DIGITAL BEAMFORMING BASED RFI MITIGATION FOR SYNTHETIC APERTURE RADAR

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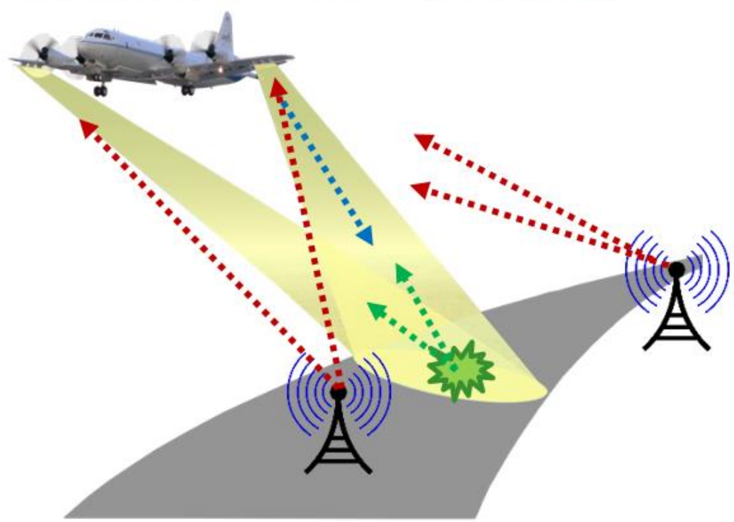
Motivation

What is the problem?

- Definition **Radio Frequency Interference**:

> Radio frequency interference is the conduction or radiation of radio frequency energy that causes an electronic or electrical device to produce noise that typically interferes with the function of an adjacent device.

SAR transmits signal and measures:
- signal reflection from ground targets (wanted)
- signals of other RF instruments (unwanted)

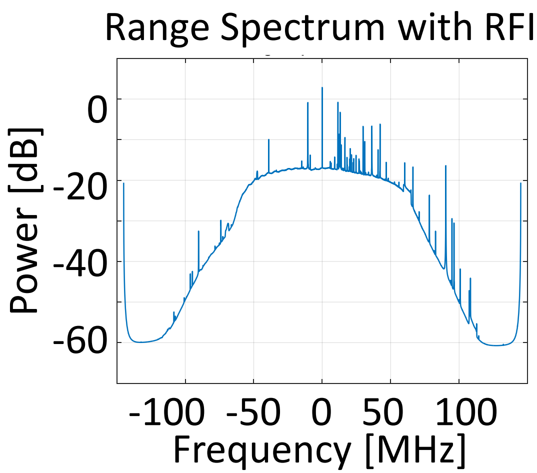


- Frequency spectrum is limited resource and shared with other users

Motivation

What has been done so far?

- **Notching:**



+ Fast processing
- Loss of SAR signal
- Distortion of Impulse Response Function (IRF)

- **Coherent Subtraction:**

  1. Modelling of RFI based on *a priori* information
  2. Coherent subtraction from data

+ No distortions
+ SAR signal preserved
- Depends on model and RFI

- **Filtering:**

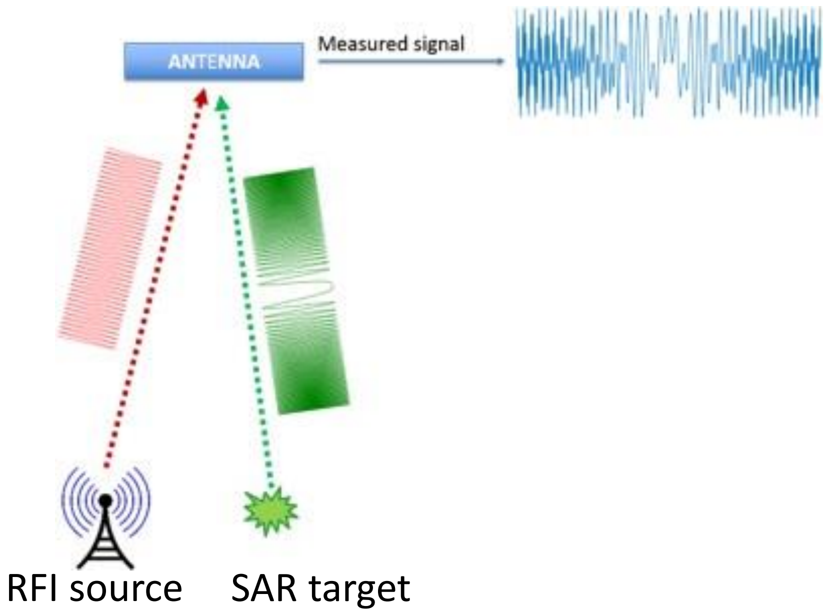
  e.g. Adaptive Least Mean Square Filter

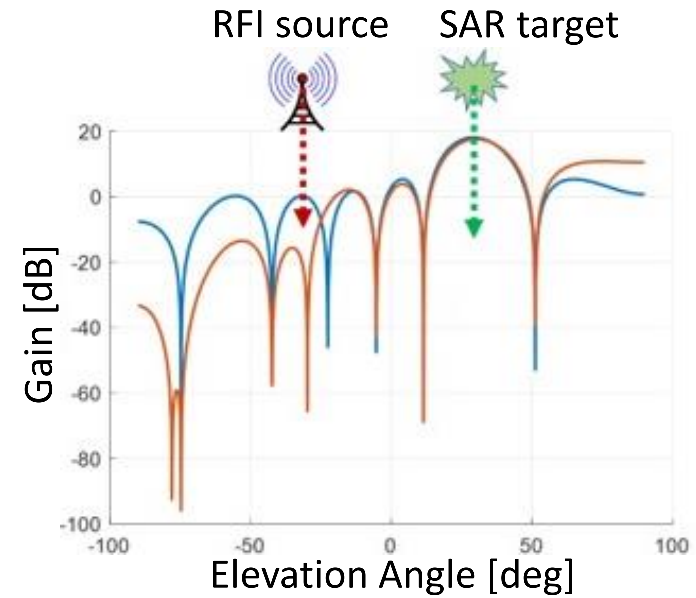
+ No distortions
+ SAR signal preserved
- Depends on filter parameters and on SAR-RFI-Ratio

Can we use Digital Beamforming to suppress RFI?

