Development of RFI Mitigation Techniques with Digital Beamforming

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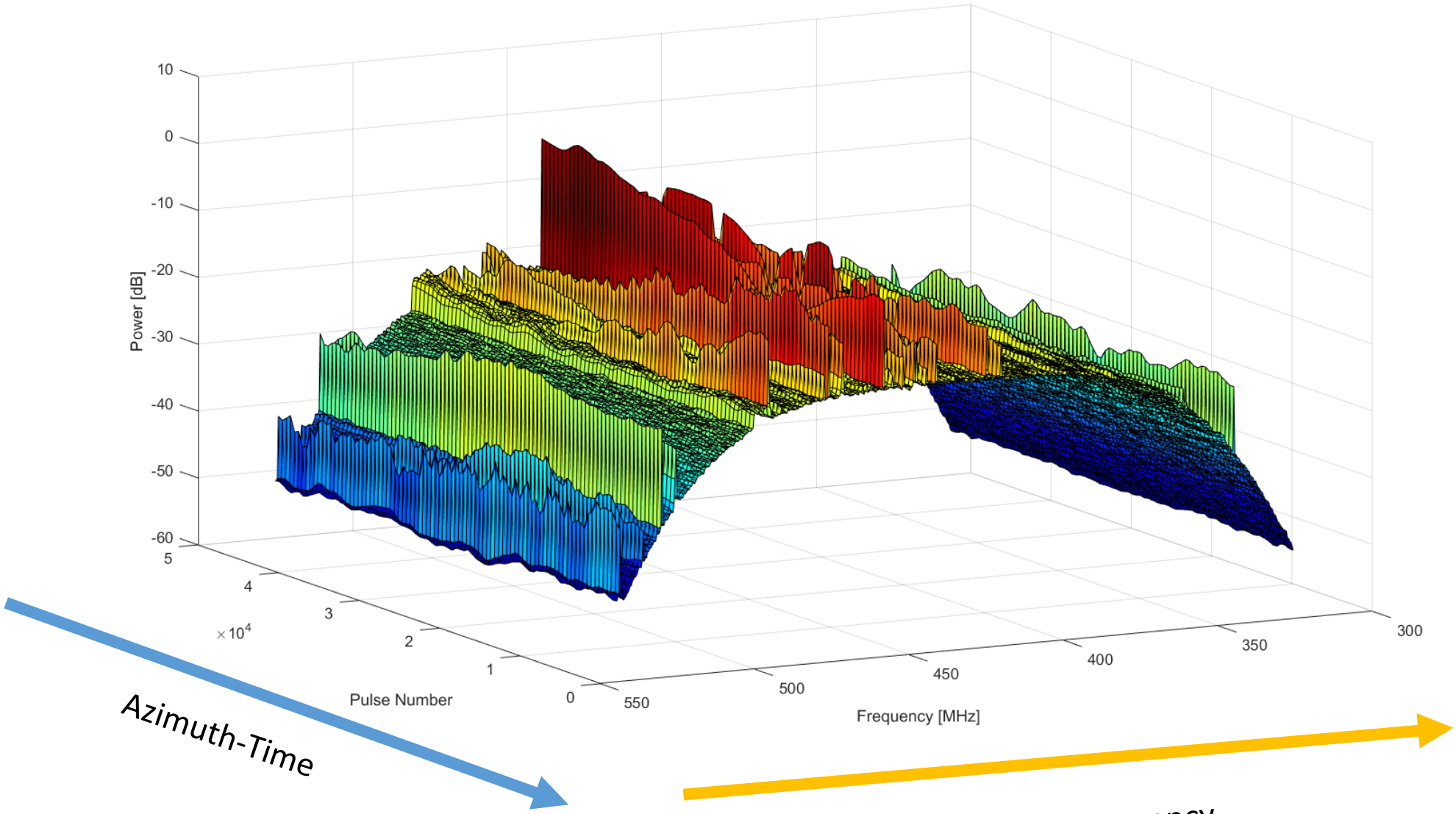
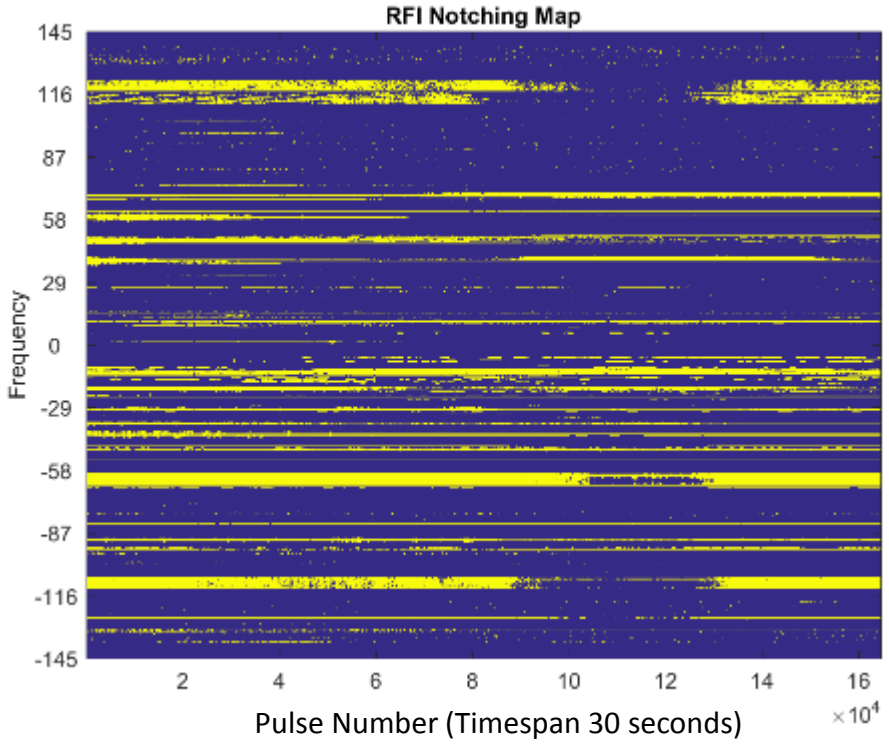
Range-FFT allows separation of RFI sources at different frequencies



Detection of affected frequency bins

1. **EcoSAR implemented sniffing in-between SAR pulses**
2. **Frequencies occupied by RFI can be detected**

Costa Rica on March 31st, 16:09 to 16:14 (EST)

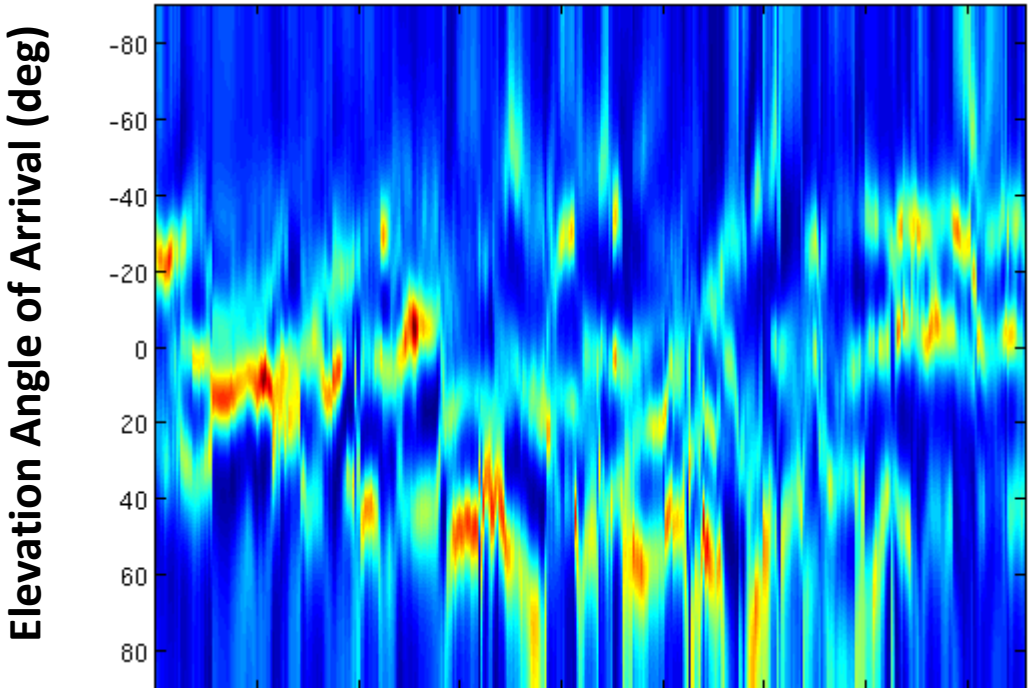


Yellow: frequency bins marked with RFI

EcoSAR lost array coefficients

Before direction of RFI can be localized, a time-delay correction in the frequency domain needs to be performed, to remove unknown time and phase delays

