*: TSNB represents the RFI whose bandwidth is narrow and centre frequency remains stationary with respect to azimuth time.

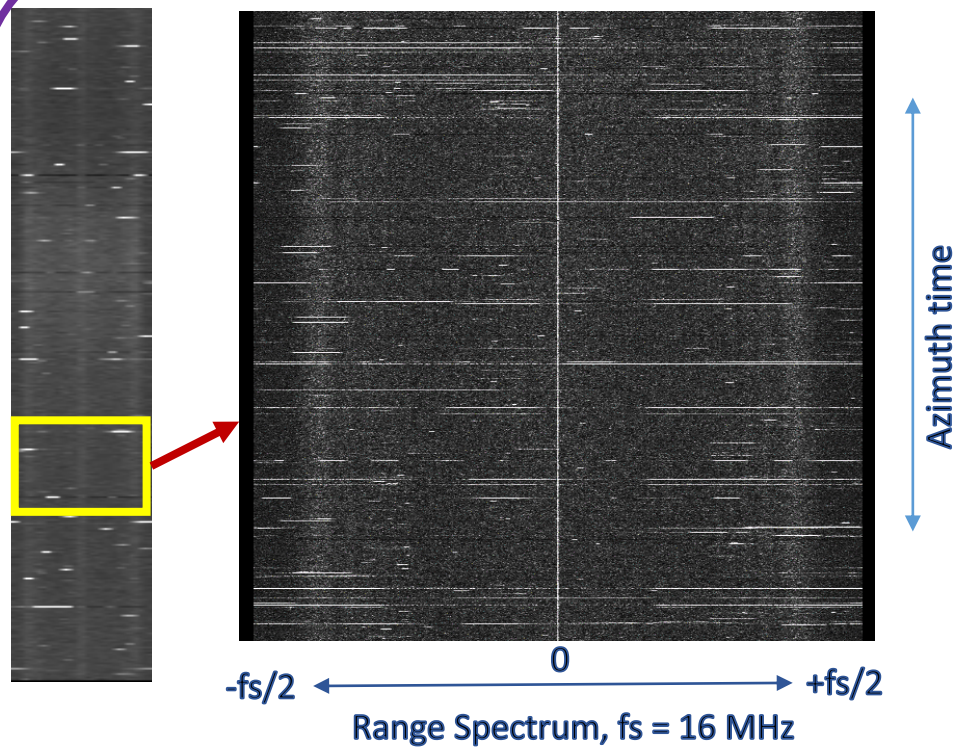
  TSNB and TVWB RFI's are the end members of the large types of RFI's that can exist in SAR data.
- RFI introduces cross patterns/haziness and various types of other patterns in the focussed image.

Why Mitigation is needed?

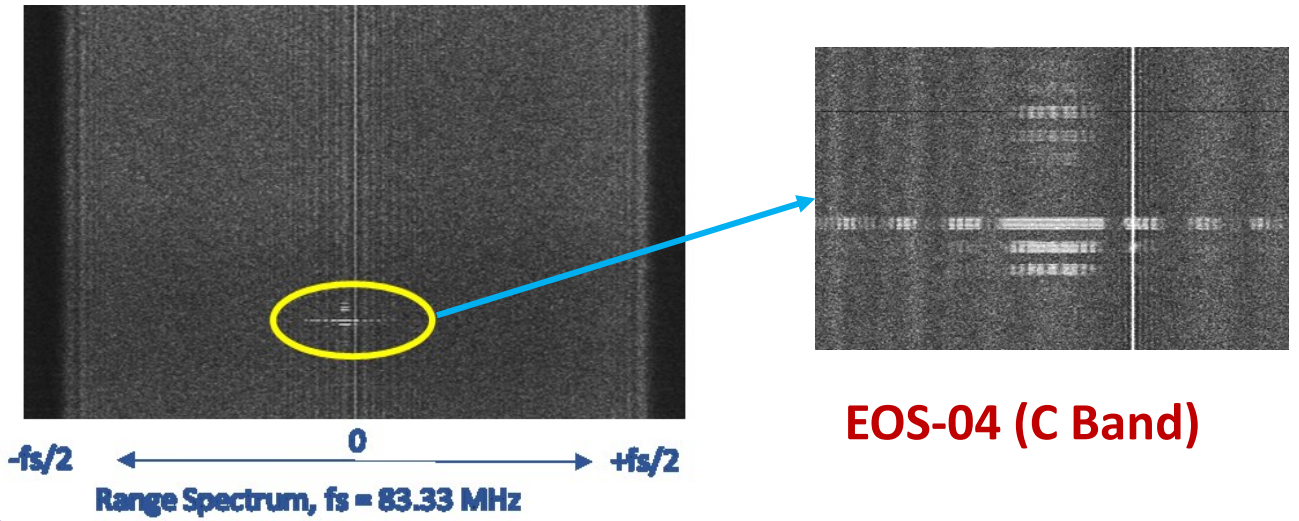
RFI affects the overall radiometric quality (like contrast) and image interpretability significantly in low SNR regions like lake, oceans, undeformed new ice etc. Potentially important targets like ships etc. could be masked to the extent that their detection becomes difficult.



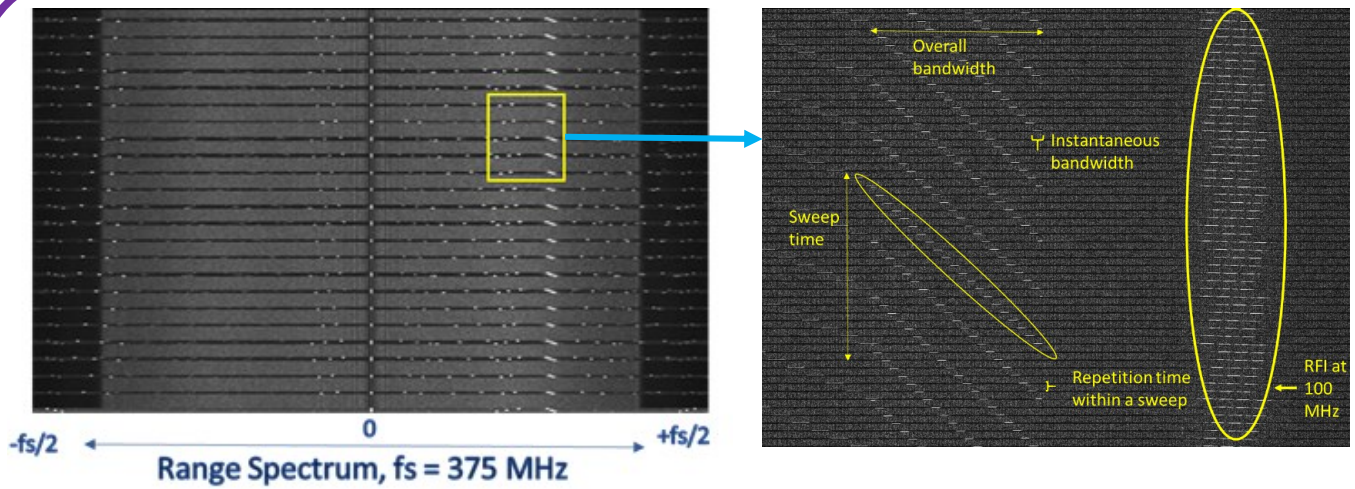
RFI signatures in Azimuth Time Range Frequency Spectrum