Digital Beamforming

The idea





Antenna pattern (AP) before (blue) and after (orange) notching RFI

- SAR and RFI signal overlap at antenna → indistinguishable after antenna
- Spatial filtering of interferences with antenna pattern before overlapping
- Direction of RFI estimated from data after receive → digital beamforming

What are the limitations and assumptions?

Digital Beamforming

Limitations and assumptions

Limitations

- An array with N active channels can only notch up to N-1 directions
- RFI from the same angular direction as the instantaneous SAR signal **can not** be separated and remains in image (conventional filtering necessary, e.g. blanking out)

Assumptions

- Received signal is neither saturated nor at non-linear operating point

How can we automatically notch RFI?
How many RFI sources can we notch for given N?
How well can we notch RFI inside the swath?

Automatic RFI Notching

MVDR Beamformer

The Minimum Variance Distortionless Response (MVDR) Beamformer that maximizes SINR is subject to

$$w^H a(\theta_d) = 1$$

$$\min w^H R w$$

w: steering weights
$a(\theta)$: steering vector
θ_d: desired signal direction
R: Interference-Noise-Covariance (INC) Matrix

and has the optimal solution

$$w = \frac{R^{-1} a(\theta_d)}{a(\theta_d)^* R^{-1} a(\theta_d)}$$

Problem: we can only estimate sample covariance that contains SAR signal

Automatic RFI Notching

INC Estimation

The Capon Power Spectrum estimates the signal power arriving from a certain angular direction

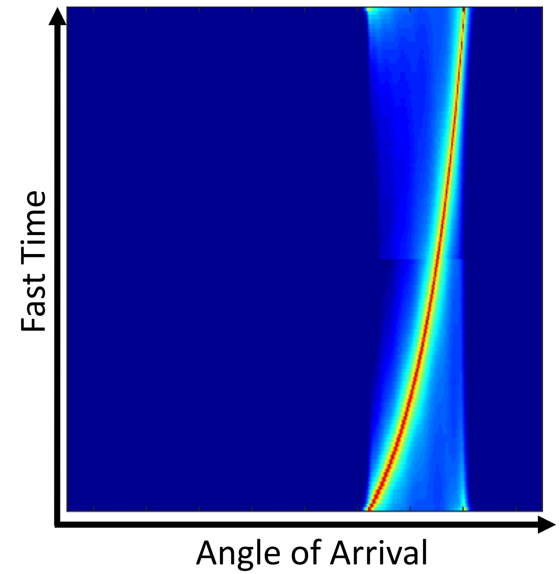
$$P(\theta) = \frac{1}{a^H(\theta) {R_S}^{-1} a(\theta)}$$

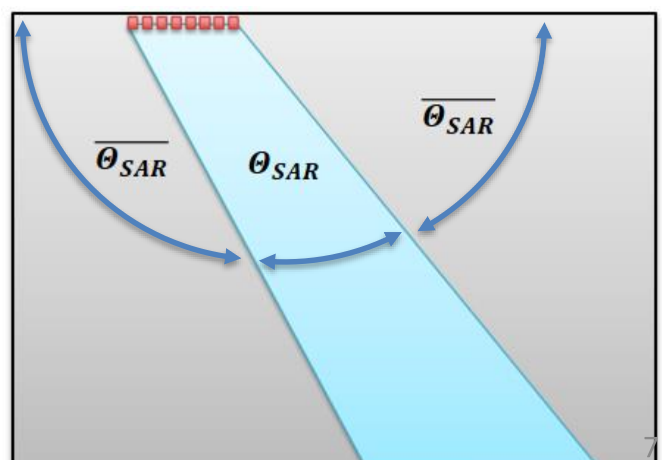
R_S: Sample Covariance Matrix

The INC in the presence of the SAR signal is estimated by integrating steering vector covariances weighted by the respective Capon Power Spectrum

$$R = \int_{\overline{\Theta_{SAR}}} \frac{a(\theta) a^H(\theta)}{a^H(\theta) {R_S}^{-1} a(\theta)} d\theta$$

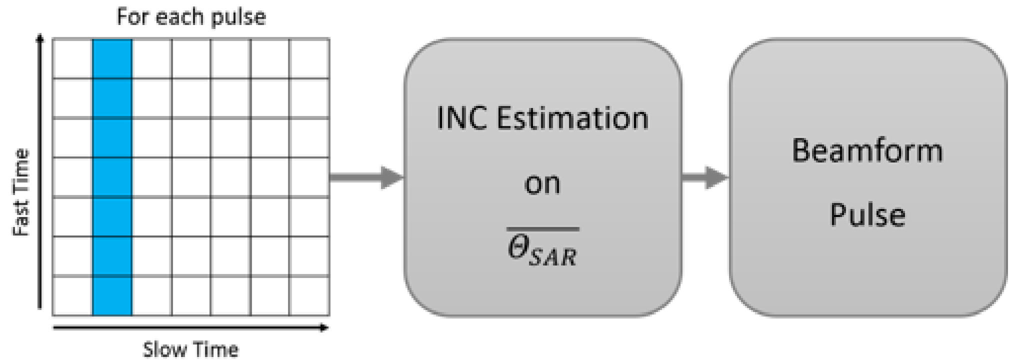
Capon Power Spectrum of Range-Compressed SAR signal