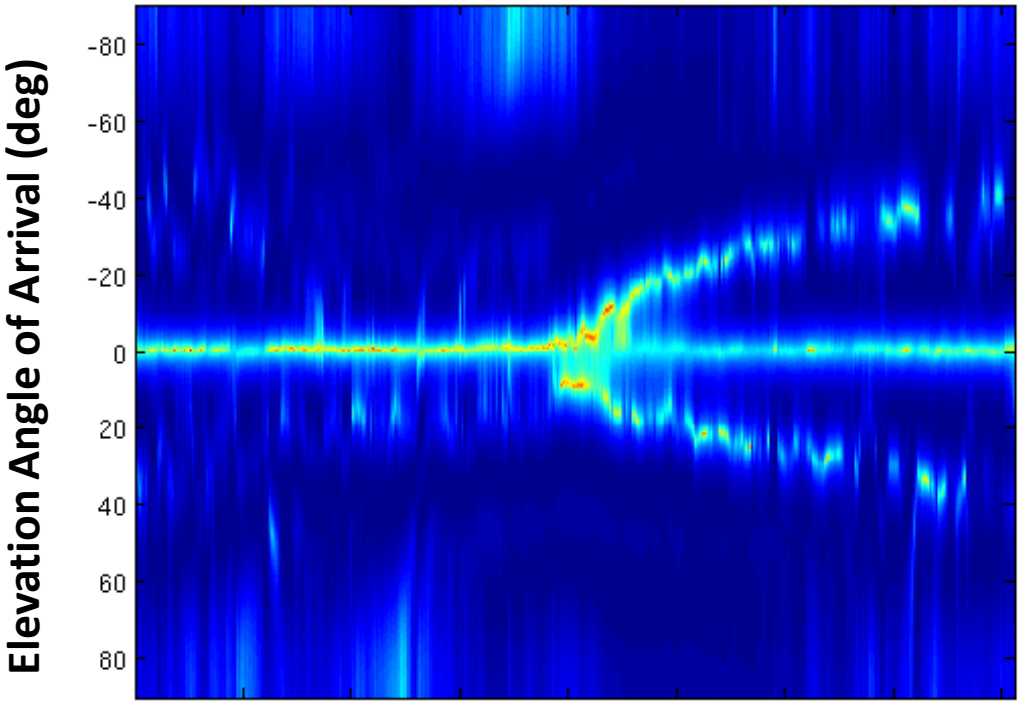
AoA Estimation before correction



Flight direction → (88 seconds)

AoA Estimation after correction

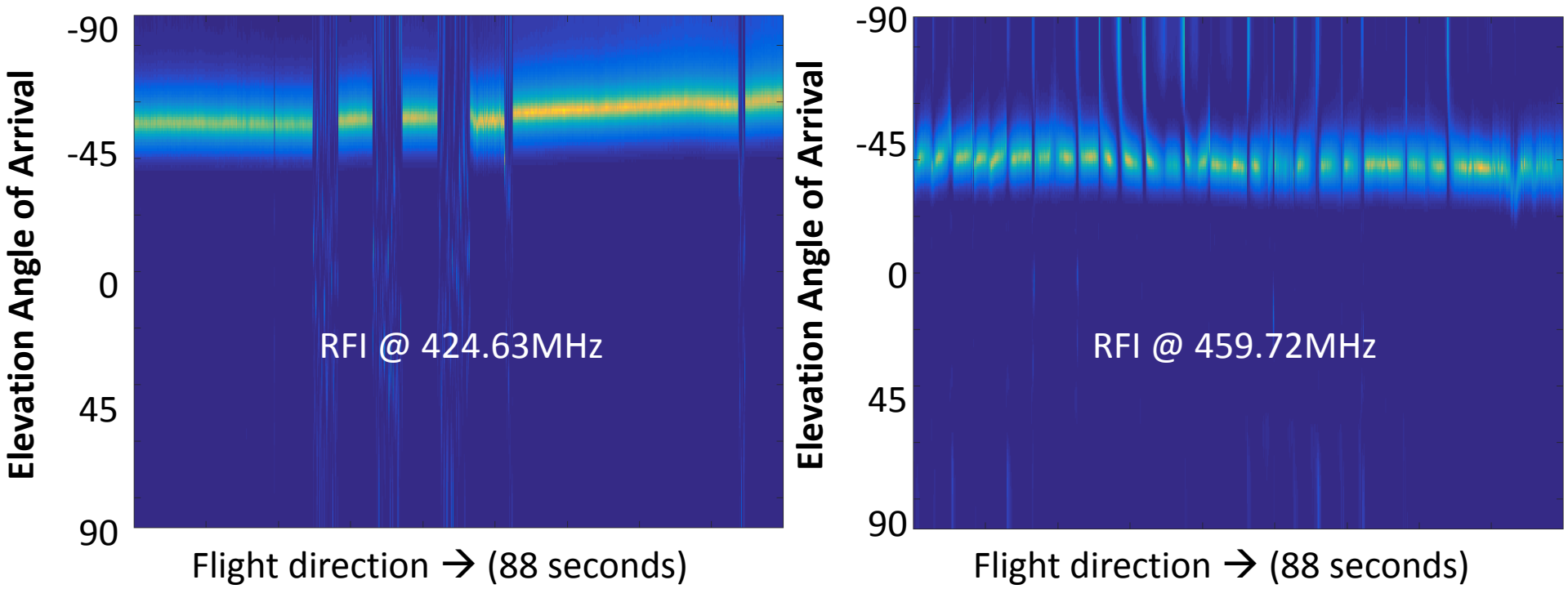
SAR return from both sides visible



Flight direction → (88 seconds)

AoA estimation using MUSIC on sniffing pulse

Two examples of non-continous RFI sources

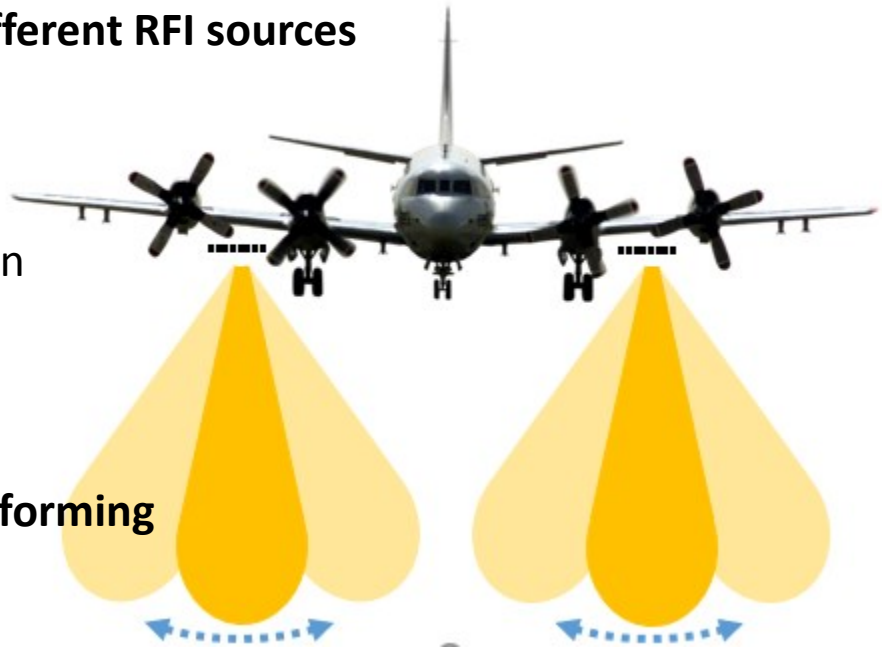


RFI Mitigation using Antenna Arrays

1. Multiple channels allow estimation of Angle of Arrival (AoA) from different RFI sources

SAR and RFI should be measured separately:

- utilizing longer receive window before expected ground return
- implementation of sniffing pulse at cost of PRF,
  one polarization channel or dedicated pulses



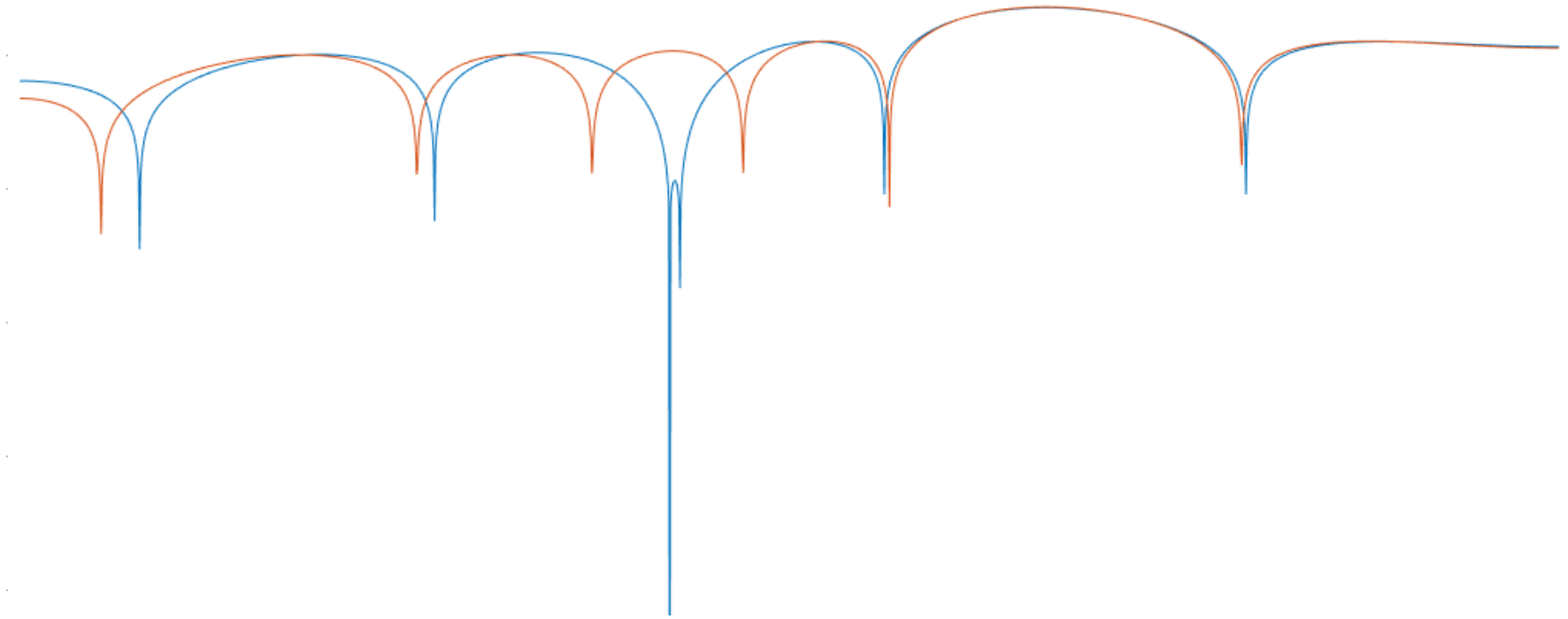
2. Using direction knowledge, RFI can be suppressed using digital beamforming

BUT: number of allowed RFI sources limited by antenna array number!
→ Separation in frequency-range, azimuth-time domain makes it easier.