ALOS (L Band)

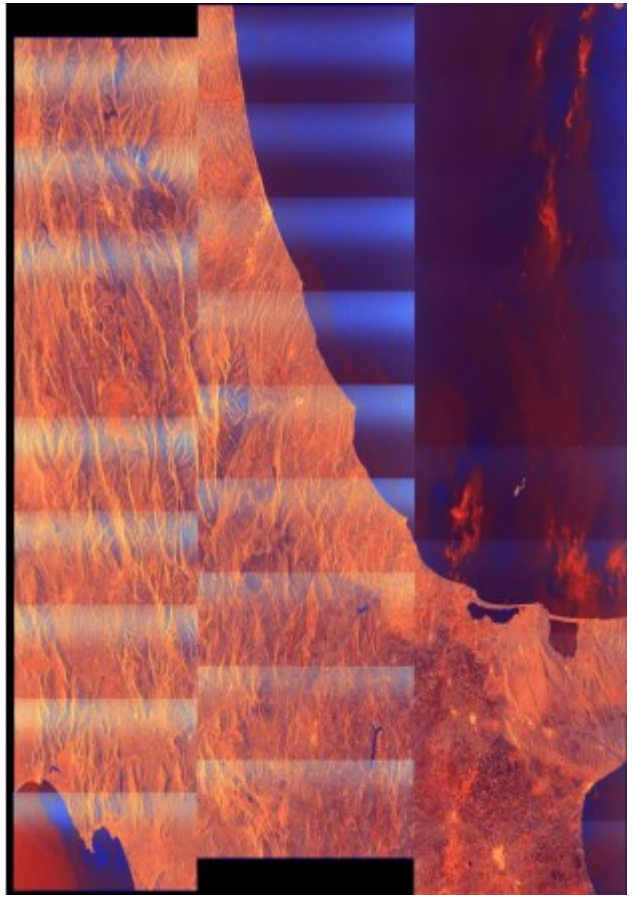


EOS-04 (C Band)

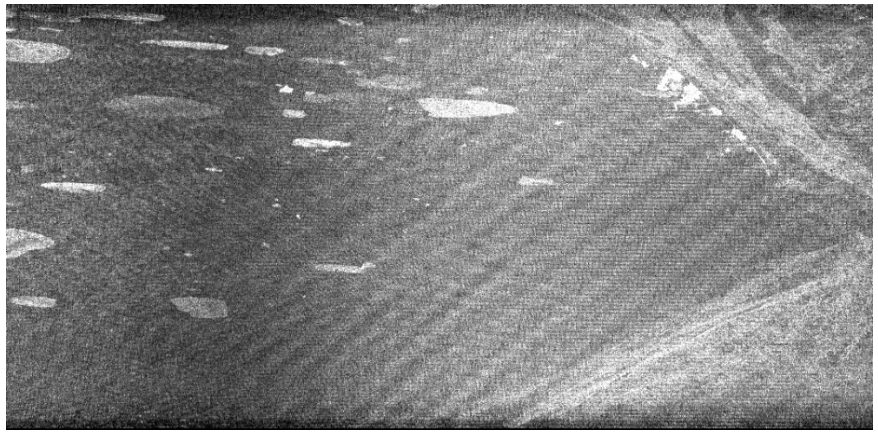


RISAT-2B (X Band)

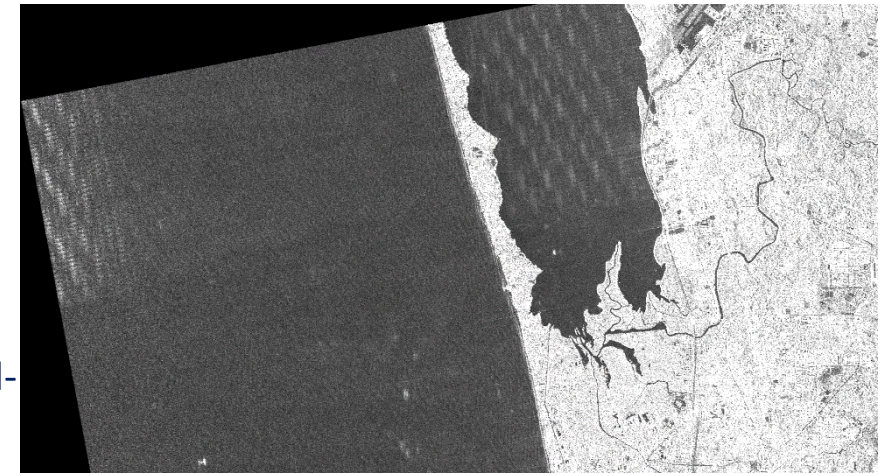
RFI Observations In SAR Data



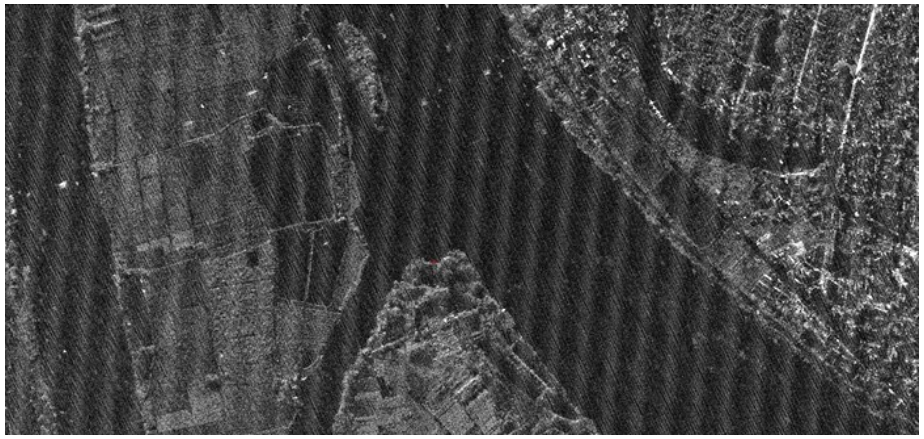
Mutual interference between Sentinel-1A and RADARSAT-2 (C Band) over Italy 2015.



Interference in L band ALOS PALSAR data over Alaska Barrow



Interference in C band EOS-04, Negombo lagoon, Srilanka



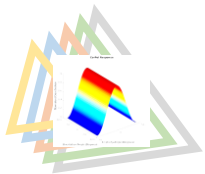
Interference in X band RISAT-2B, Waisha River, China

Interference in ISRO's P band airborne SAR, Hyderabad

Mitigation techniques

Some RFI detection and mitigation techniques discussed in literature are:

1. *Based on analysis of azimuth time range frequency characteristics of RFI*
    - Notch filtering, set samples as zero beyond a certain threshold. Too much of notch filtering leads to degradation in side lobe levels.
2. *Estimation and subtraction*
    - Interference can be reconstructed by the estimating parameters like amplitude, frequency and phase of each RFI source using least square, maximum likelihood estimator, Bayesian framework, etc. Precise parameter estimation remains a key issue.
3. *Based on the analysis of Eigen values*
    - It is based on the analysis of time-domain raw data in Eigen space wherein Eigen vectors corresponding to RFI signal are identified for RFI detection. Very Narrow TSNB RFI's are not detected sometimes.
4. *Adaptive filters (LMS)*
    - Performance not good in case of wideband interferences.
5. *Sniffer Pulses or Listen/Receive only mode*
    - enables dynamic monitoring of interfering frequencies in each pulse.