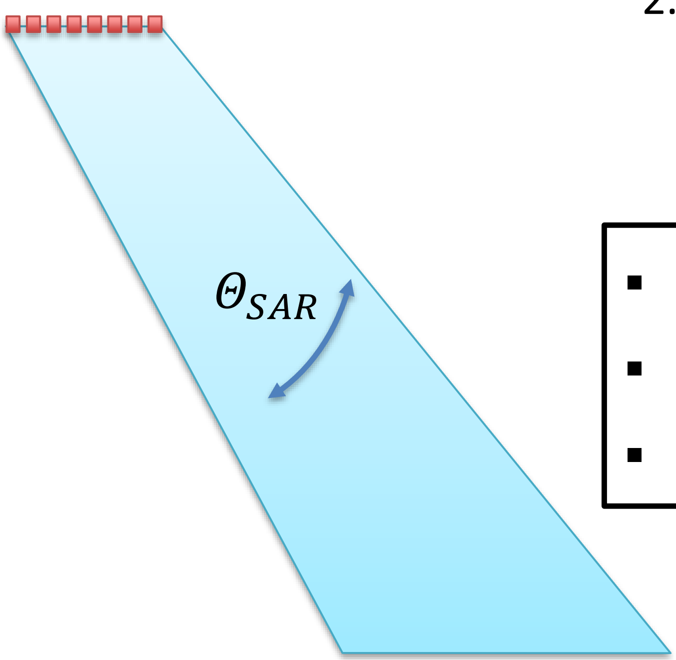


Adaptive Notching

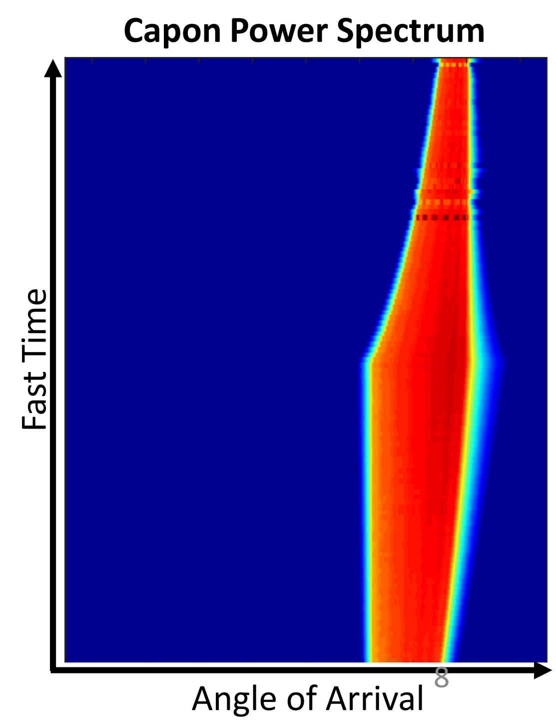
Pulse-Wise



1. Estimate INC for each pulse
2. Beamform with MVDR

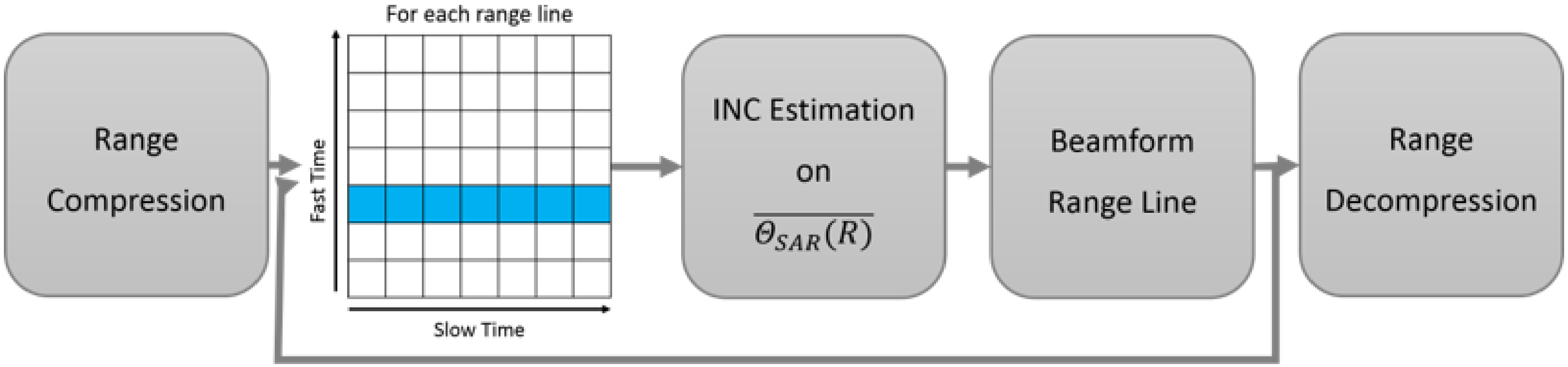


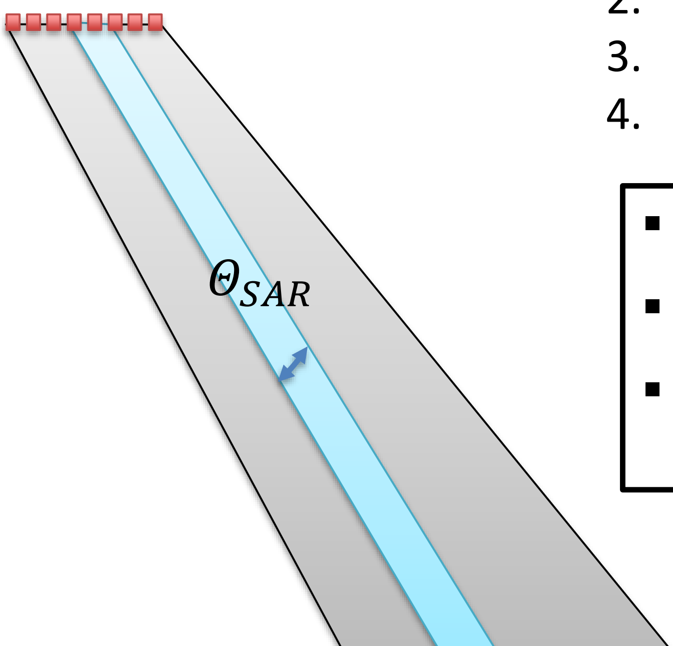
- **No of Notches:** N-1, fixed
- **Blindspot:** pulse extent
- **Advantage:** Fast



