On-Board RFI Detection in Synthetic Aperture Radar using Digital Beamforming

RFI 2022 Workshop – February 14th, 2022

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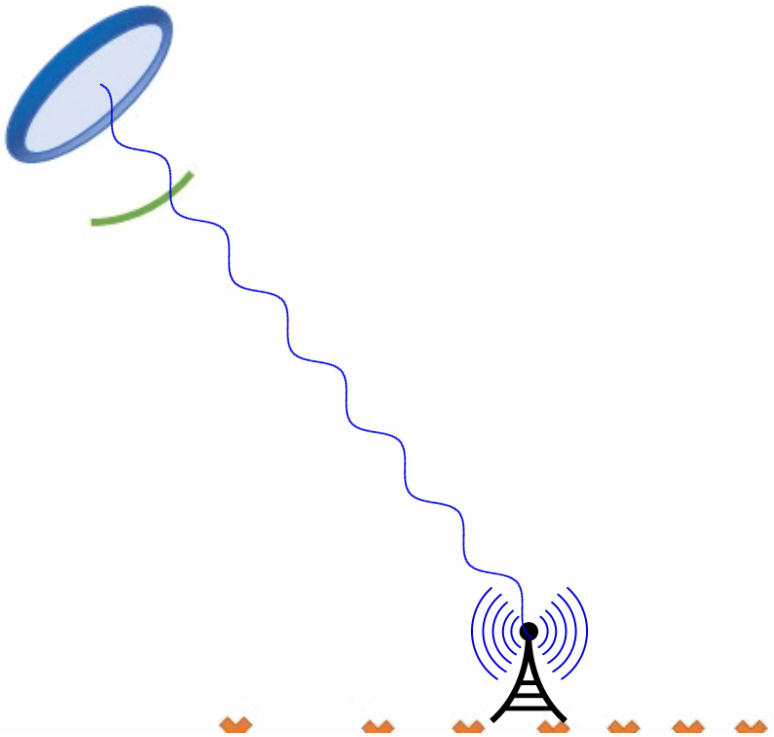
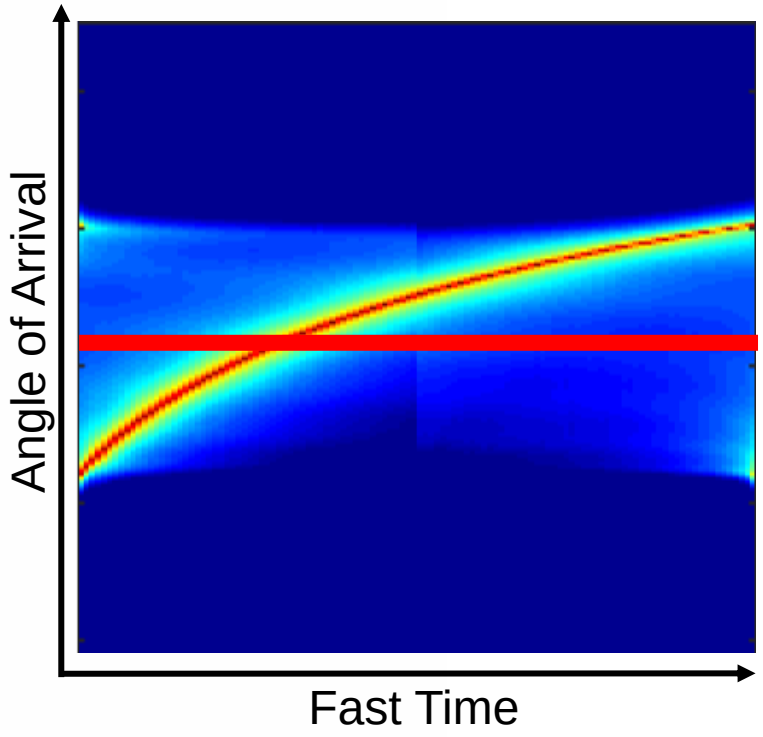
Spatial Distributions of Signals in Synthetic Aperture Radar

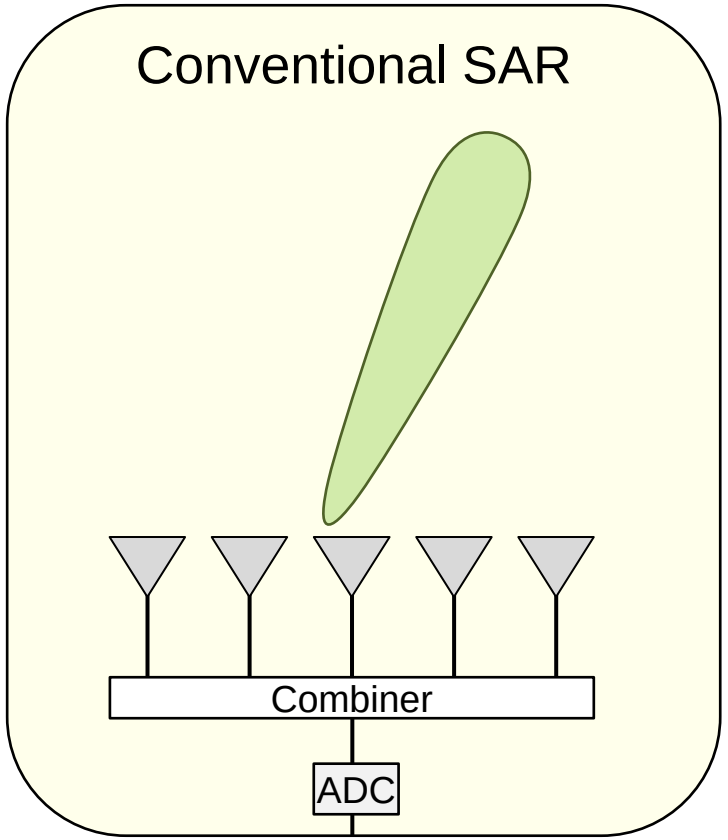
- Active system → transmission of own signal
- Receive time of echo return depends on target position