P Band Airborne SAR

- P-Band Airborne SAR is a left looking airborne SAR that has capability to operate in single, dual and full polarization.
- The first P-Band Airborne SAR campaign was held in October 2023. The second phase was held in July 2023 in which the data in Receive only mode for RFI detection was acquired.

Shivmogga Forest

Tungabhadra River

Kandankovi, Davangare

Parameters	Specifications
Airplane	B-200
Height	7.6 Kms
PRF/POL	1000 Hz
Frequency	450 MHz
Velocity	120 m/sec
Look angle	45° (30° to 54°)
Antenna Size (Length *Width)	1.5 m (Azimuth) * 0.5m (Range)
Swath (in Kms)	6 Kms
Tx BW	50 MHz
Return Time	58.52 usecs to 86.28 microsec
Data Window Duration	Swath = 6 kms , 55.29 microsec
NESN(in dB)	Better than -36 dB for whole swath
Off nadir(in Kms)	4.4 to 10.4

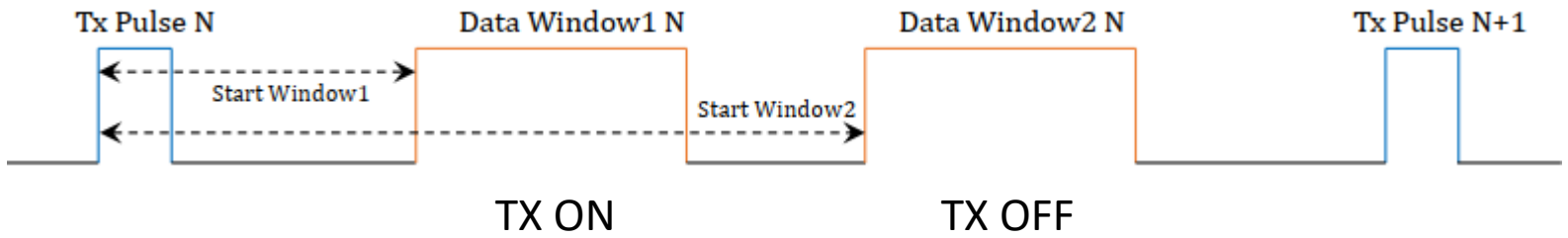
Due to high penetration capabilities, P Band SAR is used in various applications like study properties of dense forests, biomass estimation etc.

Receive Only data window

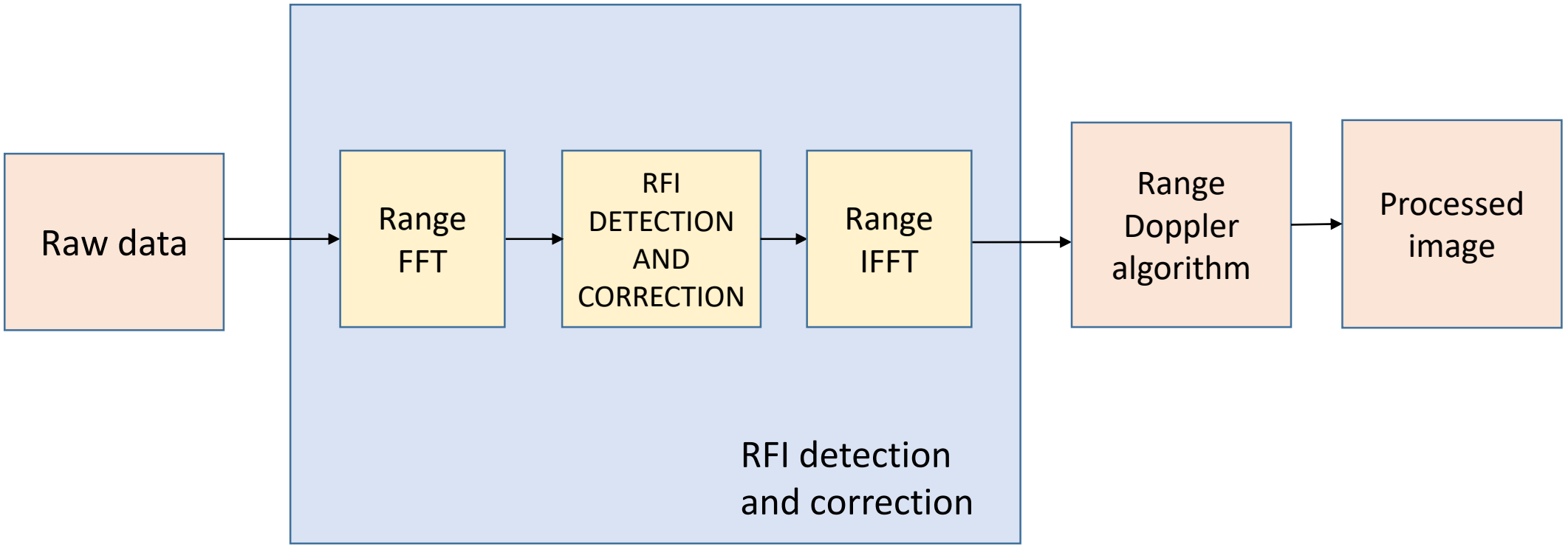
- In order to estimate the RFI contribution in imaging data, data is acquire in listen only mode with one additional data window in imaging session.
- This additional window will be offset to the original data window so that it will have minimum contribution from ground reflections and will only capture the RFI data.
- Width of the new data window is the same as data window specified for imaging session.