Adaptive Notching

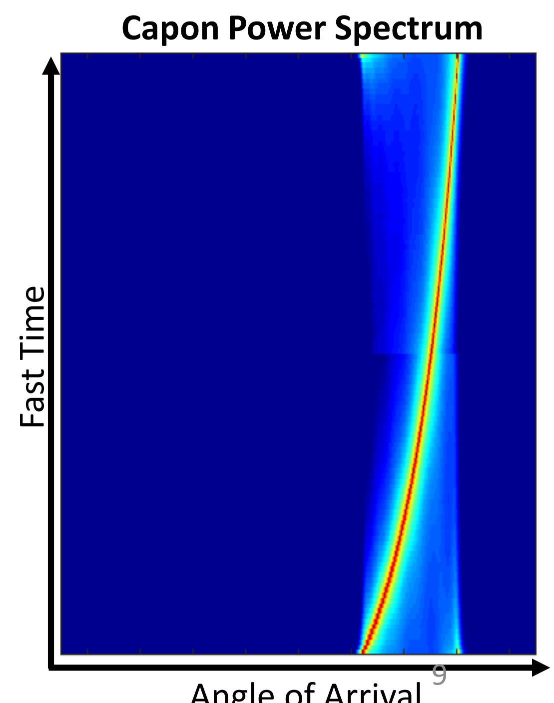
Range-Dependent Time MVDR





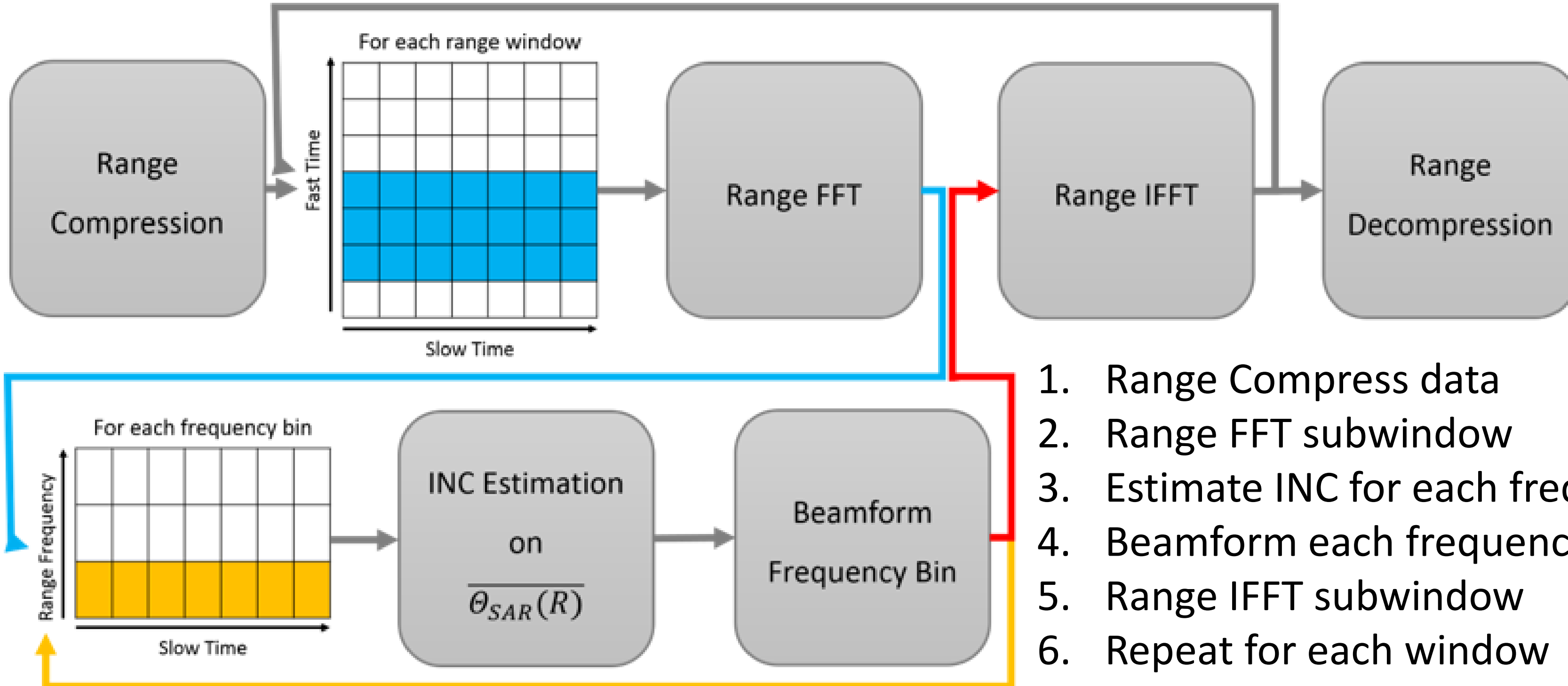
1. Range Compress data
2. Estimate INC for each range line
3. Beamform with MVDR
4. Range Decompress data

▪ **No of Notches:**	N-1 per range
▪ **Blindspot:**	IRF resolution
▪ **Advantage:**	decreased blindspot



Adaptive Notching

Range-Dependent Frequency MVDR



1. Range Compress data
2. Range FFT subwindow
3. Estimate INC for each frequency
4. Beamform each frequency
5. Range IFFT subwindow
6. Repeat for each window
7. Range Decompress data