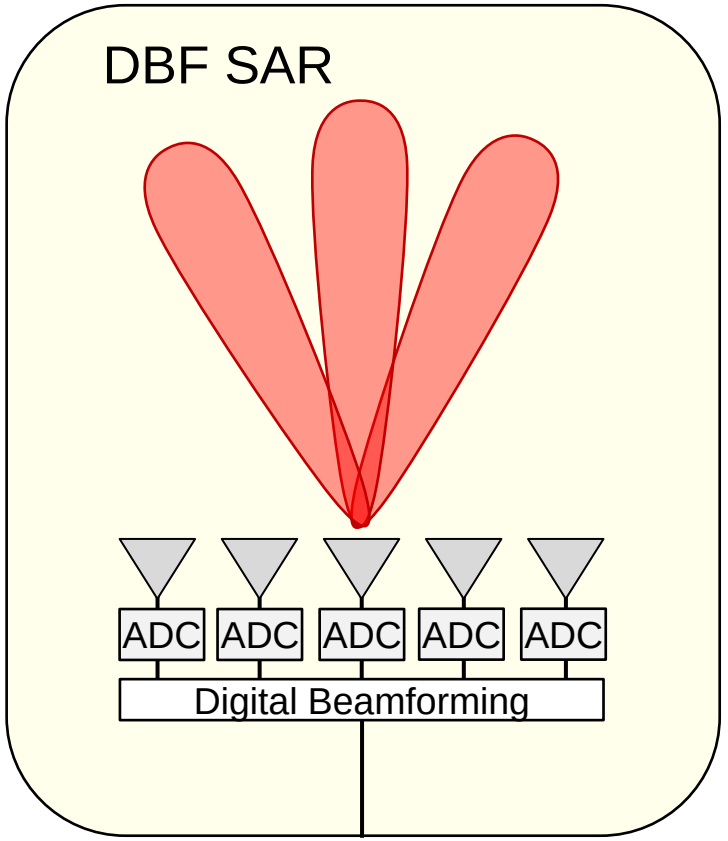


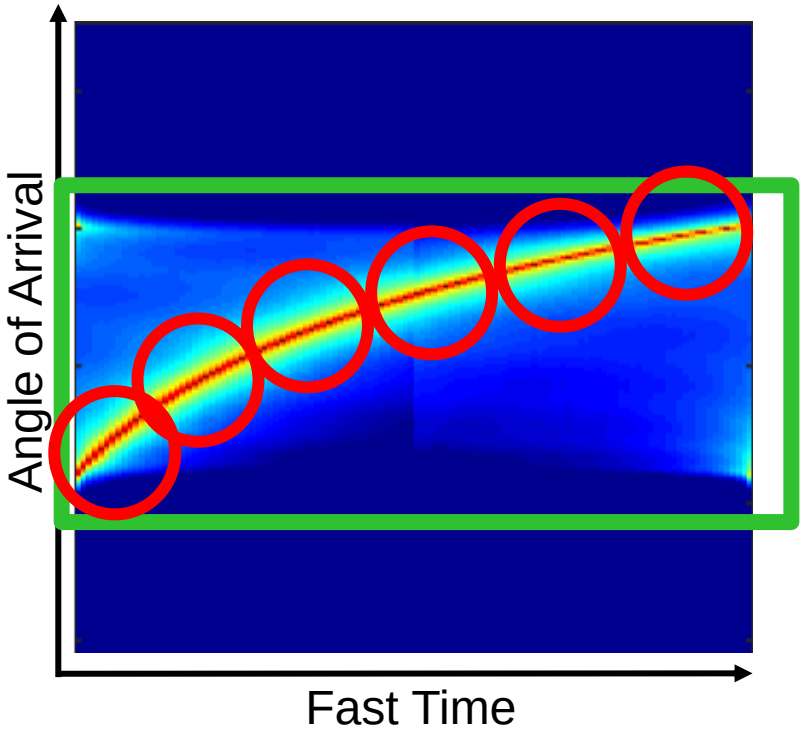


→ RFI source and SAR signal spatially overlap only temporarily

Spatial Filtering in Future Digital Beamforming SAR Systems







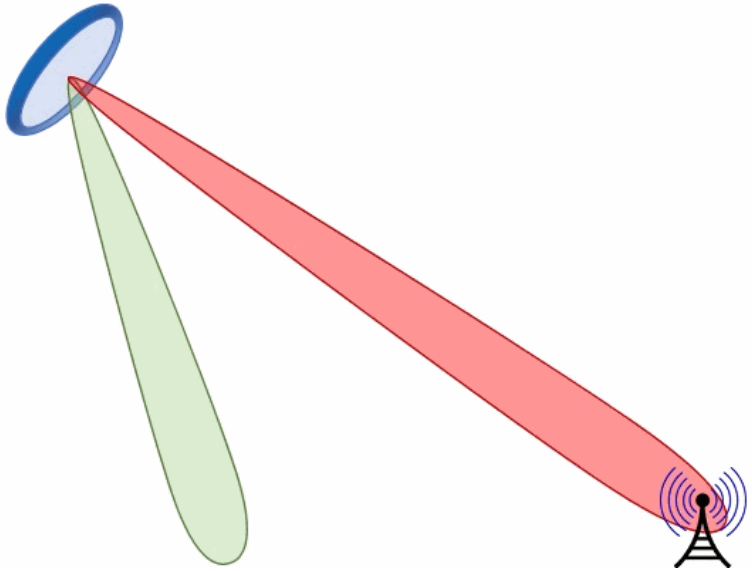
Measuring and Estimation of RFI with Auxiliary Beams