PSAR Phase 1

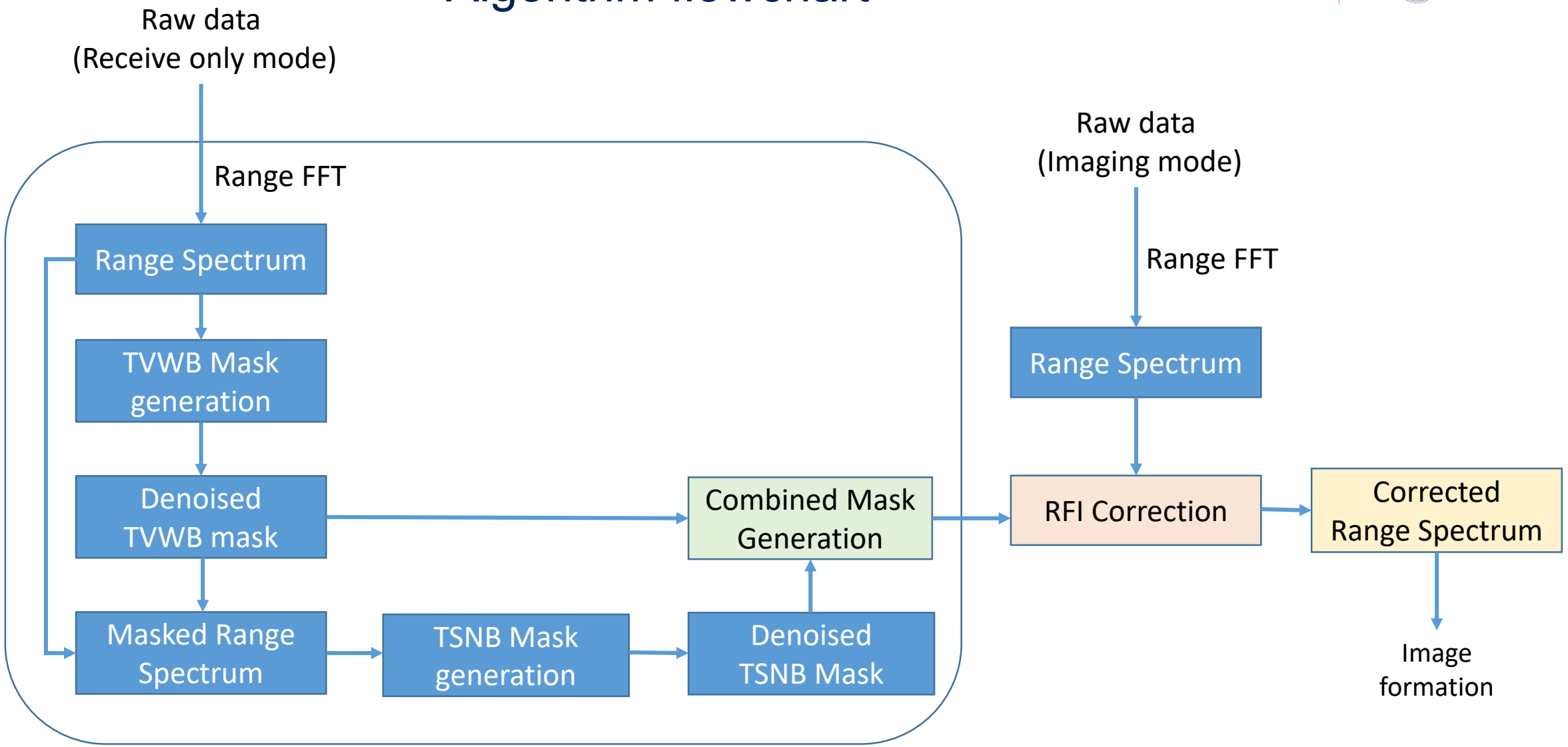
PSAR Phase 2



RFI DETECTION AND MITIGATION

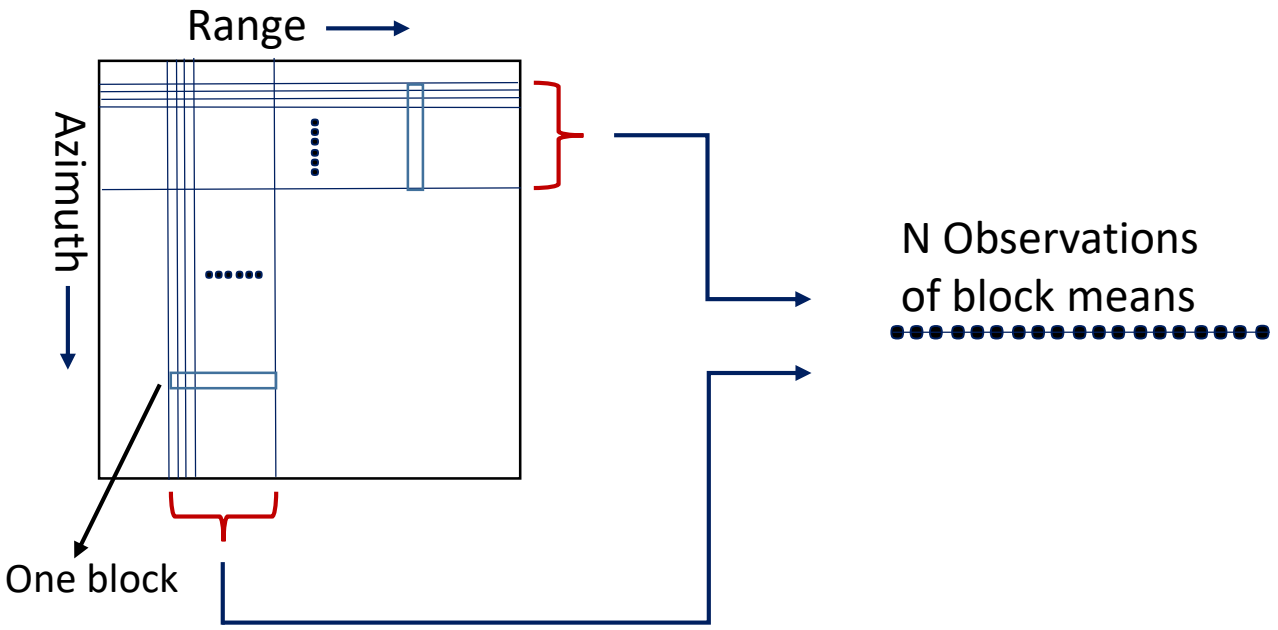


Algorithm flowchart



Parikshit Parasher, Krishna M Agrawal and V M Ramanujam, “RFI detection and mitigation in SAR data,” 1-4. *10.23919/URSIAP-RASC.2019.8738633*, March 2019

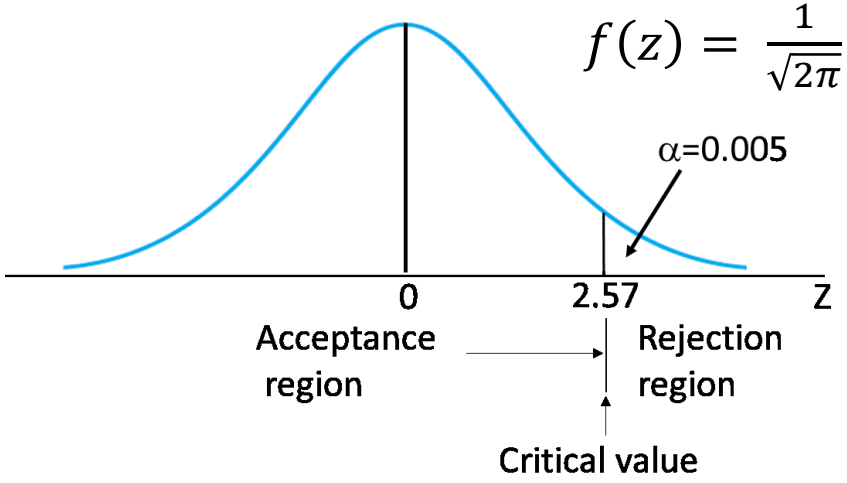
Detection concept



$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma'}\right)^2}$$

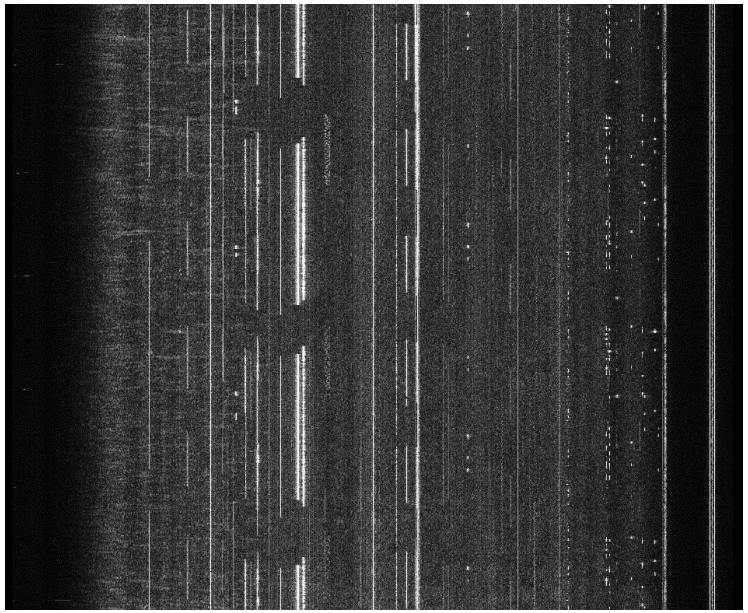
$$Z = \frac{|H(t)|^2 - \mu}{\sigma'} \qquad \sigma' = \frac{\sigma}{\sqrt{n}}$$