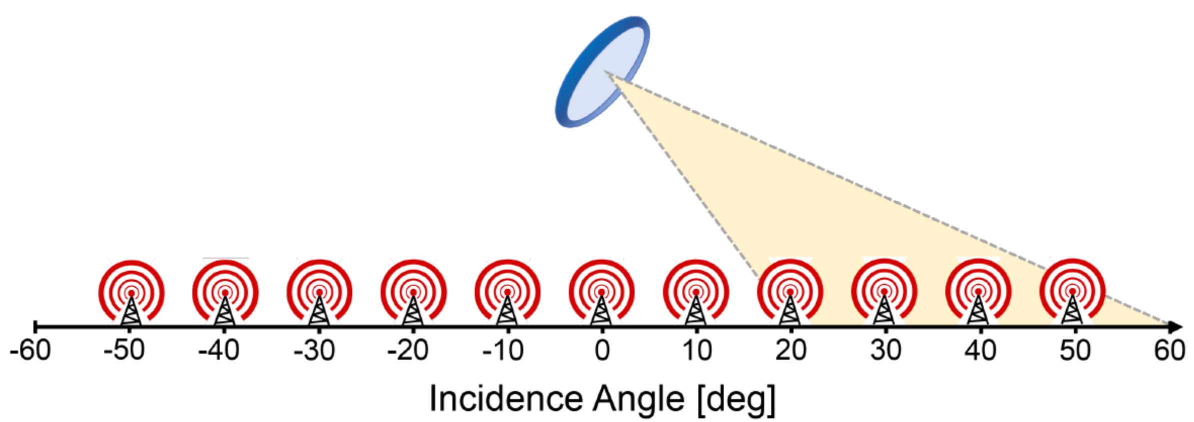
- **No of Notches:** N-1 per range and frequency bin
- **Blindspot:** IRF resolution of subwindow
- **Advantage:** frequency dependent notching can improve performance at cost of processing power

Simulations

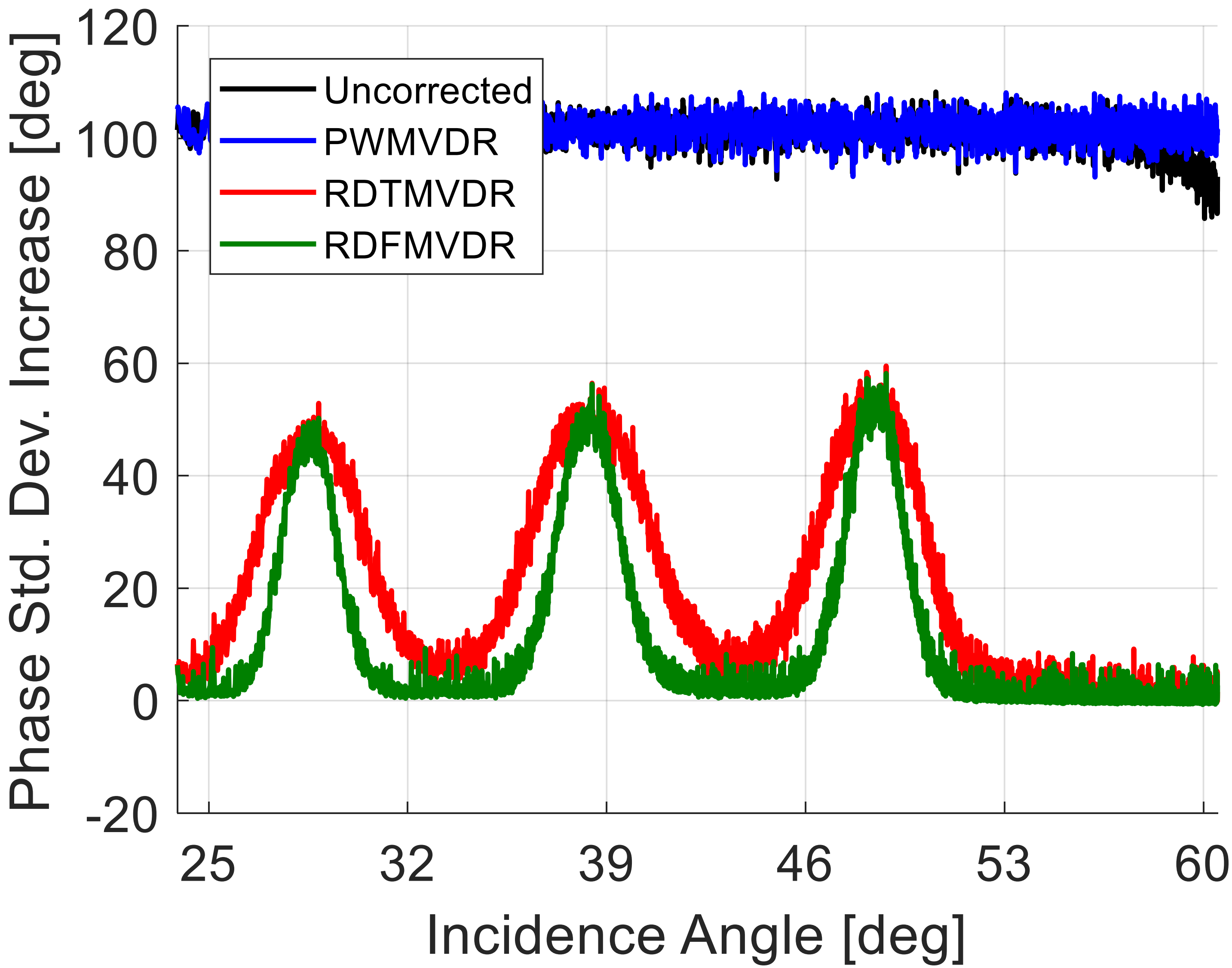
Airborne SAR Parameters

Number of antenna elements N	2 - 64
Antenna element separation d	0.5 wavelength
Center frequency f	435 MHz
Sampling frequency	290 MHz
Pulse Bandwidth	120 MHz
Pulse Duration	20 microseconds
SAR Target locations	21 to 60 deg