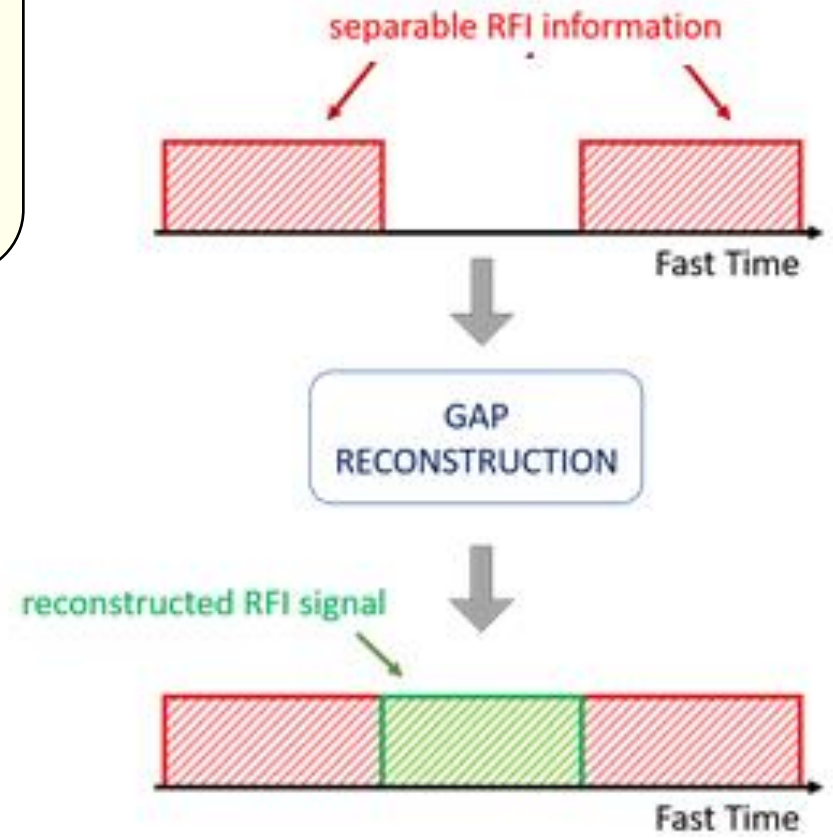
Simultaneous formation of auxiliary beam (red) with same antenna

→ Extraction of RFI information with high gain

→ Gives information about RFI in sidelobes of SAR beam

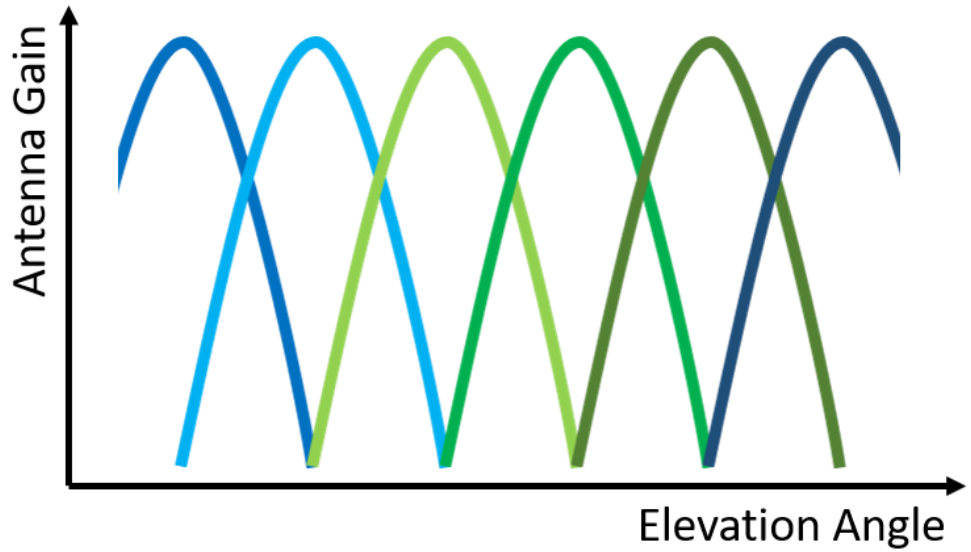
→ reconstruction of RFI in main beam under certain conditions





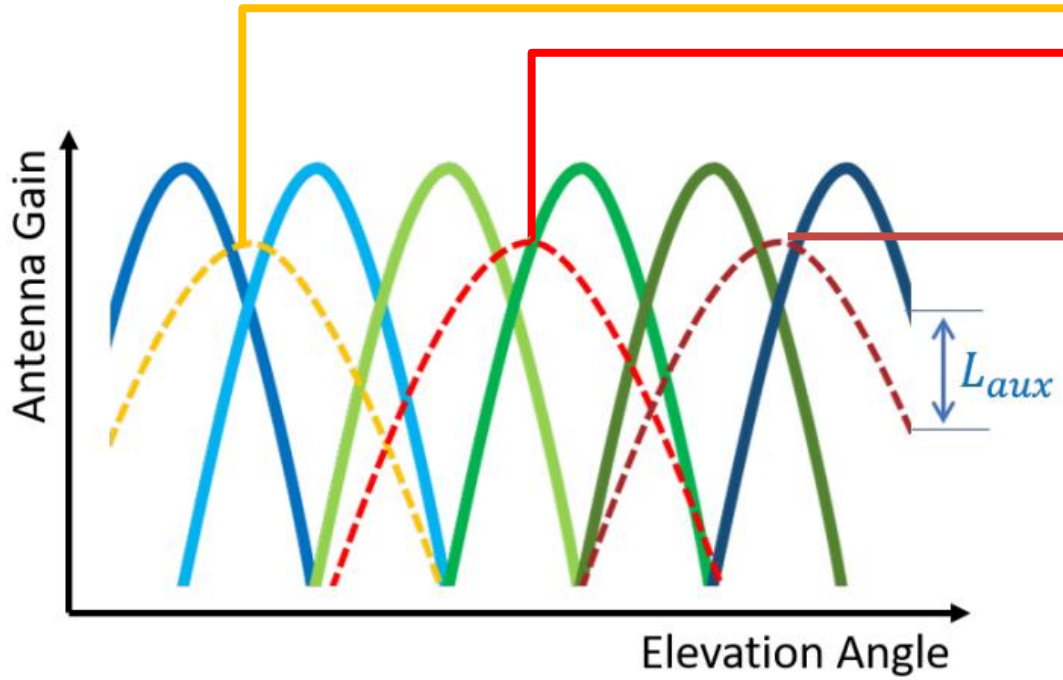
→ Requires on-board RFI detection and angle-of-arrival estimation