$$f(z) = \frac{1}{\sqrt{2\pi}}\, e^{-\frac{1}{2}z^2}$$



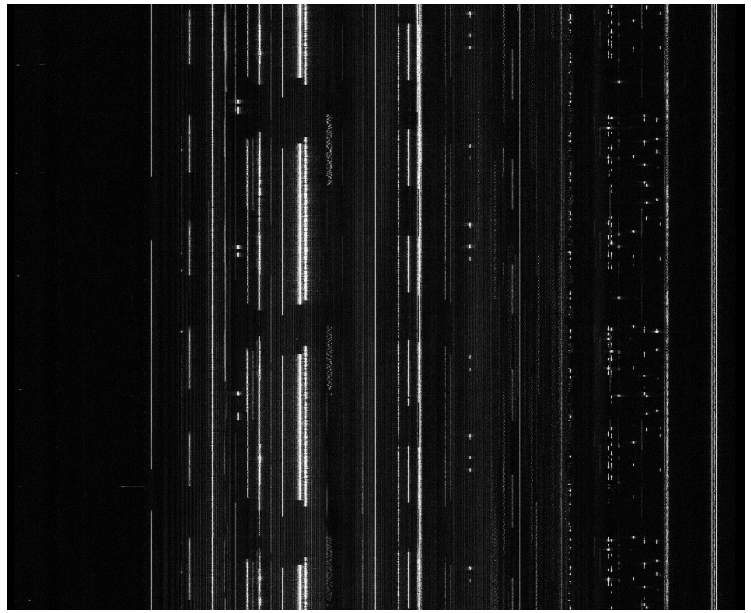
- It is based on the analysis of time-frequency characteristics of RFIs in the range frequency domain.
- The technique is based on a z-test combined with Tukey biweights to estimate robust statistics for RFI detection.
- Averaging over block in range direction detects the TVWB
- Averaging over block in azimuth direction detects the TSNB

Detection and Suppression Results

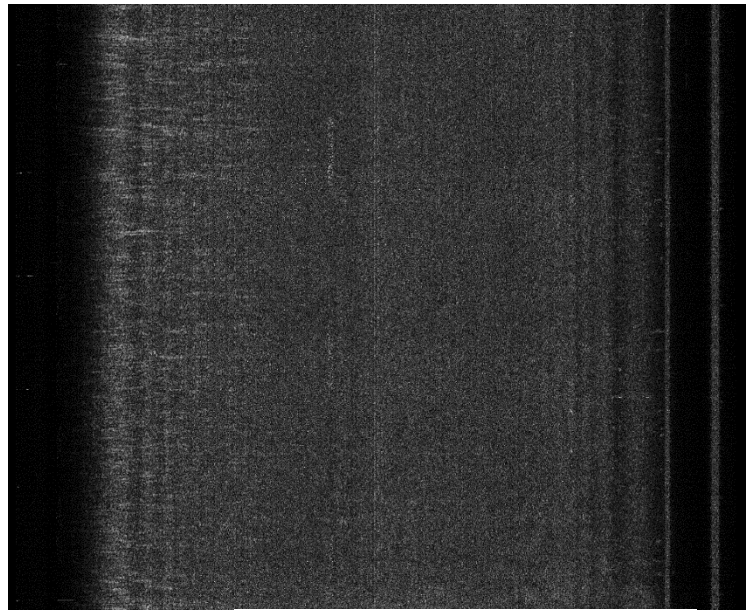


-fs/2 ⟷ +fs/2

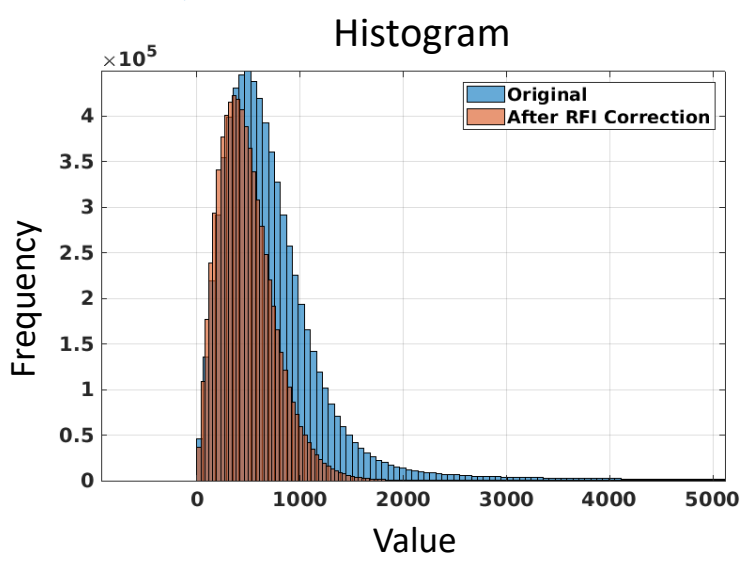
Range spectrum (f_s=62.5 MHZ)

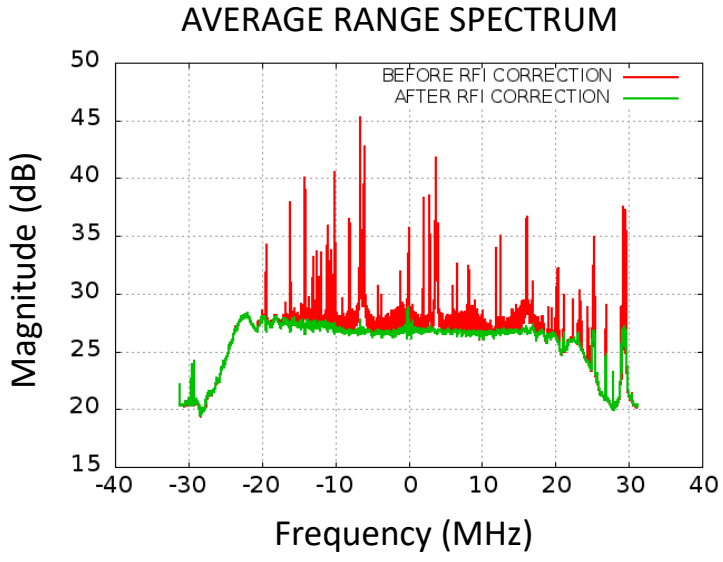


RFI Mask (using Receive only mode)