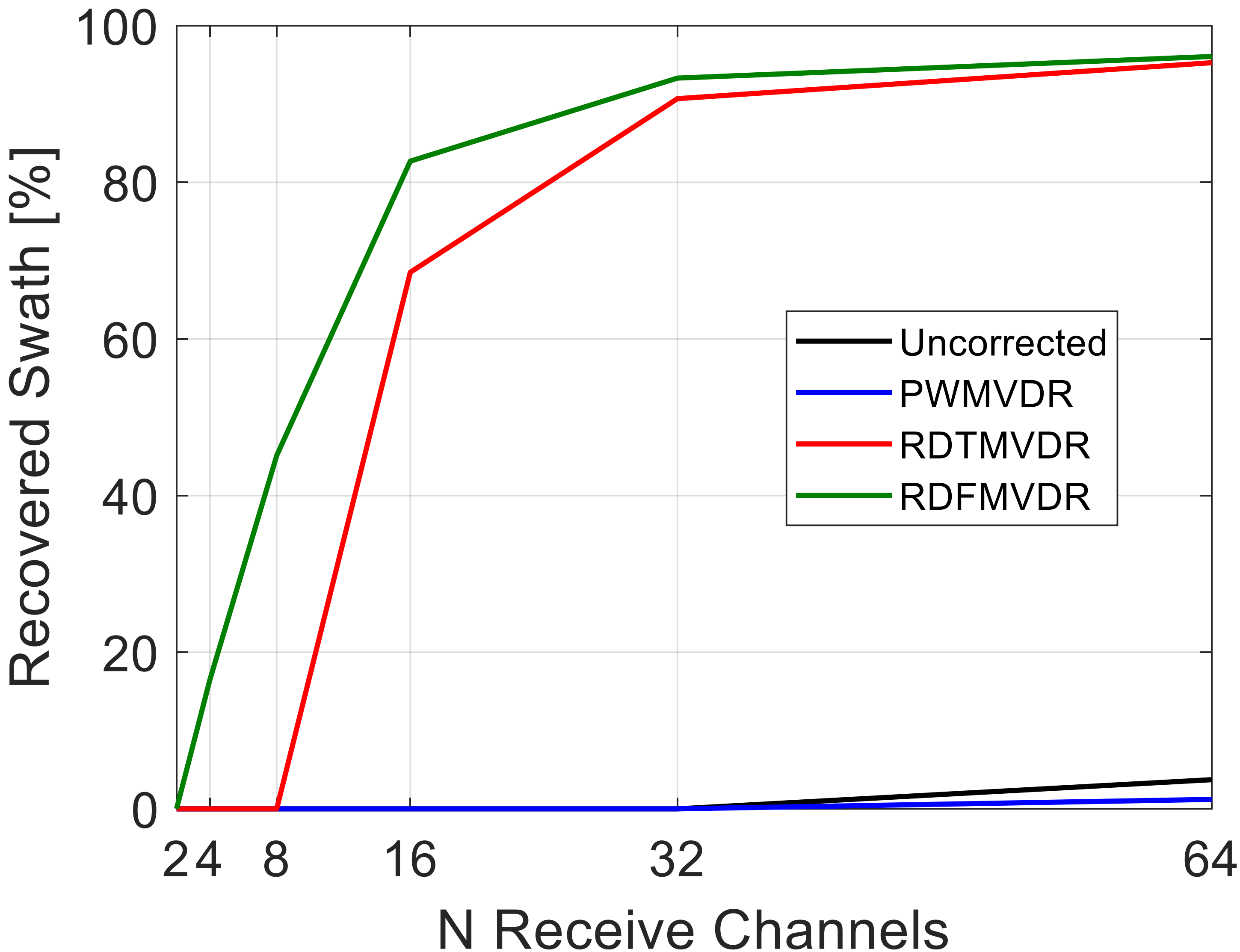
11 Interferers from -50deg to +50deg, 10 degree spacing, f=375MHz to 425MHz with 5MHz spacing