Digital Beamforming to Notch RFI Direction

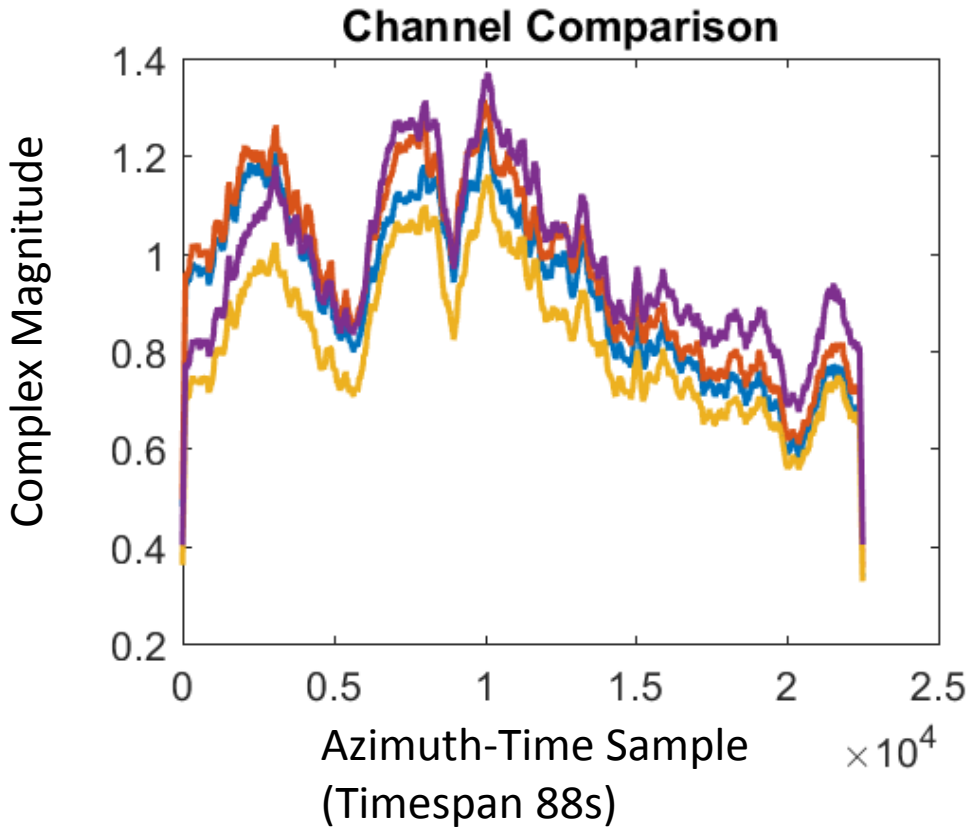
Nulling of antenna pattern for each frequency bin allows to notch more directions than antenna elements (not in same bin)

But: requires good antenna pattern knowledge/calibration



Without antenna pattern knowledge:

RFI signal in a frequency bin at 4 different channels



IDEA: If the RFI signal at this frequency comes from <u>one</u> dominant source:

→ Signal should only differ in phase due to spatial antenna element separation (And magnitude due to calibration)

Without antenna pattern knowledge:

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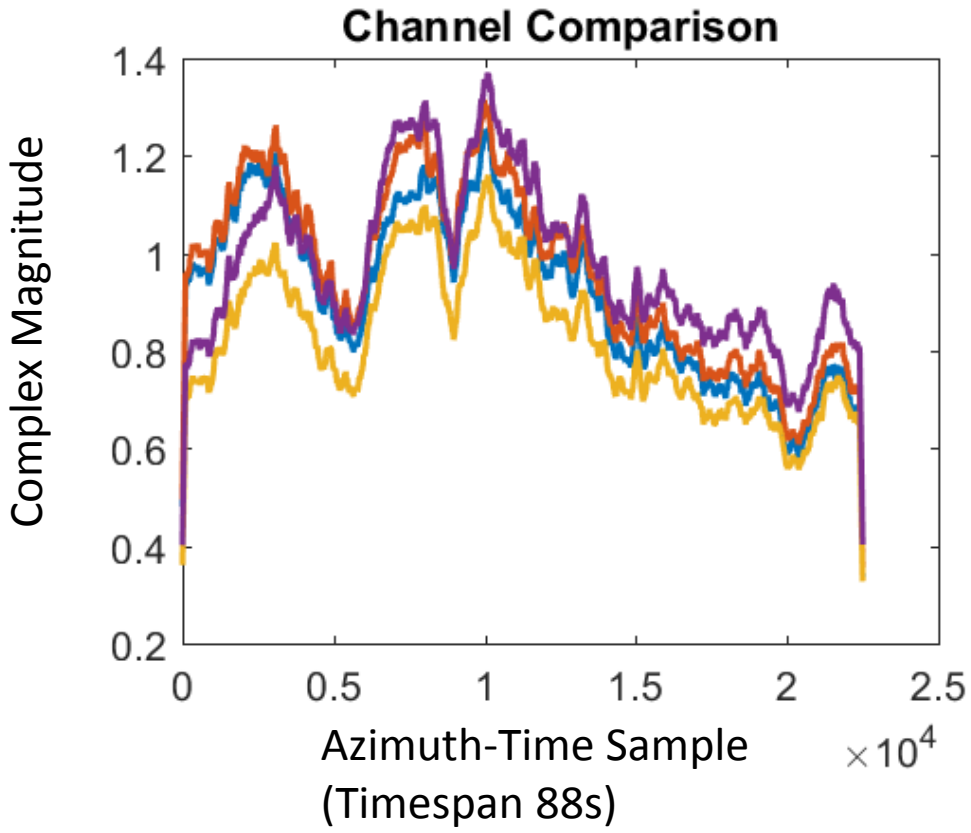

1. Estimate AoA at each frequency bin
2. Steer to AoA

   → Extracts reference signal of RFI, noise and SAR from same direction
3. Subtract this reference from each channel with phase shift according to AoA

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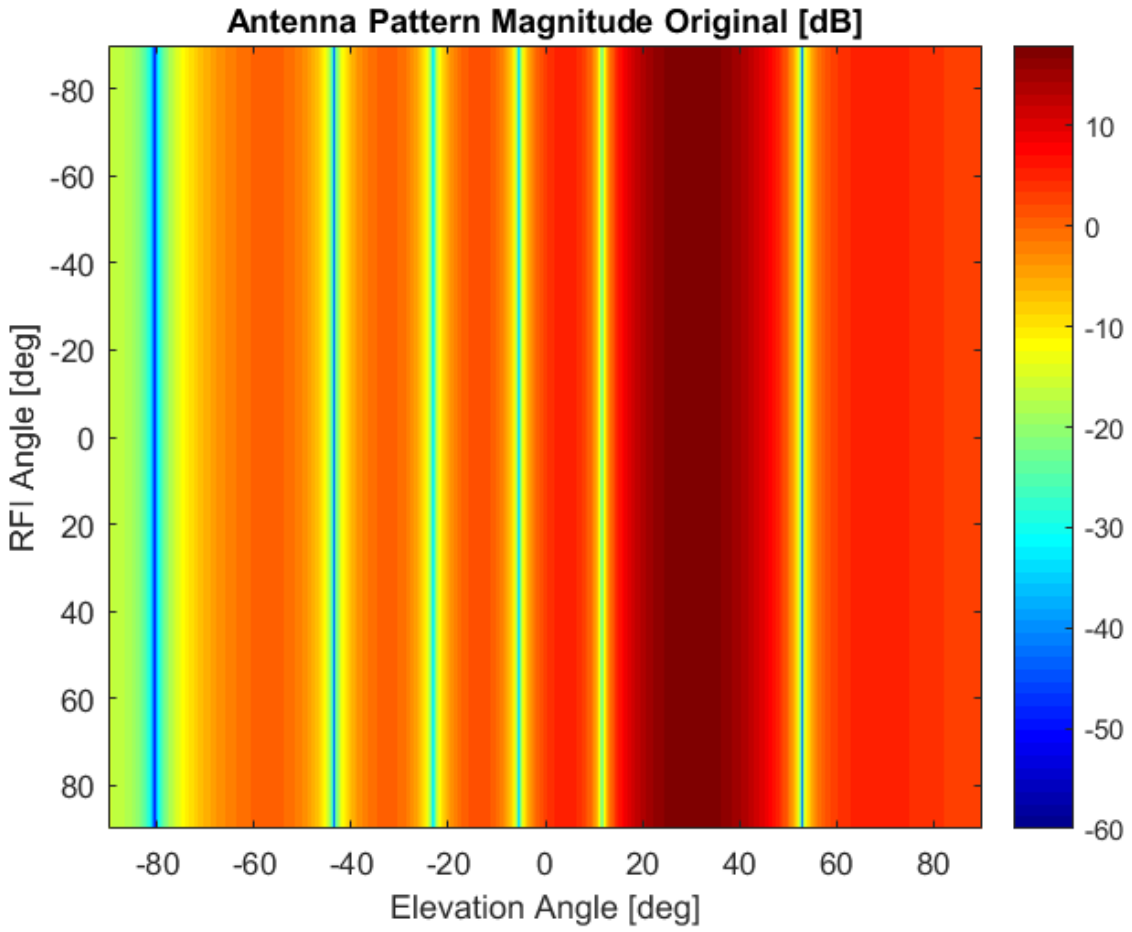
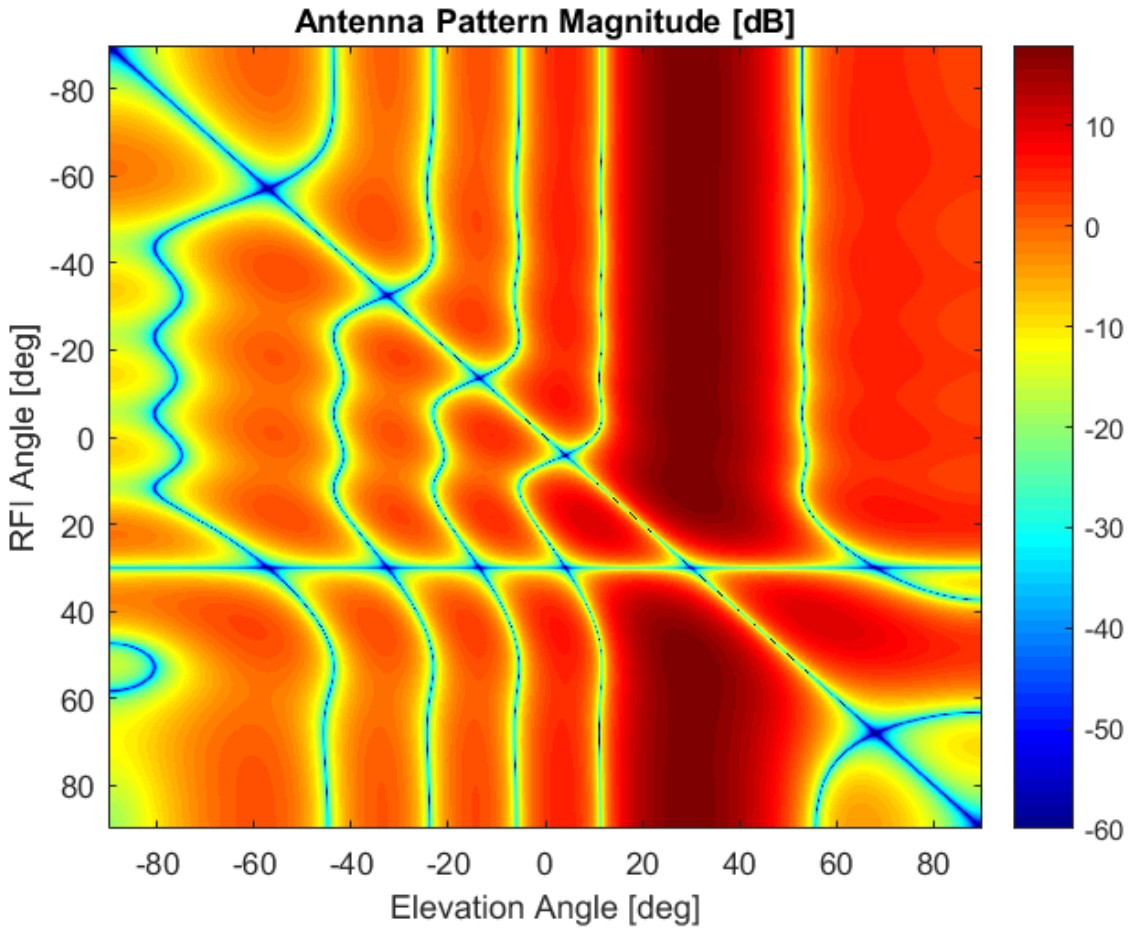
Resulting antenna pattern for this method