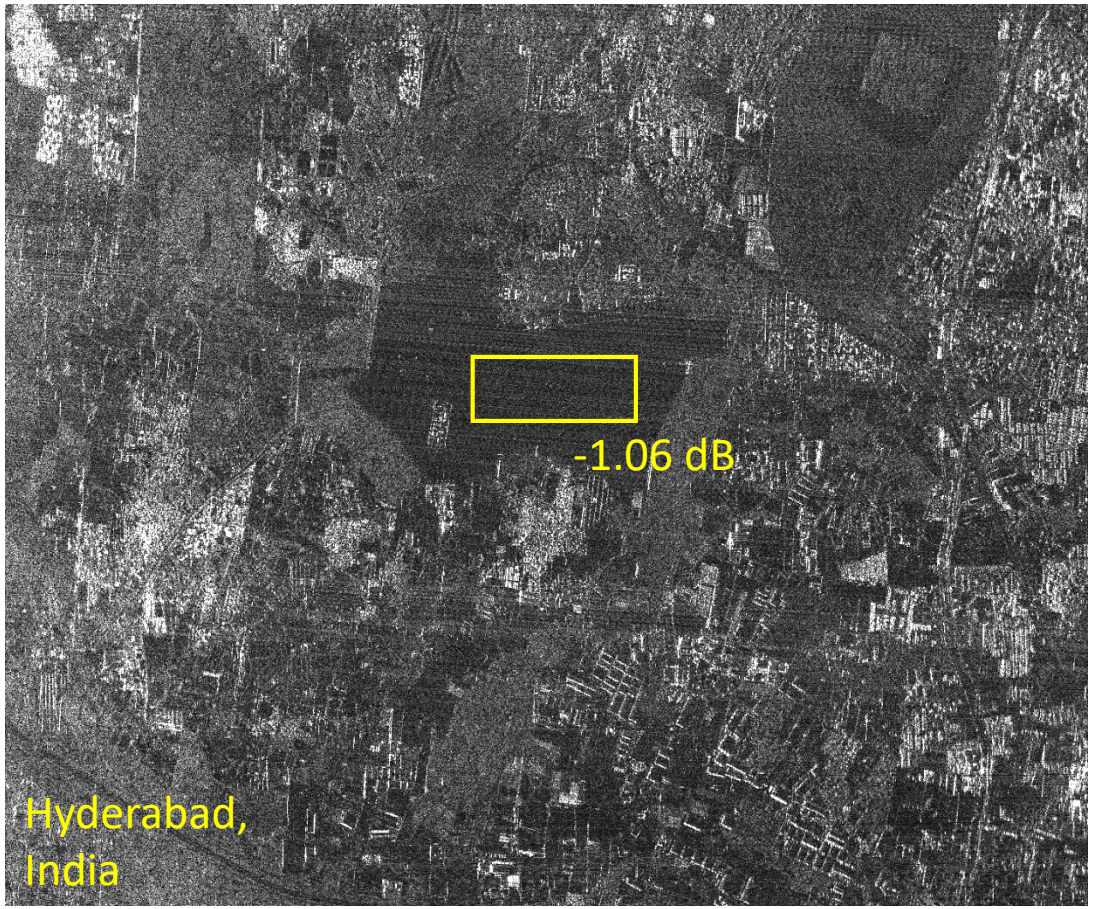


After RFI Suppression

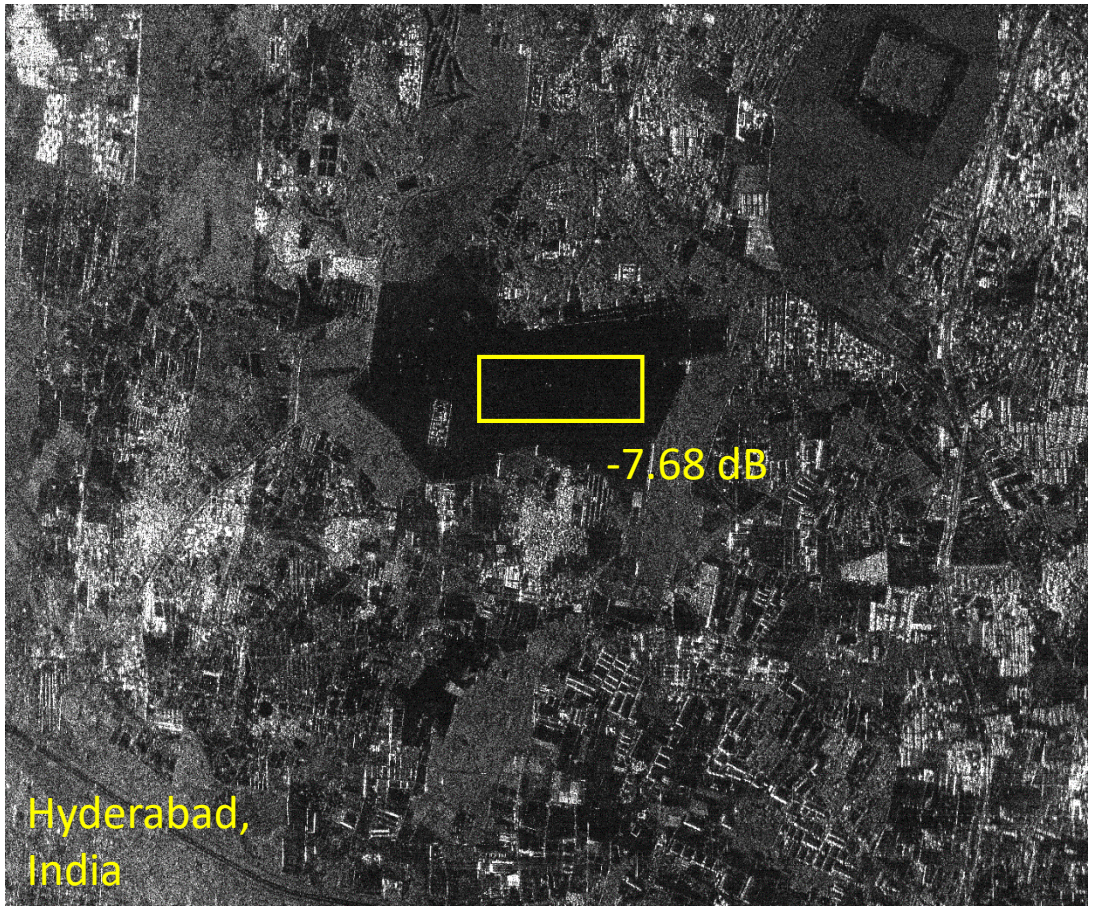




Impact on Processed Image



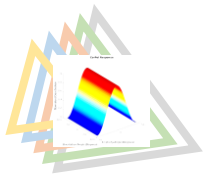
Before RFI Suppression



After RFI Suppression

Conclusion

- Depending on the source, RFI artifacts in range spectrum can manifest in the form of various patterns, e.g. random, systematic and localized signatures.
- RFI artifacts can vary randomly from one processed image to another depending on RFI characteristics in frequency domain.
- RFI suppression improves the sigma naught significantly in low SNR regions.
- RFI detection and suppression enhances the image contrast and overall image radiometry. Which further facilitates better target detection and image interpretability.
- In PSAR, some cases a large part of spectrum is observed to be affected by RFI, the residual RFI remains after correction.
- It is imperative to suppress RFI to get good quality SAR images.