N = 16, RFI-Noise-Ratio = 40 dB



Percentage of Swath Recovered

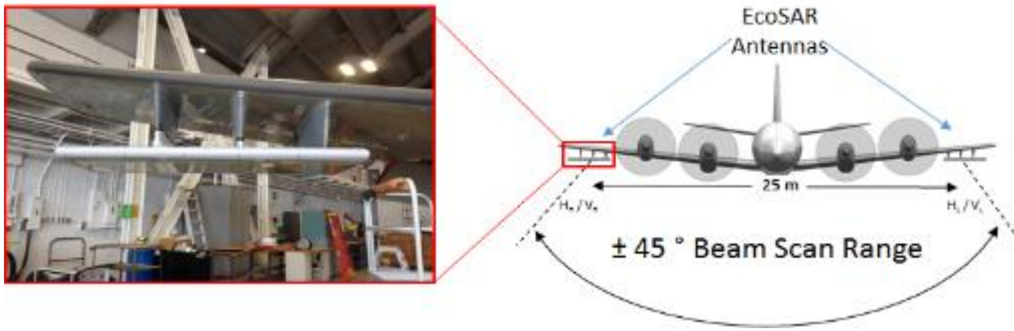


About EcoSAR

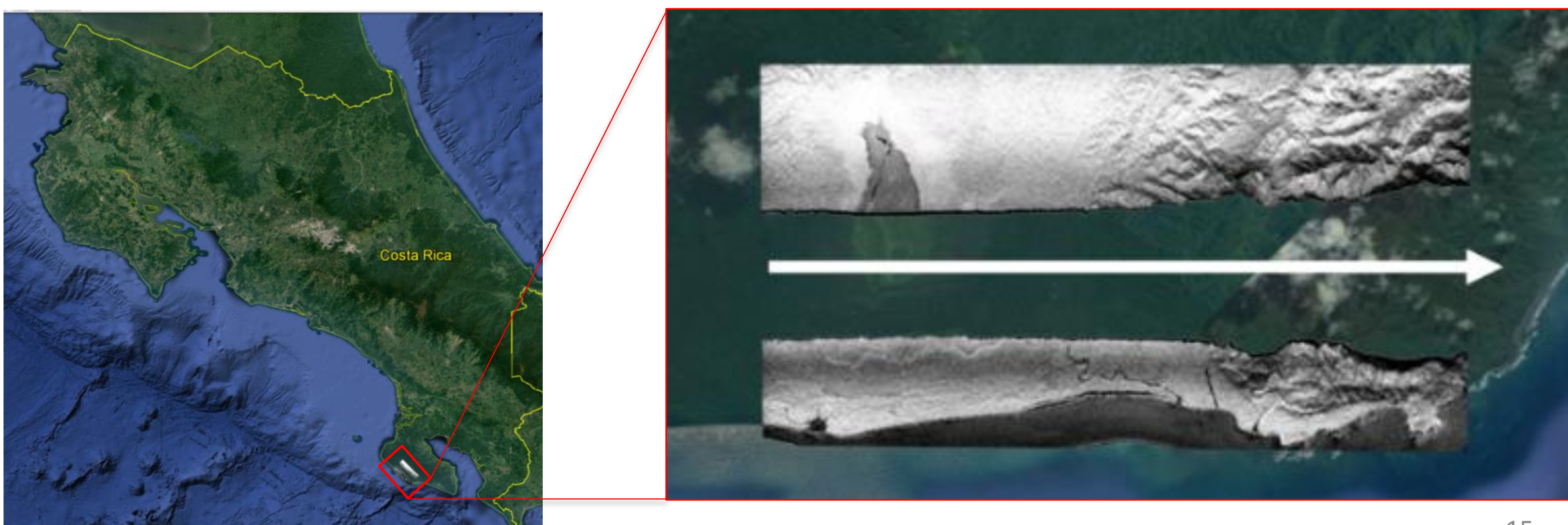
- Two fully polarimetric, nadir-looking antennas (one per wing) for single-pass interferometry
- 32-channel (8 elements, 2 antennas, 2 polarizations)
- Beamforming architecture enables across-track scanning with customized Tx and Rx beams over a range of +-45 degrees.

Center Frequency	435 MHz	**Pulse Length**	1 usec – 50 usec
Maximum Bandwidth	200 MHz	**Array Peak Power**	40 Watts
Polarization	HH, VV, VH,HV	**PRF**	100 Hz – 10 KHz
Polarization Isolation	> 30 dB	**Swath**	4 km – 8 km
NESZ	- 41 dB	**Finest Range Resolution**	0.75 m
Total Number of active Channels	32	**Single Look Azimuth Resolution**	0.5 m
Interferometric baseline	25 m	**Vertical Accuracy**	~ 1 m