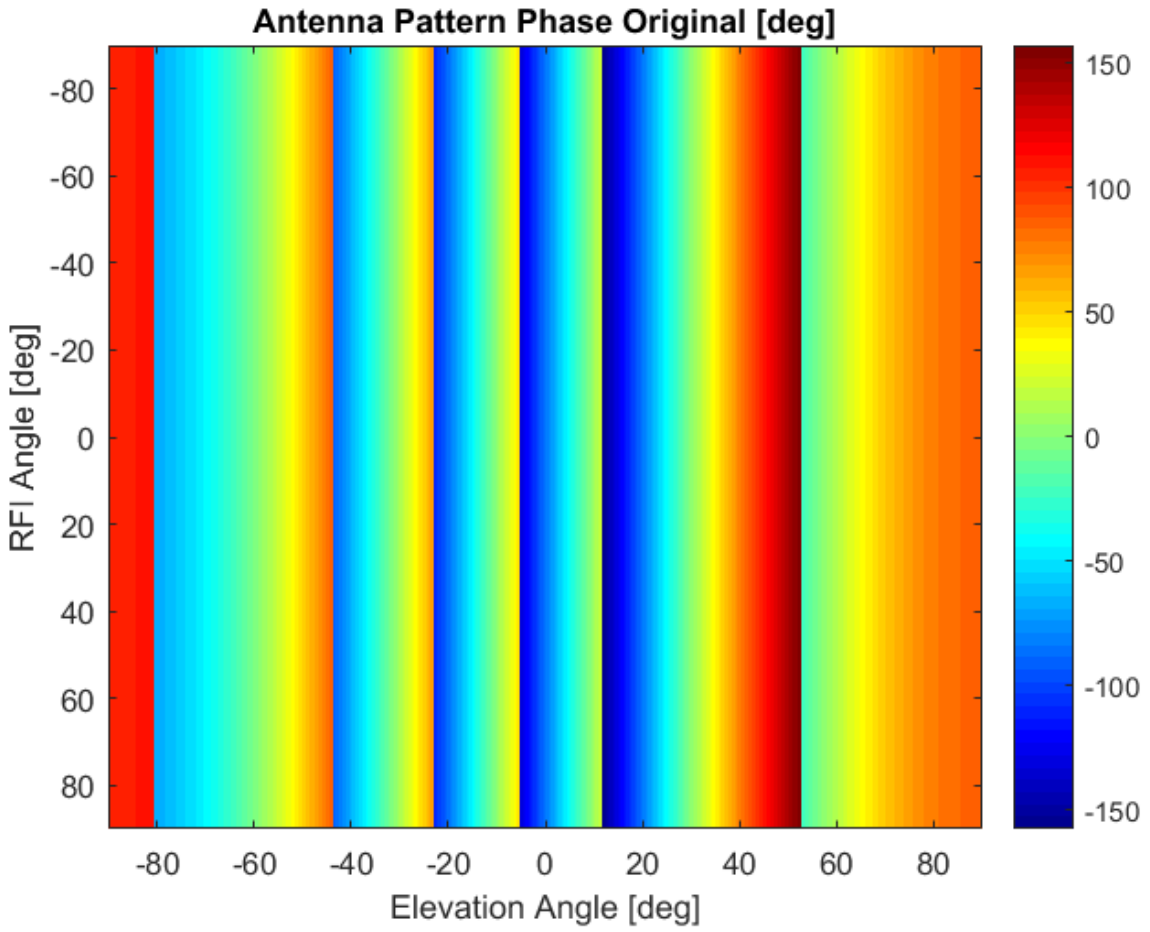
After Correction



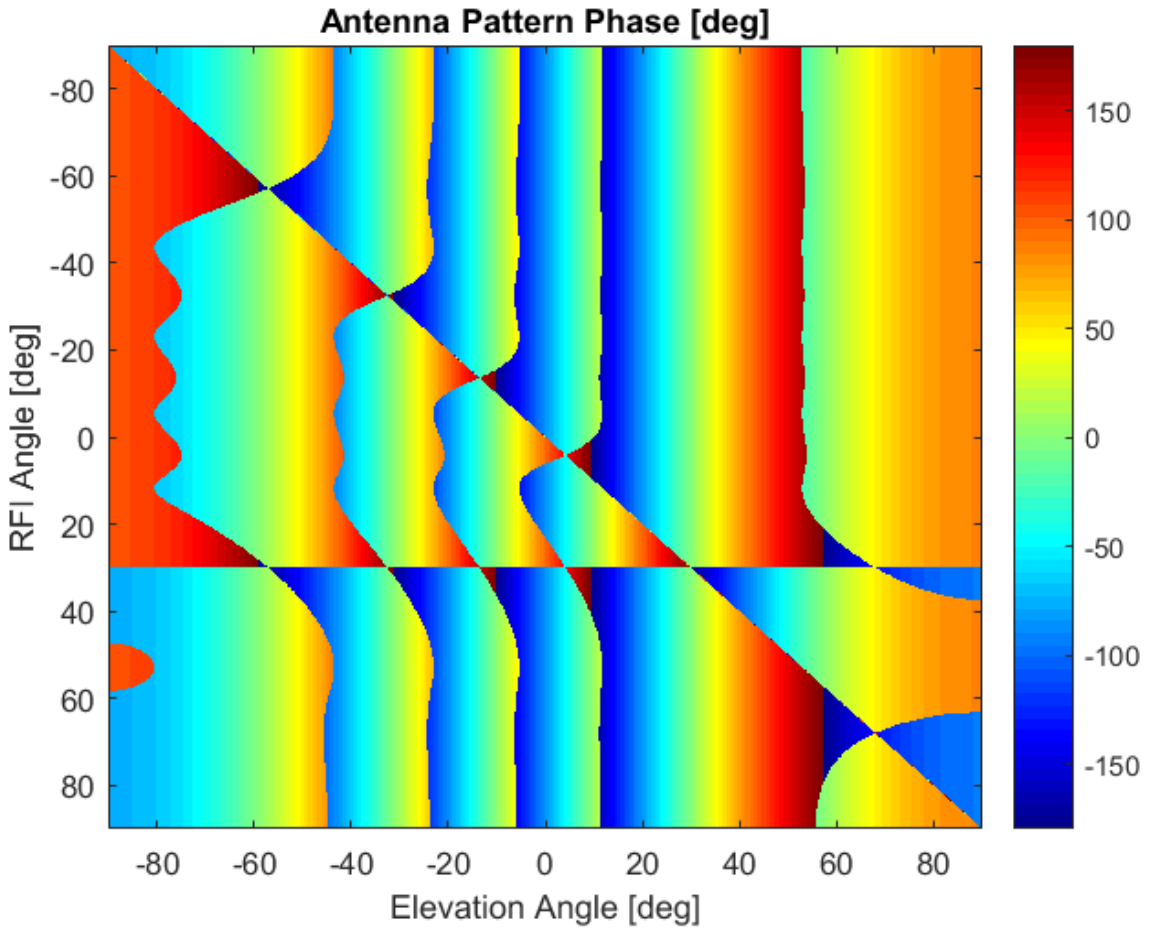
Antenna Pattern for varying RFI angle and fixed Main Lobe at +30deg