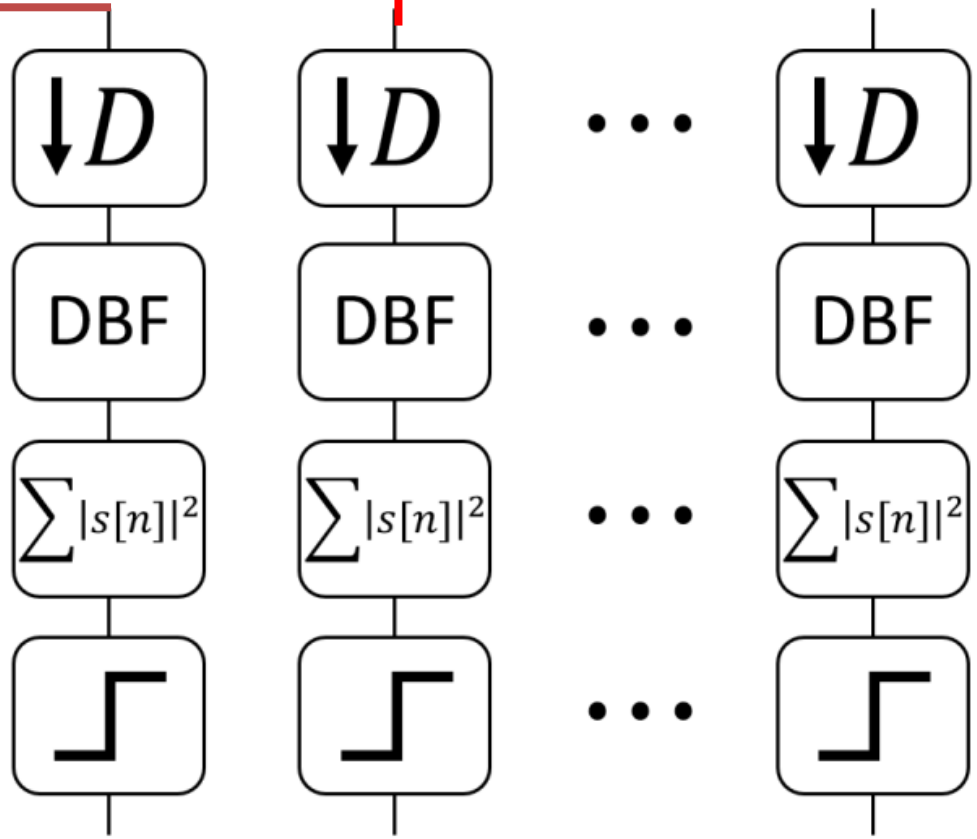
On-Board Implementation of Scan-On-Receive



- Sequential activation of pre-computed SCORE beams
- Scanning across ground

A Series of Digital Square-Law Detectors



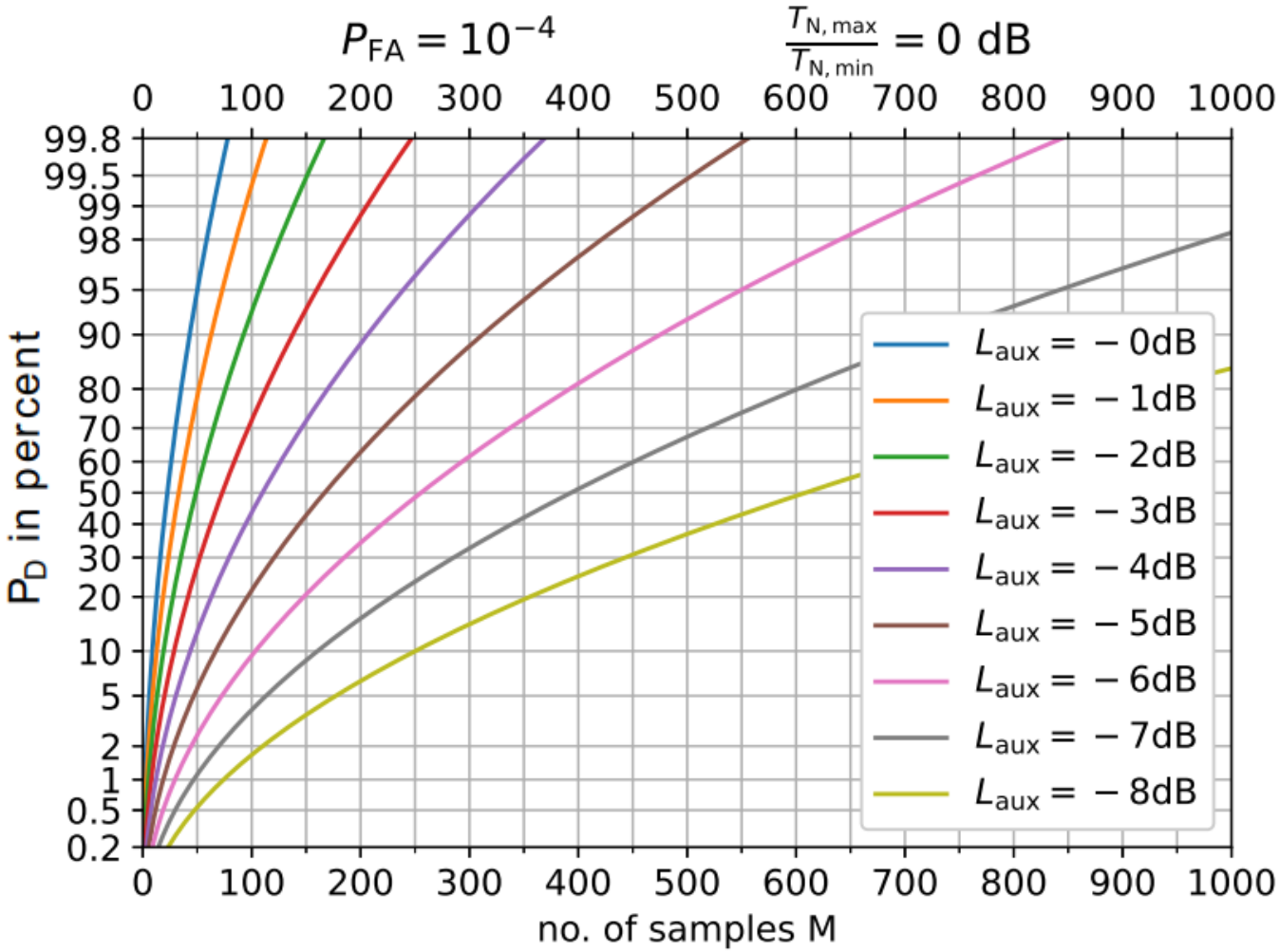


- Selected auxiliary beams measuring different directions (with notch towards instantaneous SAR signal)
- Trade-off: number of beams ←→ sensitivity loss
- Detection on decimated data stream