References

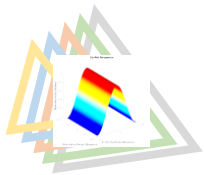
[1] Parikshit Parasher, K M Agrawal and V M Ramanujam, “Experiences of RFI Signatures in SAR Across Different Frequency Bands,” *2023 IEEE India Geoscience and Remote Sensing Symposium (InGARSS)*, Bangalore, India, 2023, pp. 1-4, doi: 10.1109/InGARSS59135.2023.10490334.

[2] Tobias Bollian et al., Detection and Geolocation of P-Band Radio Frequency Interference Using EcoSAR, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 11, NO. 10, October 2018.

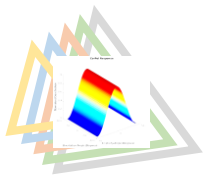
[3] Mingliang Tao et al., “Mitigation of Radio Frequency Interference in Synthetic Aperture Radar Data: Current Status and Future Trends”, *Remote Sens. 2019*, 11, 2438; doi:10.3390/rs11202438.

[4] Parikshit Parasher, Krishna M Agrawal and V M Ramanujam, “RFI detection and mitigation in SAR data,” 1-4. *10.23919/URSIAP-RASC.2019.8738633*, March 2019.

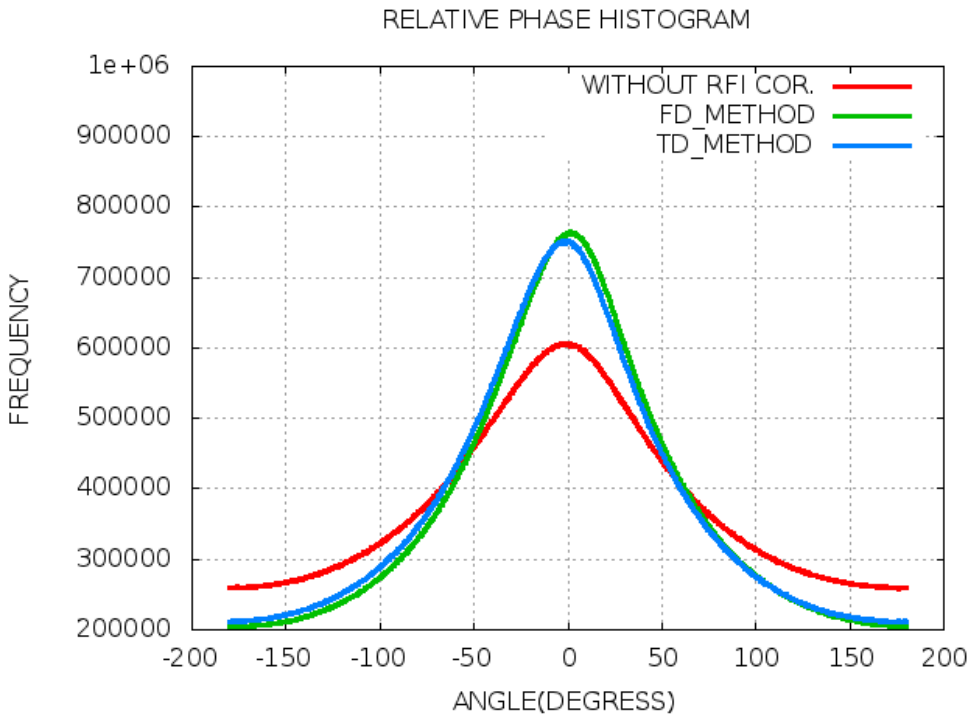
[5] F. J. Meyer, J. Nicoll, and A. P. Doulgeris, “Correction and Characterization of Radio Frequency Interference Signatures in L-Band Synthetic Aperture Radar Data,” IEEE Transactions on Geoscience and Remote Sensing, Vol. 51, No. 10, October 2013.