Errors in RFI Angle knowledge will result in not fully subtracting RFI signal

Resulting antenna pattern for this method



After Correction



Antenna Pattern for varying RFI angle and fixed Main Lobe at +30deg

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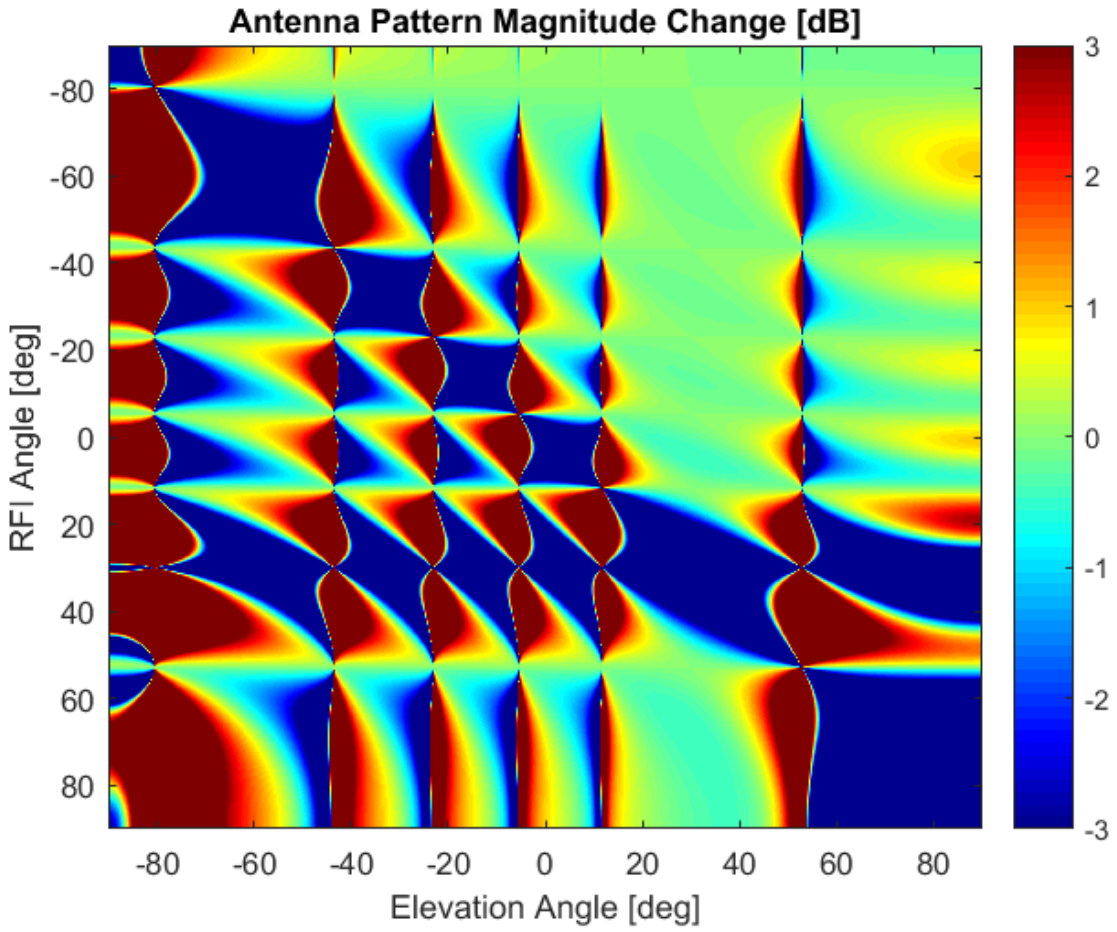
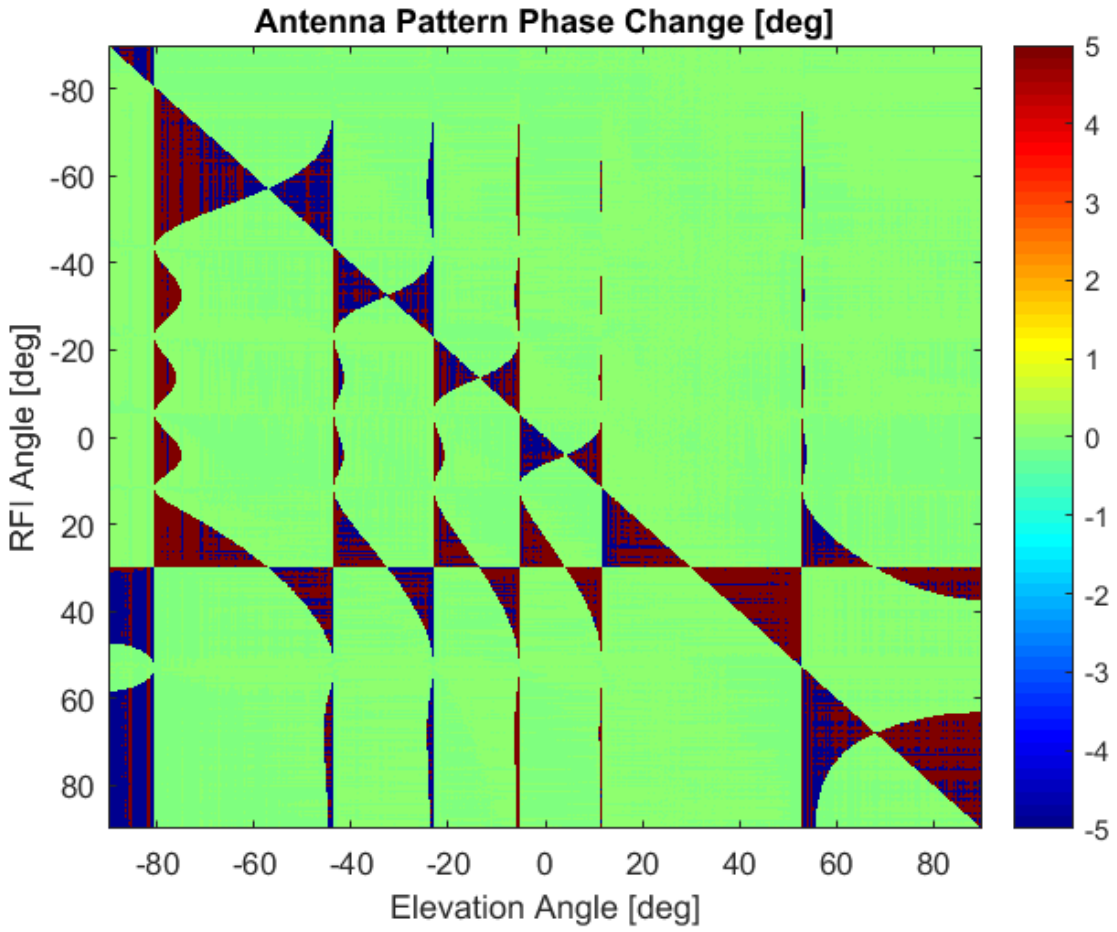