Theoretical Detection Performance – Constant Noise Floor

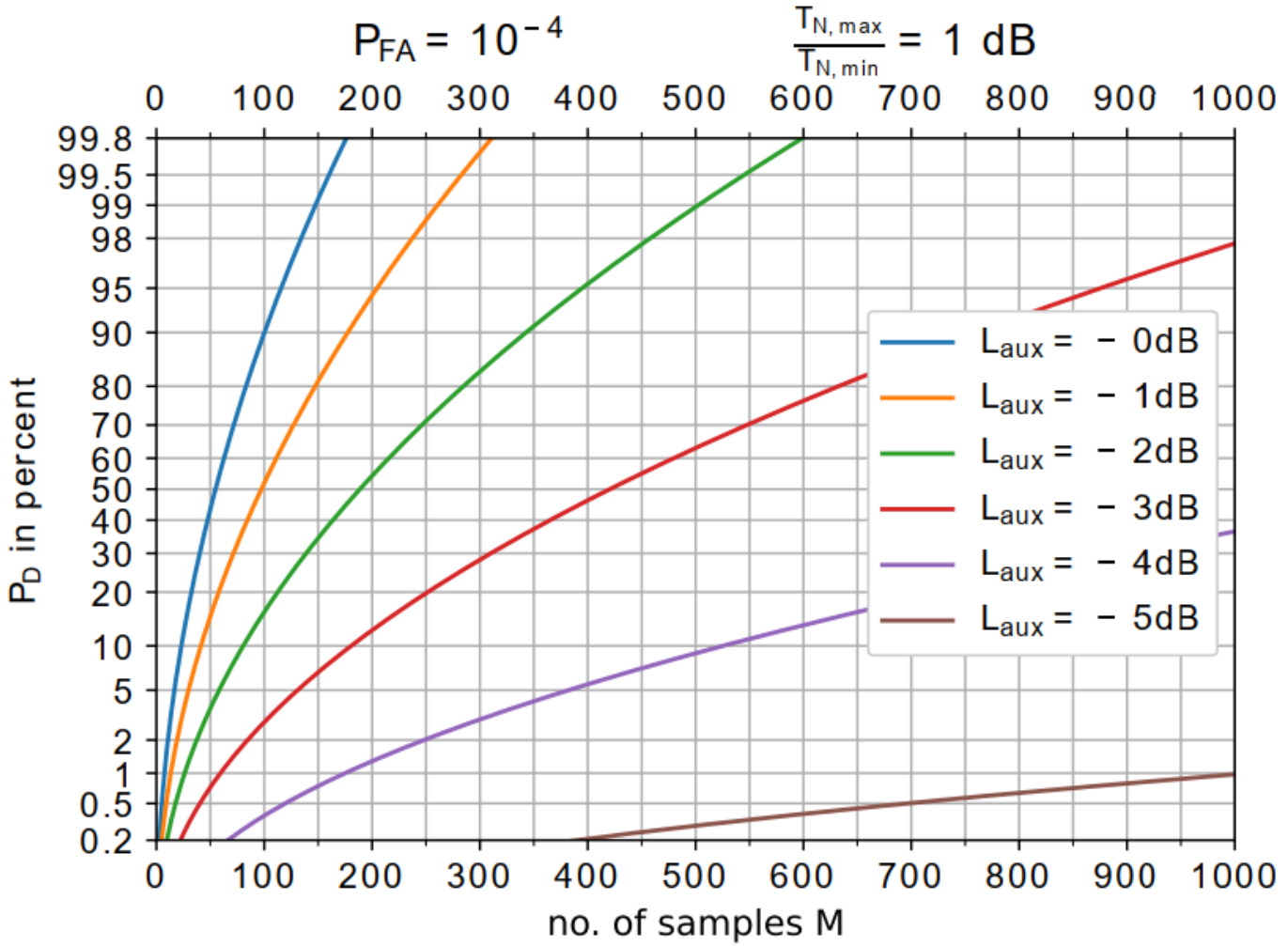
Assumption:
required detection of RFI above noise level
(interference-to-noise ratio > 0 dB)

$$P_{\mathrm{D}} = Q\left(\sqrt{2M\overline{\mathrm{INR}}}, \sqrt{2T}\right) + e^{-T-M\overline{\mathrm{INR}}} \cdot \sum_{r=2}^{M} \left(\frac{T}{M\overline{\mathrm{INR}}}\right)^{(r-1)/2} I_{r-1}\left(\sqrt{4TM\overline{\mathrm{INR}}}\right),$$



Theoretical Detection Performance – Variable Noise Floor

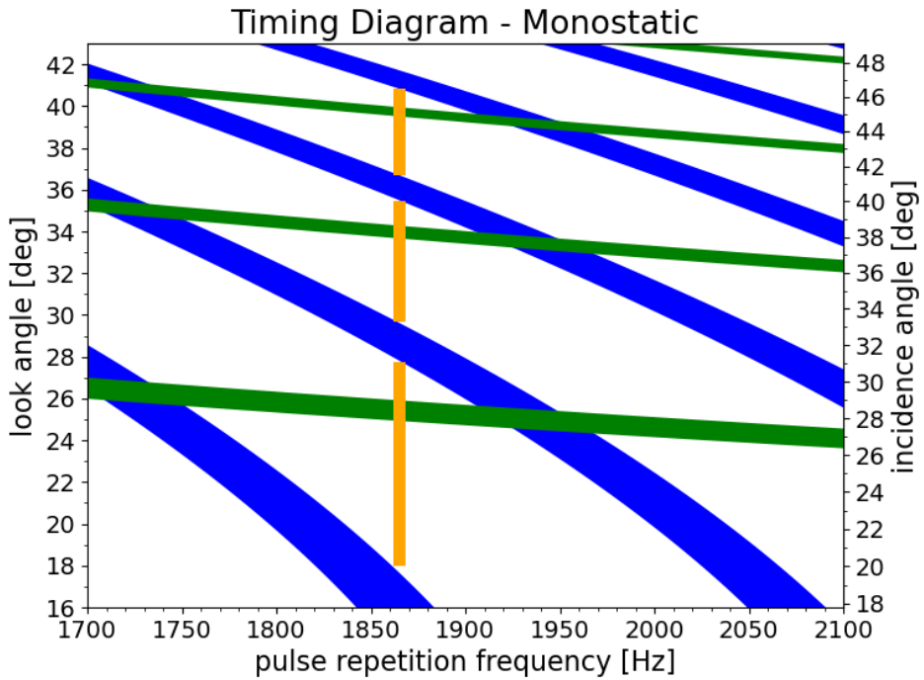
- Performance bias for uncertainties in noise floor
- Possible reasons:
  - variations in system temperature along orbit
  - variation of surface brightness
- Assumption: fluctuations of ± 0.5 dB as seen in [1]