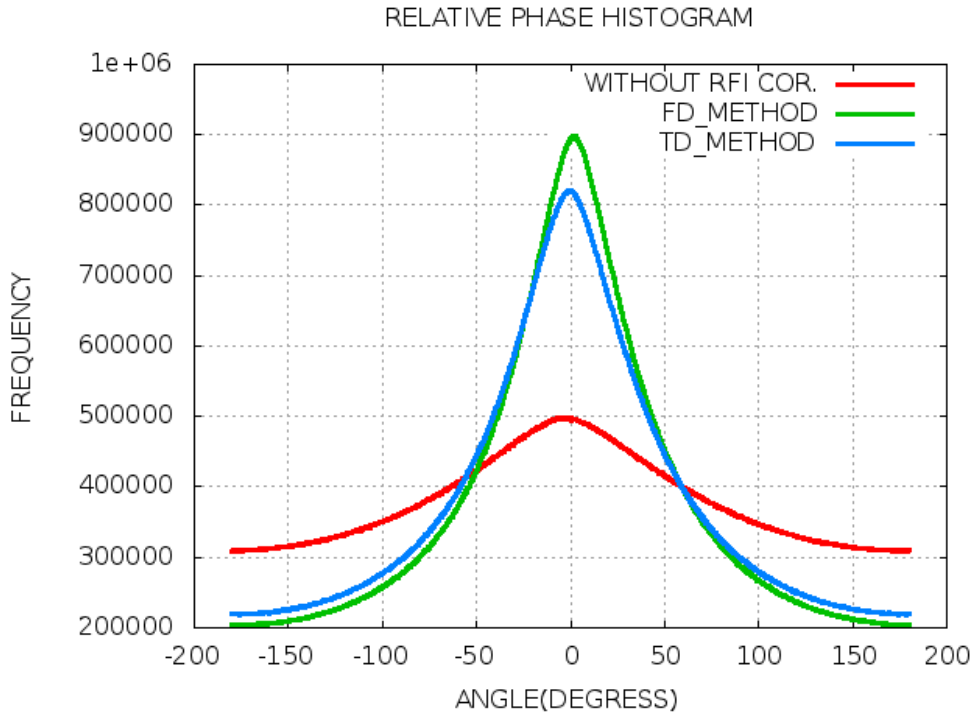


THANK YOU



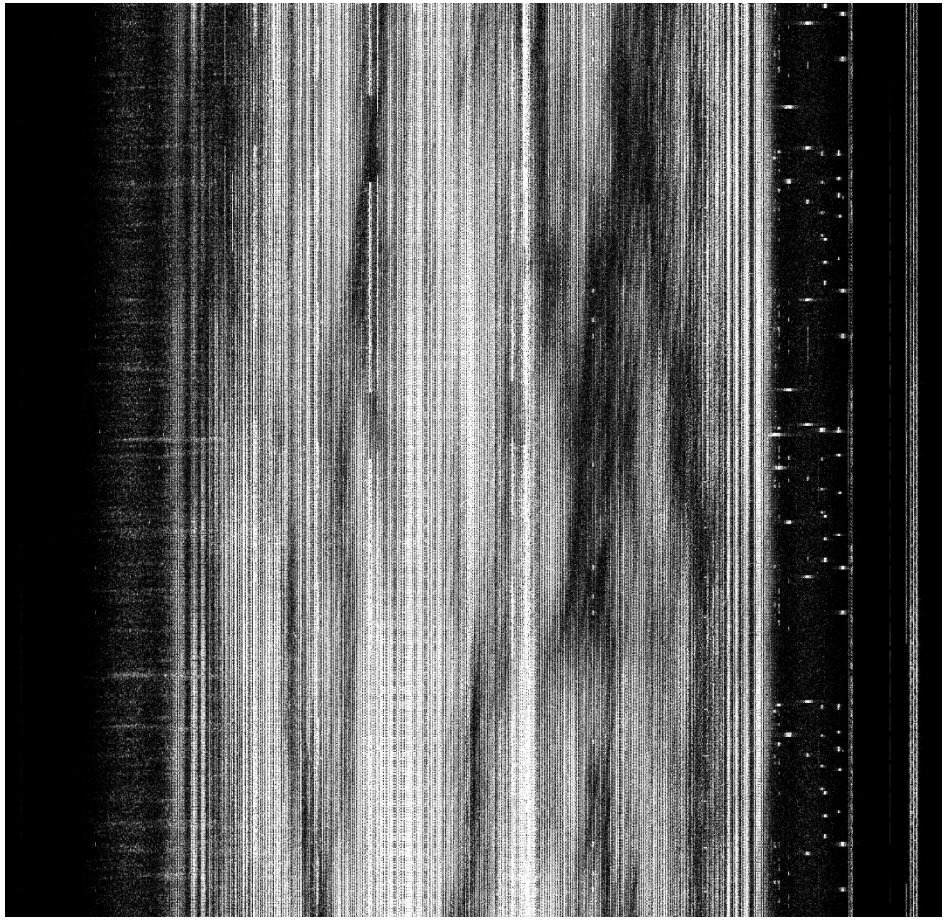
IMPACT ON RELATIVE PHASE (L and S band airborne SAR)





Data ID	Channel	Without RFI cor.	TD method	FD method
1702 (Rosamund)	HH, VV	0^0	2^0	-0.9^0
	HV, VH	0^0	0.8^0	-2.6^0
30510 (Palisade glacier)	HH, VV	0^0	1.1^0	-1.1^0
	HV, VH	0^0	0.5^0	1.1^0
Peak Values of Relative phase histogram				

Severe case of RFI



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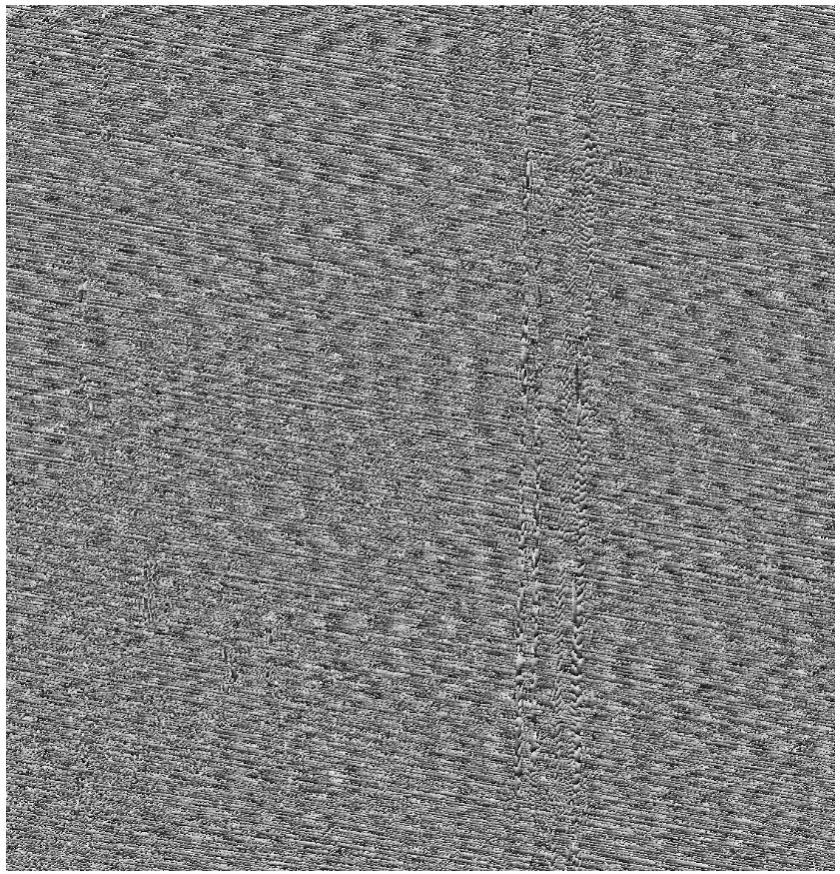
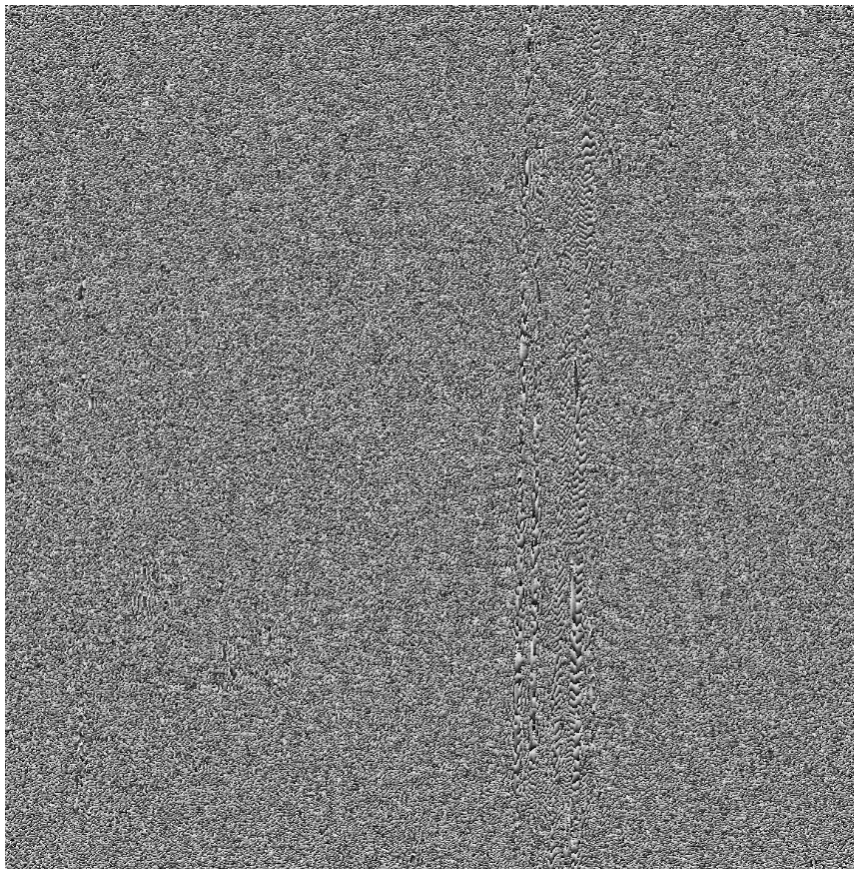
Range spectrum (f_s=62.5 MHZ)

P-Band Airborne SAR (Jain University)



Phase image (Before RFI Correction)



Phase image (After RFI Correction)