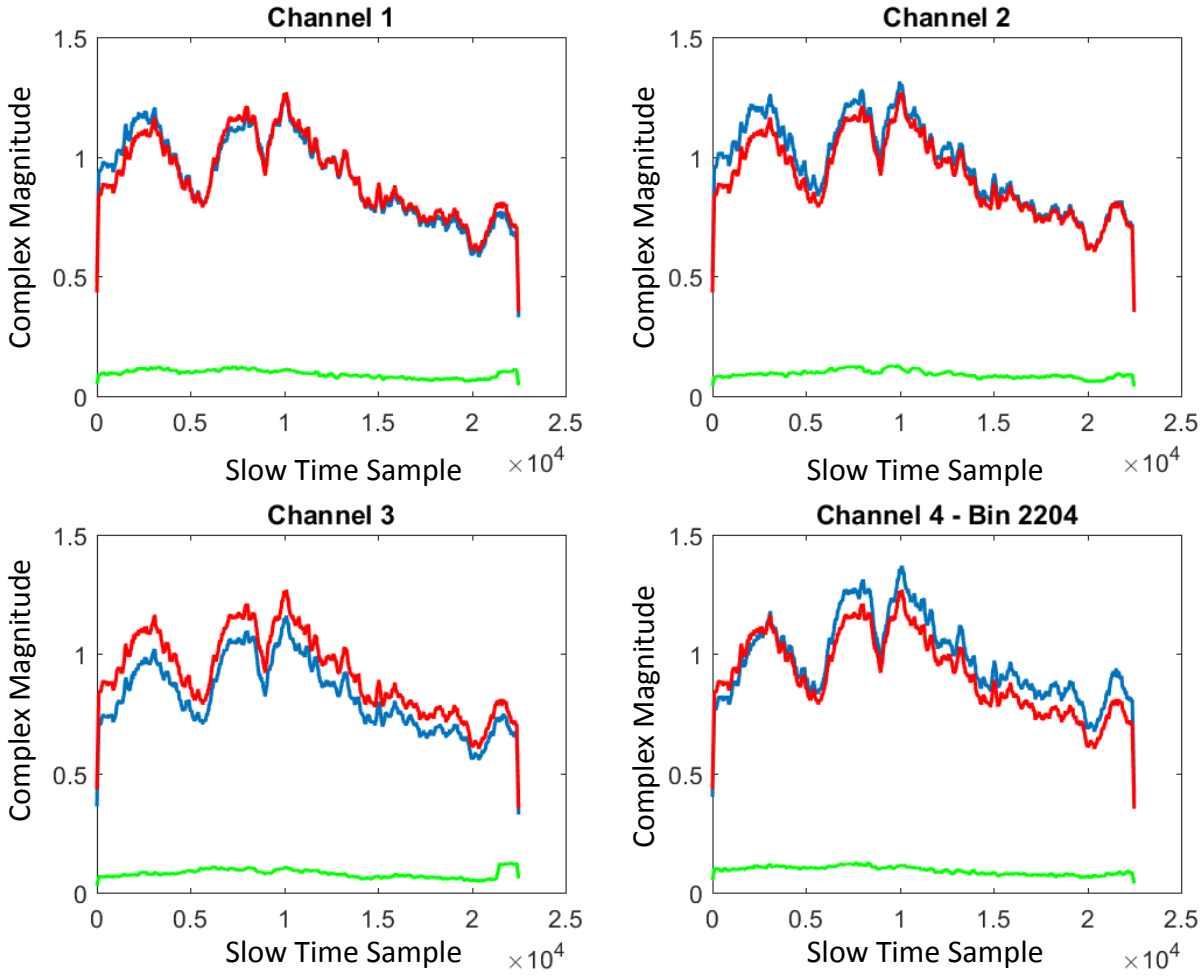


Antenna Pattern for varying RFI angle and fixed Main Lobe at +30deg

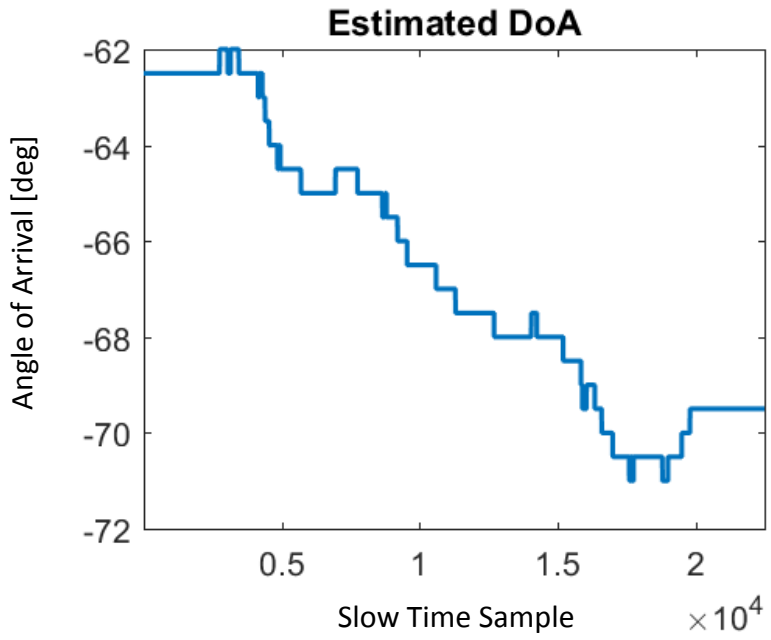
Errors in RFI Angle knowledge will result in not fully subtracting RFI signal

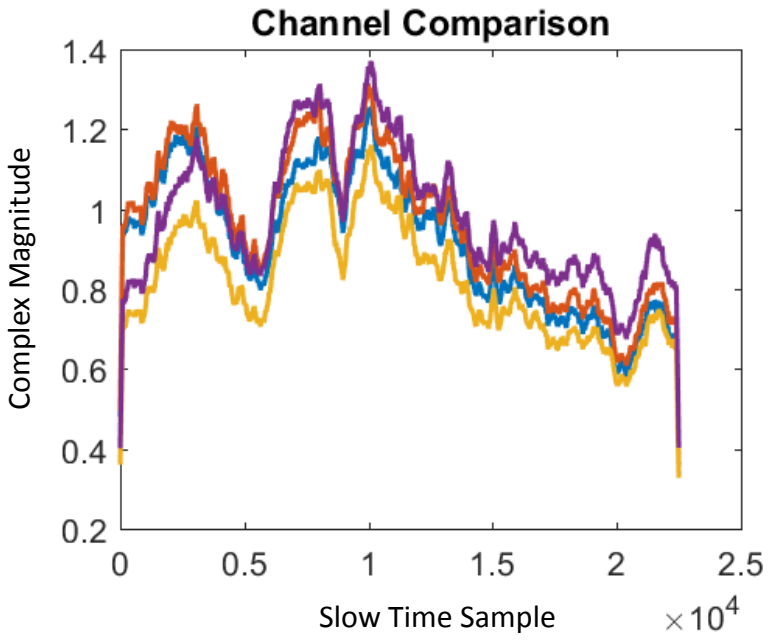
Results using sniffing pulse (real EcoSAR data)

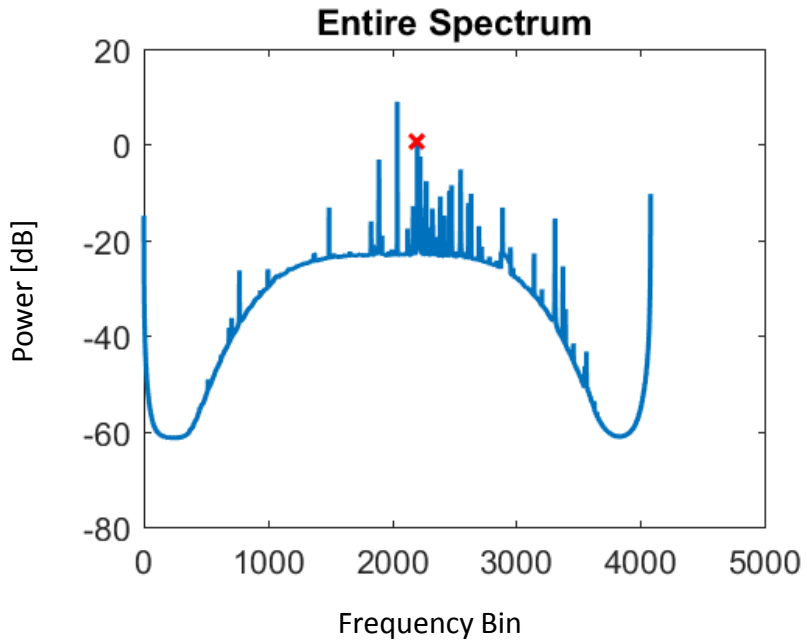
a) Every even sniffing pulse sample is used to retrieve steering vector
b) Every odd sample of sniffing pulse: RFI signal that is used for algorithm