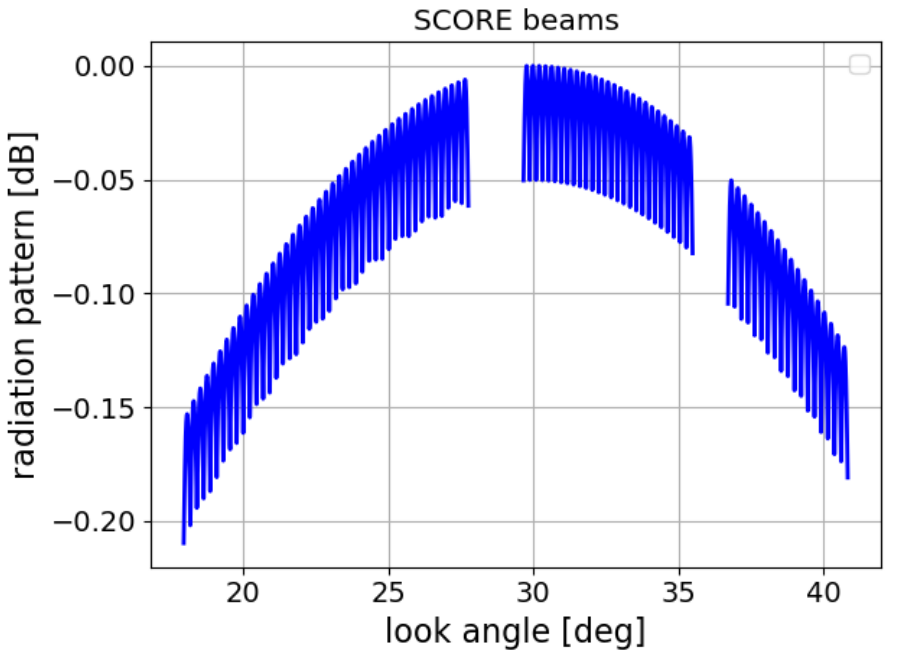


[1] Monti-Guarnieri, Andrea, Davide Giudici, and Andrea Recchia. **Identification of C-band radio frequency interferences from sentinel-1 data** Remote Sensing 9.11 (2017): 1183.

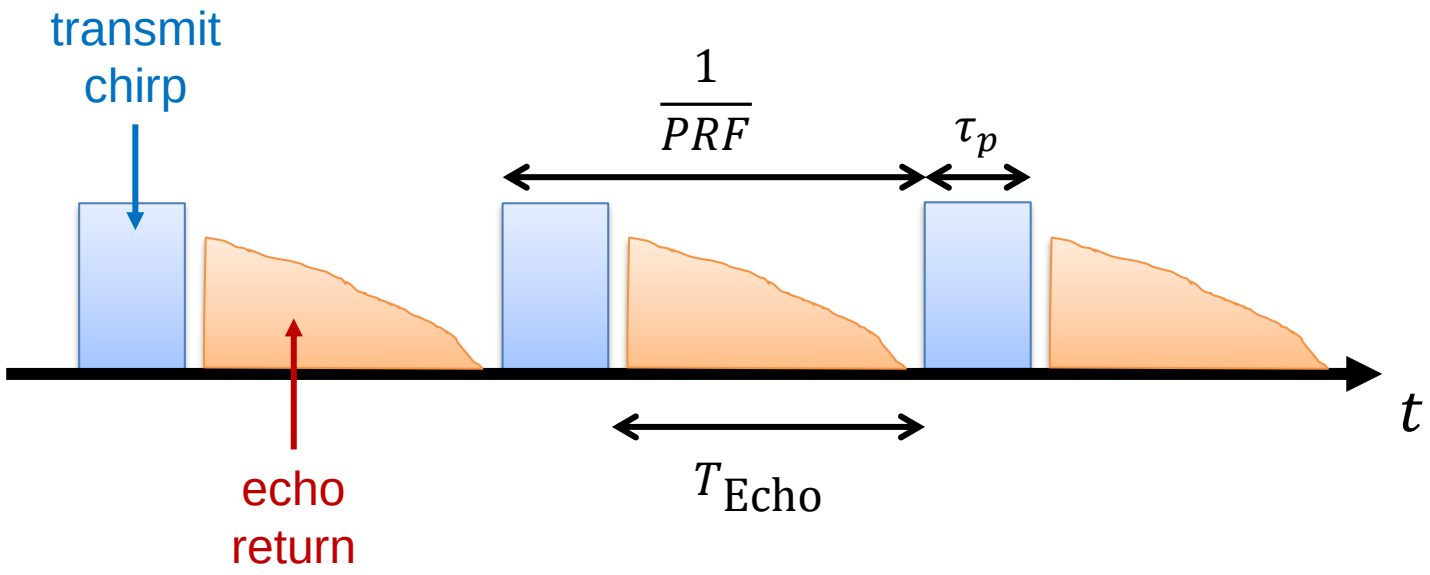
Simulated SAR System

Parameter	Value
Elevation Channels	63
Channel Spacing	0.5 λ
Array Tilt	30°
Platform Altitude	693 km
PRF	1865 Hz
Start Look Angle	17.96°, 29.66°, 36.70°
Stop Look Angle	27.76°, 35.48°, 40.82°
Swath Width	400 km
No. SCORE Beams	43, 27, 18
Decimation of Data Stream for RFI Detection	110