Application to measured EcoSAR data

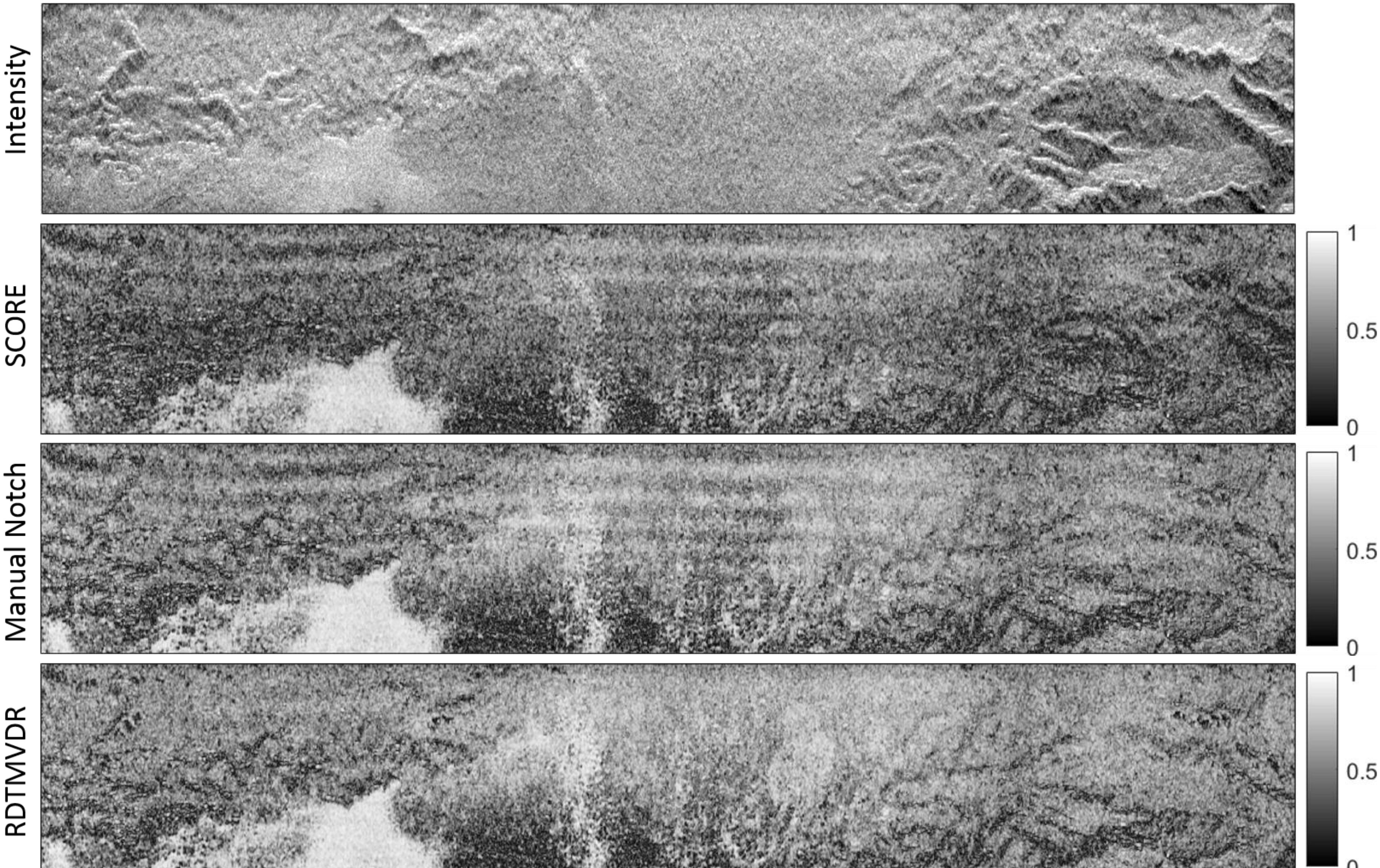


Center Frequency	479MHz
Bandwidth	20MHz
Pulse Length	10usec
PRF	690Hz
Physical Baseline	25m
Polarization	HH
Antenna Elements	8
Antenna Spacing	29cm



Application to measured EcoSAR data

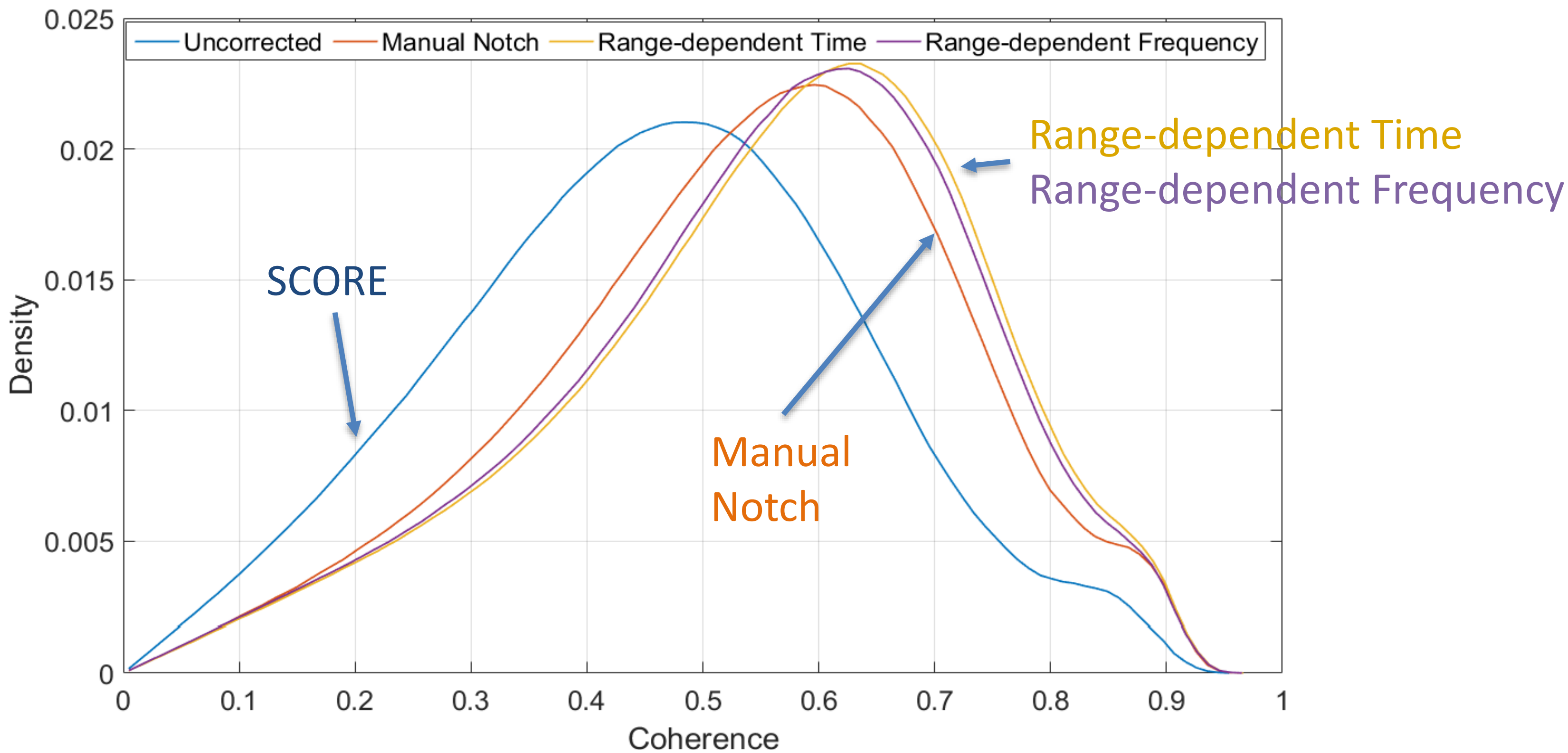
Intensity and coherence images for different antenna patterns



SCORE: Scan-on-Receive only, **Manual Notch:** Placement of wide notch at negative steering angle, **RDTMVDR:** Range-Dependent Time MVDR

Application to measured EcoSAR data

Histogram peak shifts from 0.48 (uncorrected) to 0.62 (RDTMVDR)



Conclusion

- Spatial distribution of SAR signal that is inherent to imaging geometry can be used to notch RFI with DBF
- Range Dependent Frequency MVDR showed best performance in simulations (e.g. interferers in swath)
- Performance of Range Dependent Time MVDR similar for RFI Mitigation in EcoSAR data

Outlook

- Multiple azimuth channels can utilize spatial SAR signal distribution in range-doppler domain