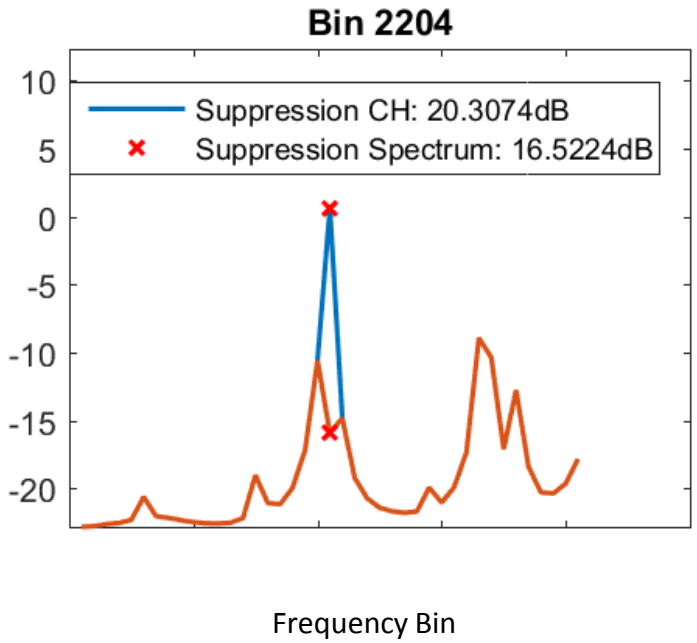


Blue: Measured RFI
Red: Estimated RFI
Green: Residual



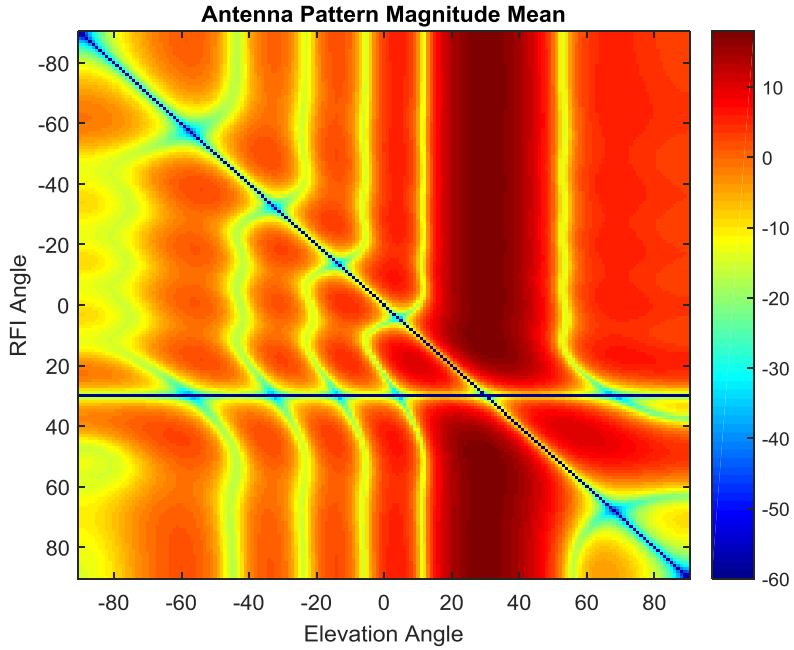


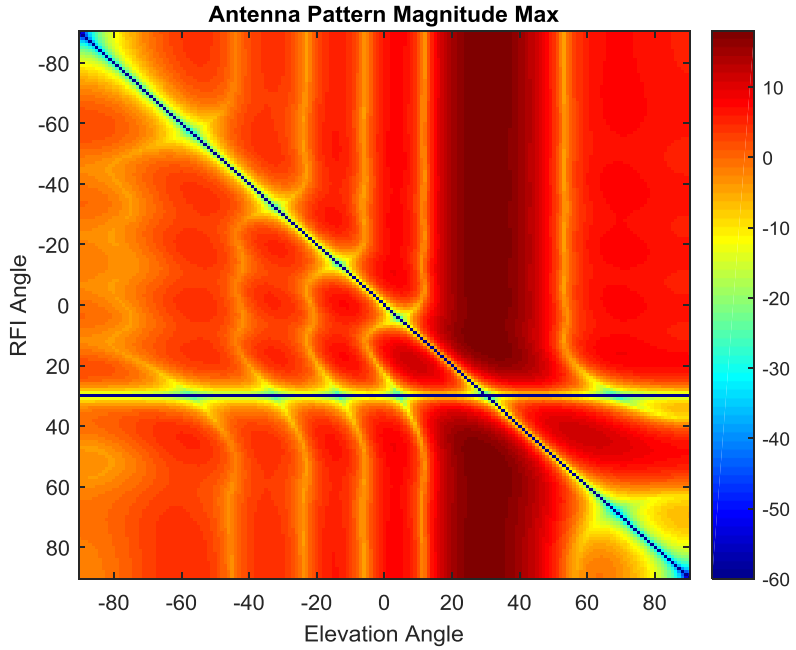


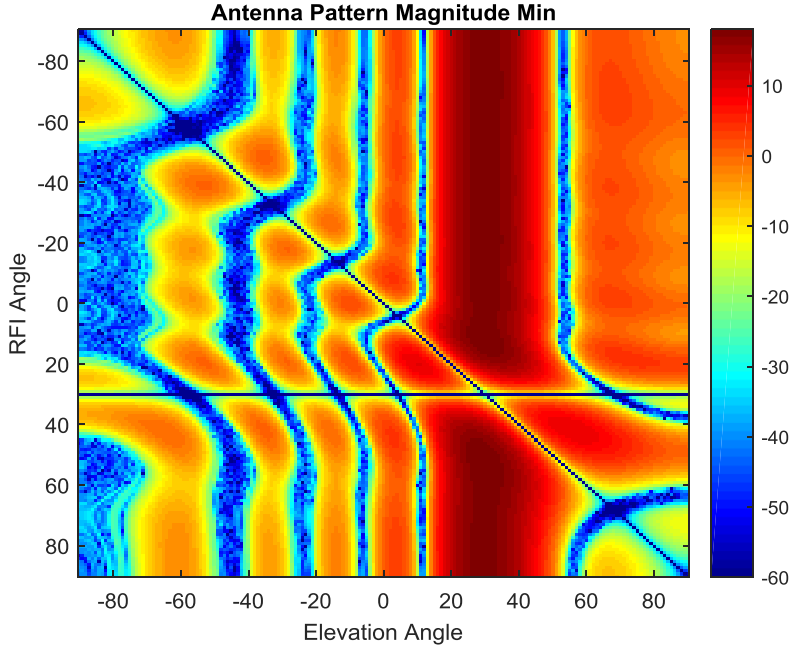


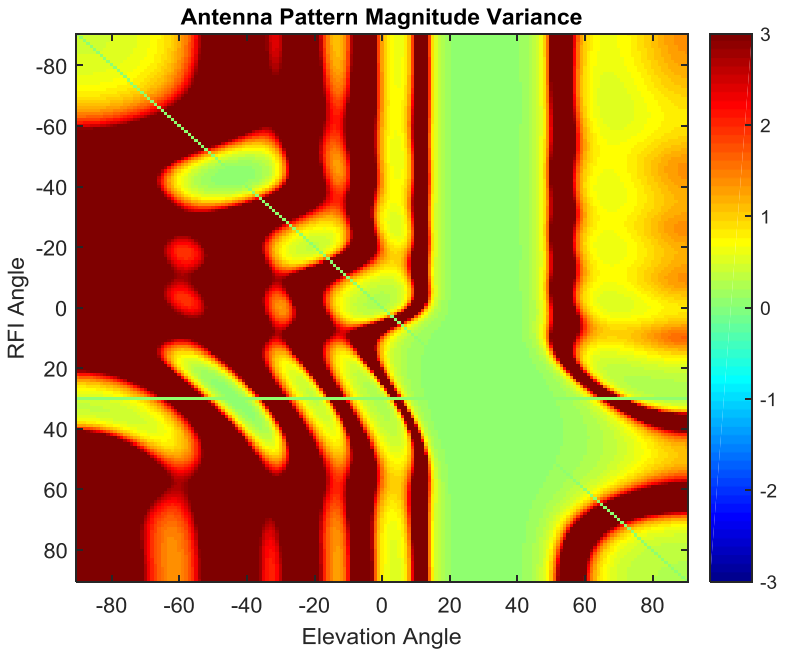
RFI Spectrum for main beam steered to +30deg
Blue before correction
Brown after correction

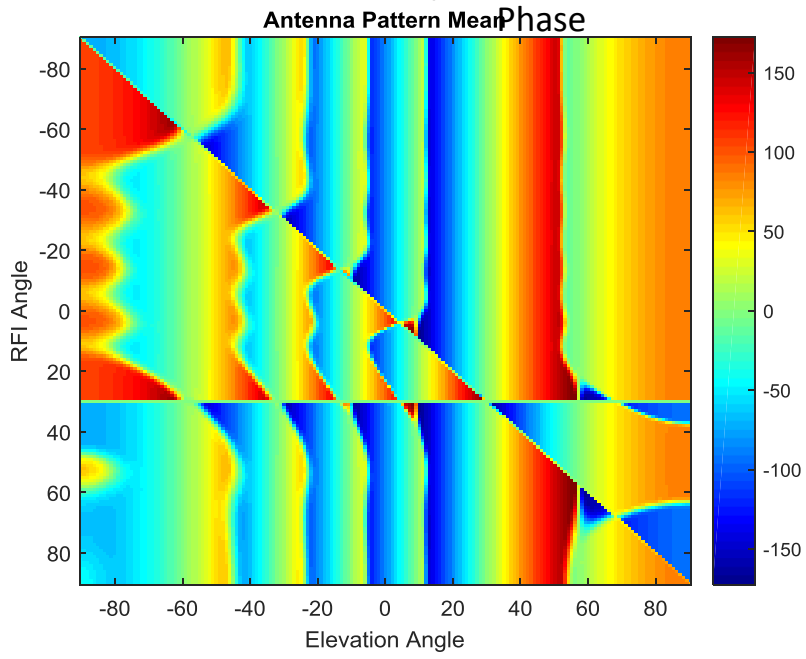
Phase Errors between channels (Monte Carlo:5deg std, 1000 iterations) [EcoSAR lost coefficients]