SAR Echo Receive Window

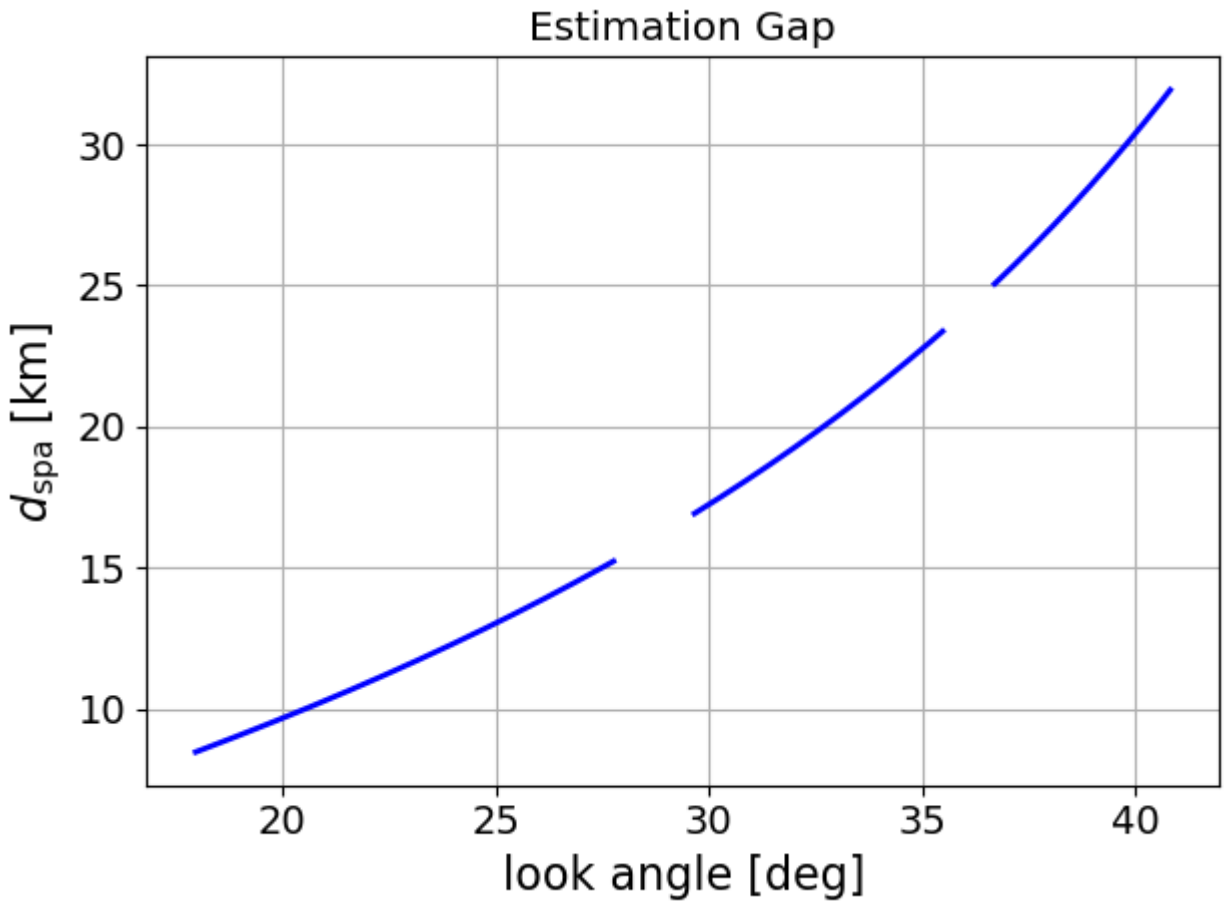


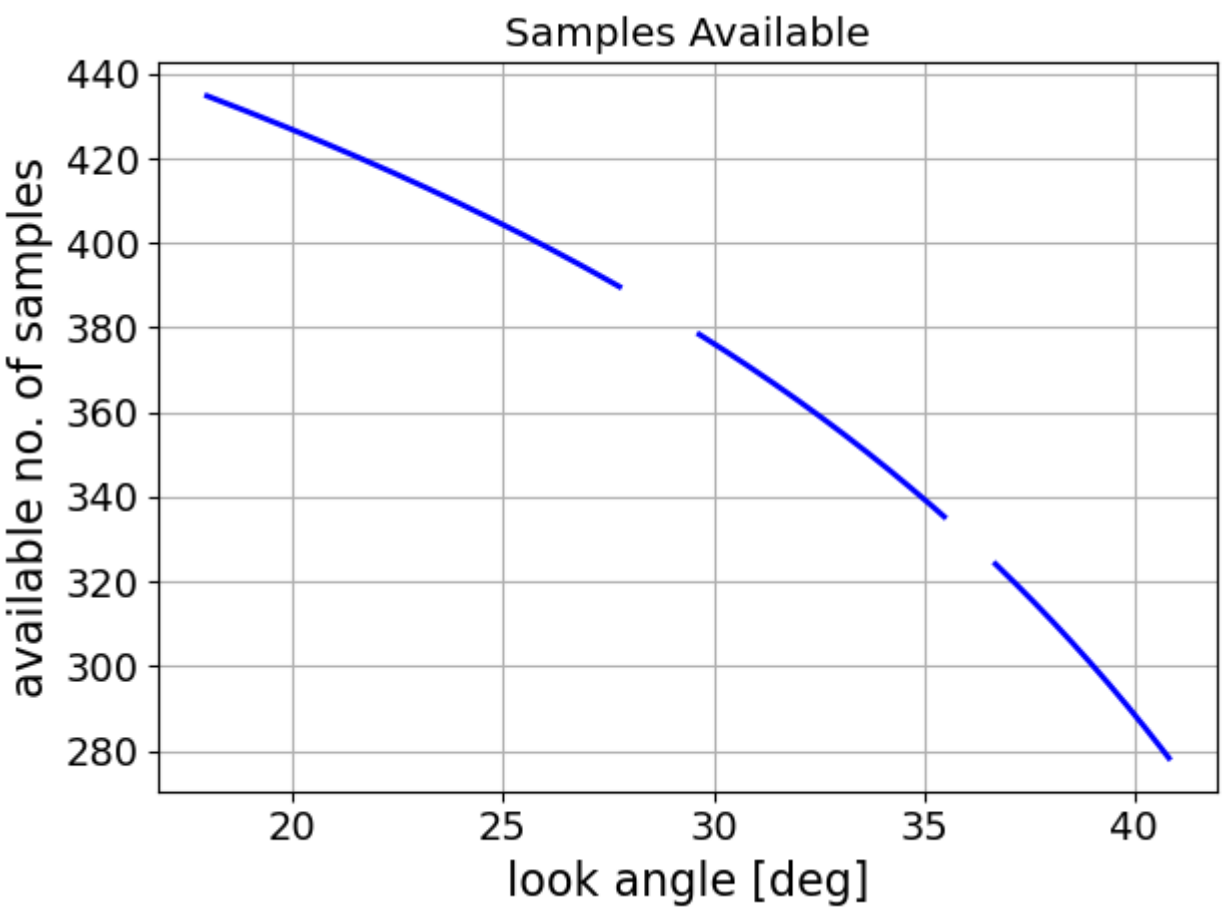
$$T_{\mathrm{Echo}} = \frac{1}{\mathrm{PRF}} - \tau_{\mathrm{p}} - \tau_{\mathrm{g}}$$

$$M = \left(T_{\mathrm{Echo}} - \frac{2}{c_0} d_{\mathrm{gap}} \right) \frac{f_s}{D}$$

due to spatial overlap of
SCORE beam
and
auxiliary beam

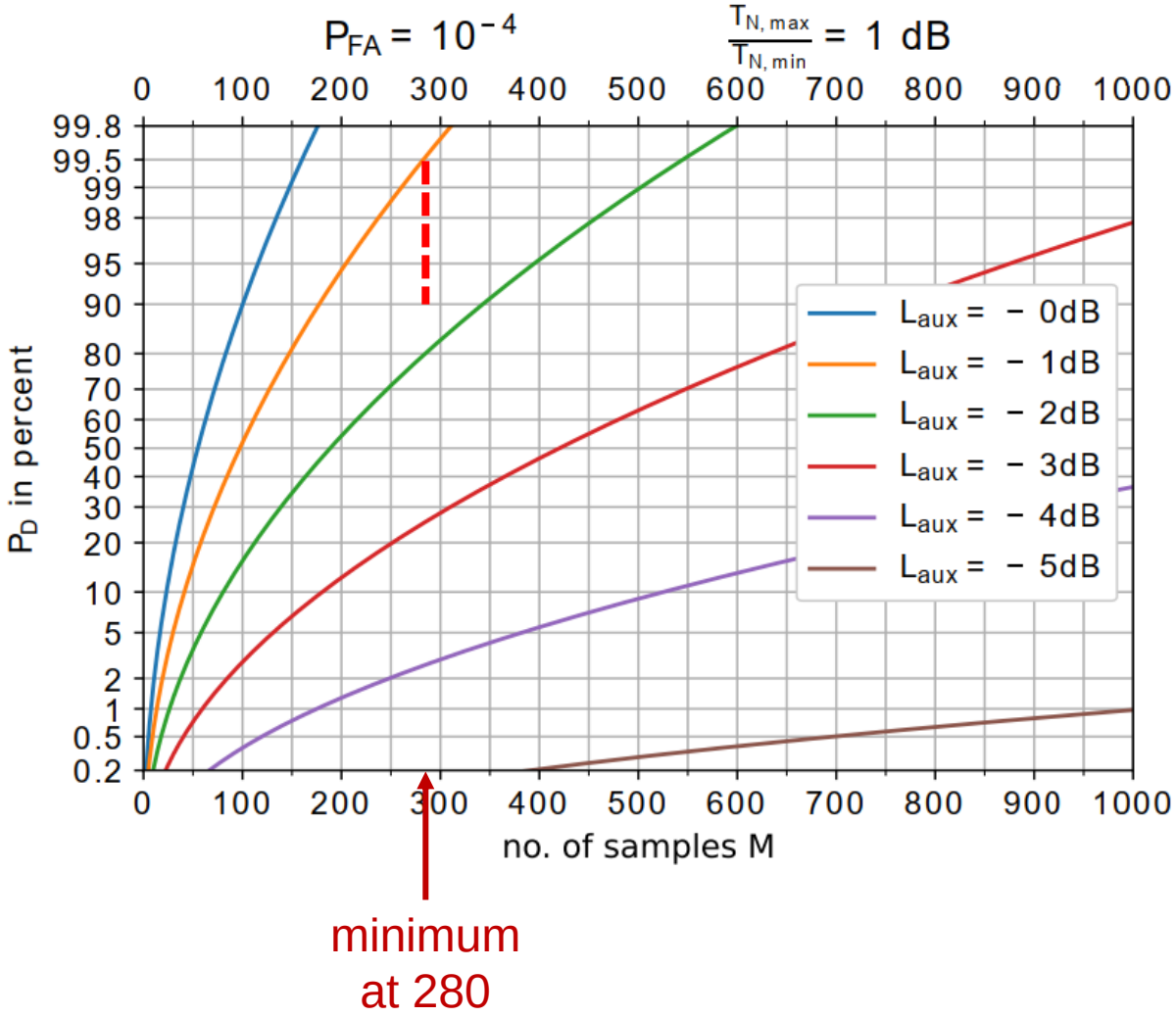
Samples Available for RFI Detection





Detection Performance of the Simulated SAR System

- Worst-case: 280 samples
- Assumed noise floor fluctuations: ± 0.5 dB
- Detection performance depends on L_{aux}
- $L_{aux} > -2$ dB provides reasonable results



Conclusion

- Application of digital square-law detectors for determination of auxiliary beam seems feasible
- Simultaneous detection and angle-estimation
- Reasonable performance ($P_{\mathrm{FA}} = 10^{-4}$; $P_{\mathrm{D}} \gg 90\%$) even with large decimation

Outlook

- Impact assessment of:
  - unknown topography
  - satellite attitude errors
- Reduction of no. of digital square-law filters
- Simulation of look-angle-dependent L_{aux} for current system

→ Potential solution for RFI detection and angle-of-arrival estimation for future DBF SAR systems with auxiliary beams