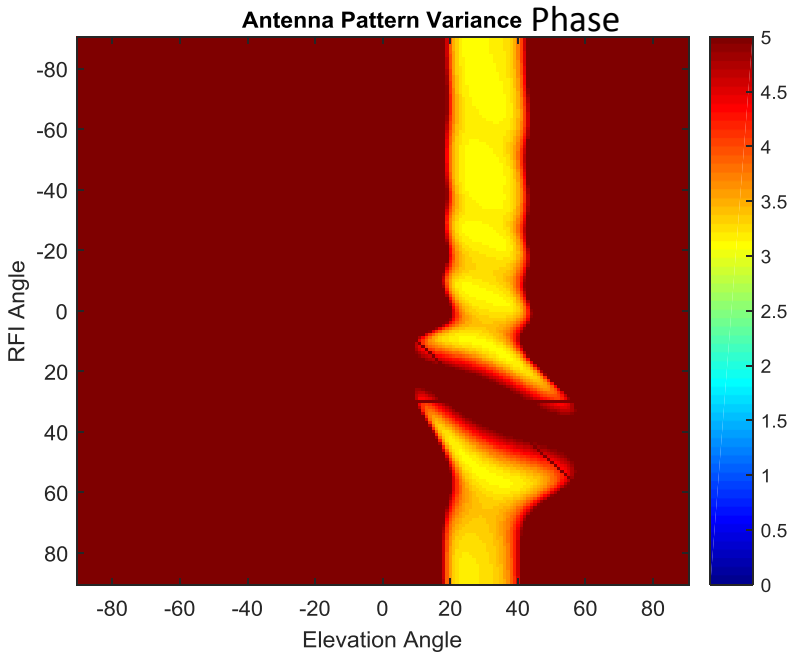




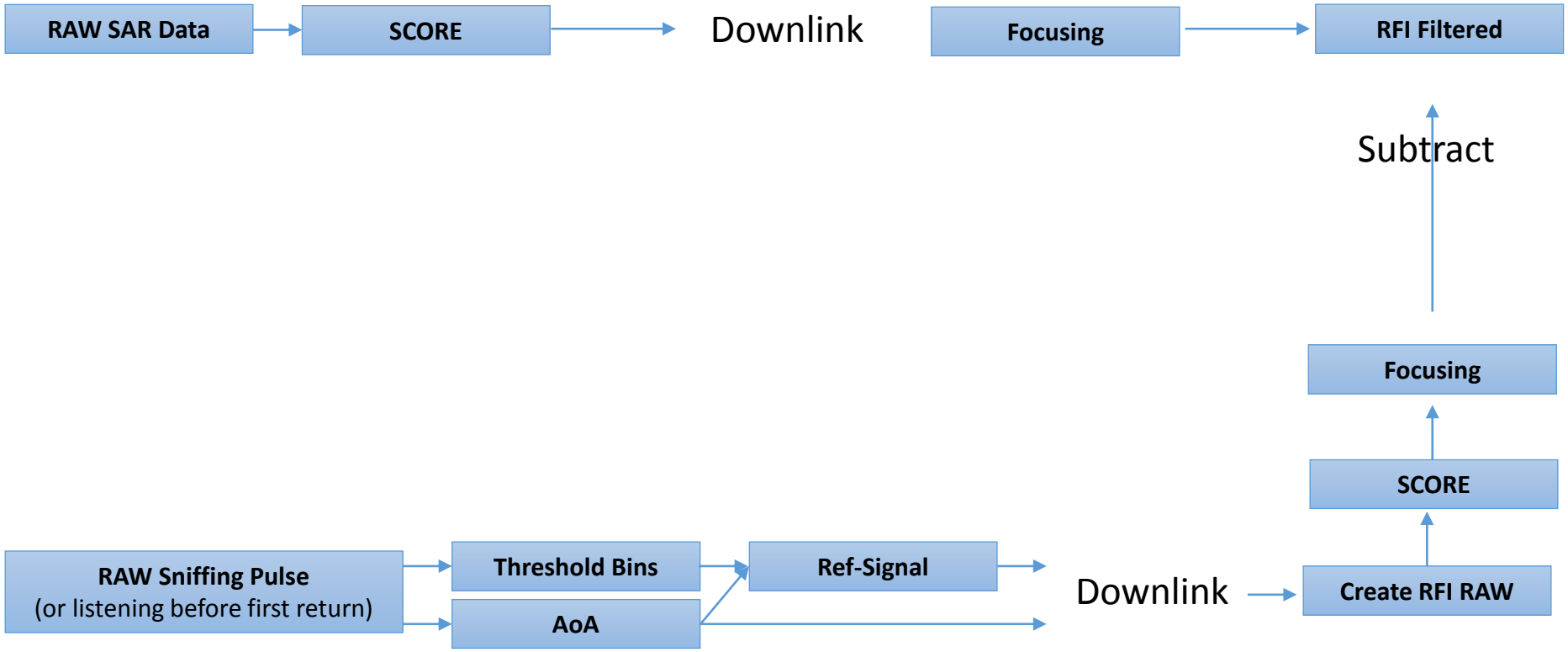








Processing Strategy



Increase of transmitted data

1.) On-Board AoA estimation

2.) On-Board RFI-reference extraction by digitally steering to AoA

3.) Transmit RFI-reference signals and responding instantaneous AoA

4.) On-ground RFI-only construction of each RFI-channel

5.) Beamforming (and processing) of RFI-only data

6.) Subtraction from received SAR data/image

If **k** percentage of frequency bins are affected by RFI,
transmitting each reference signal+AoAs would increase data rate by **up to 2*k** percent
(respectively to the transmittion of one beamformed image)

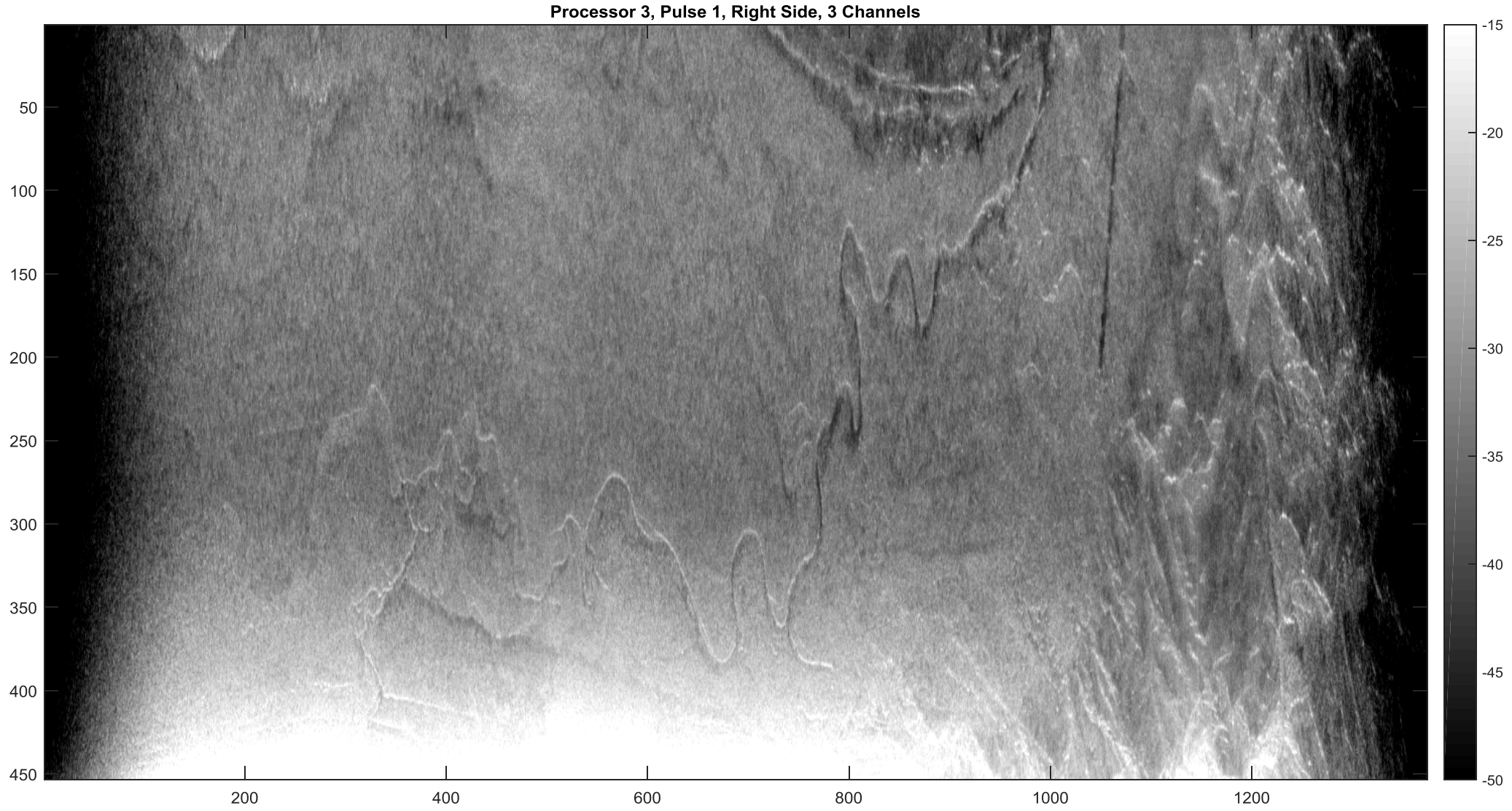
Example: 204 out of 4083 bins (5%) are affected by RFI: increase of the transmitted data by up to 10%

However, AoA angle accuracy could be reduced / modelled / compressed
Reference signal quantization could possibly be reduced (has to be investigated)

Simple Test

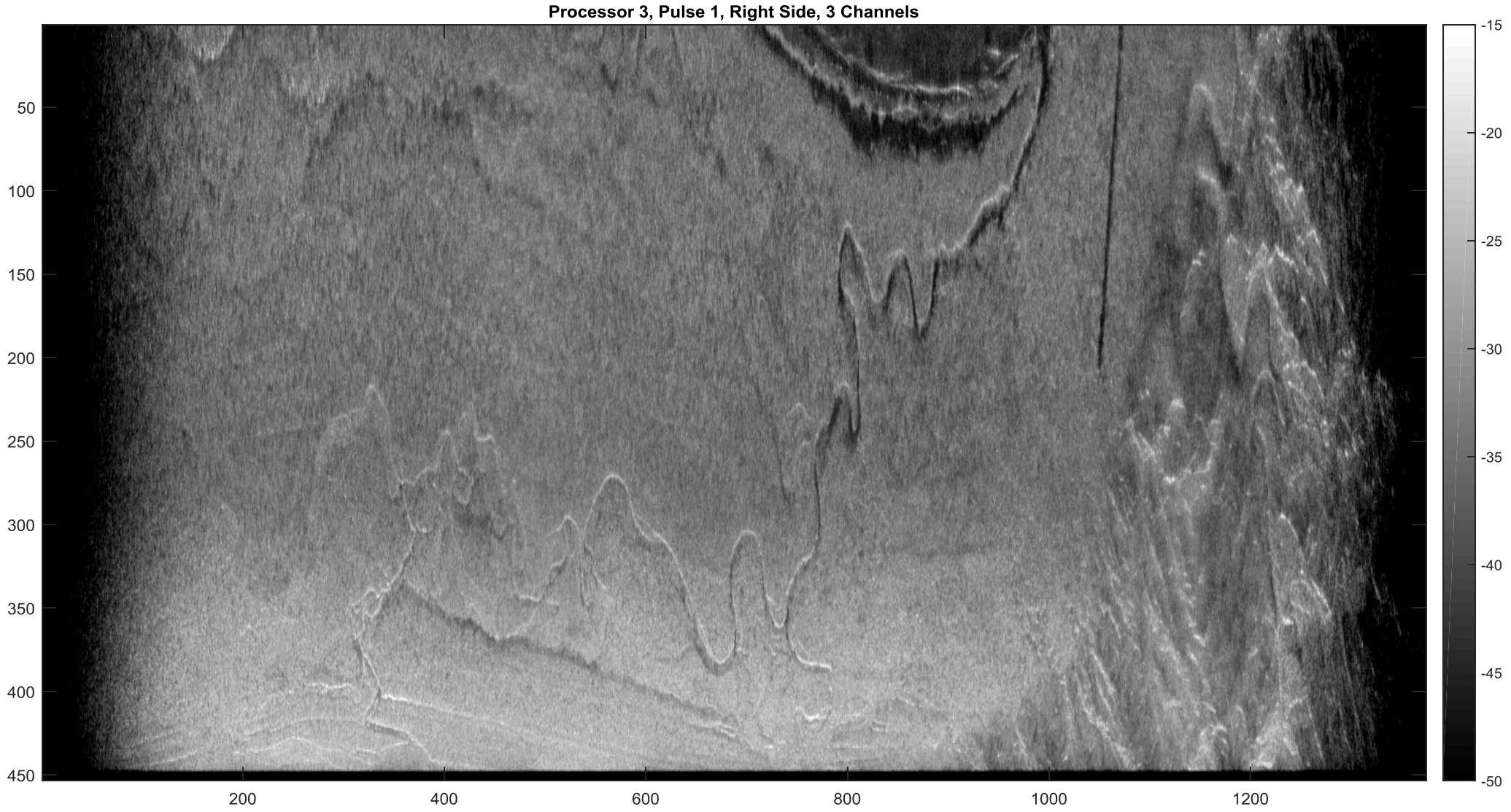
If SAR return from ‘other’ side is regarded as ‘RFI’, then the subtraction method should also be able to suppress the side lobes of the image.

HH, different wings (Proc3P1), 3 antenna elements, strong ambiguities



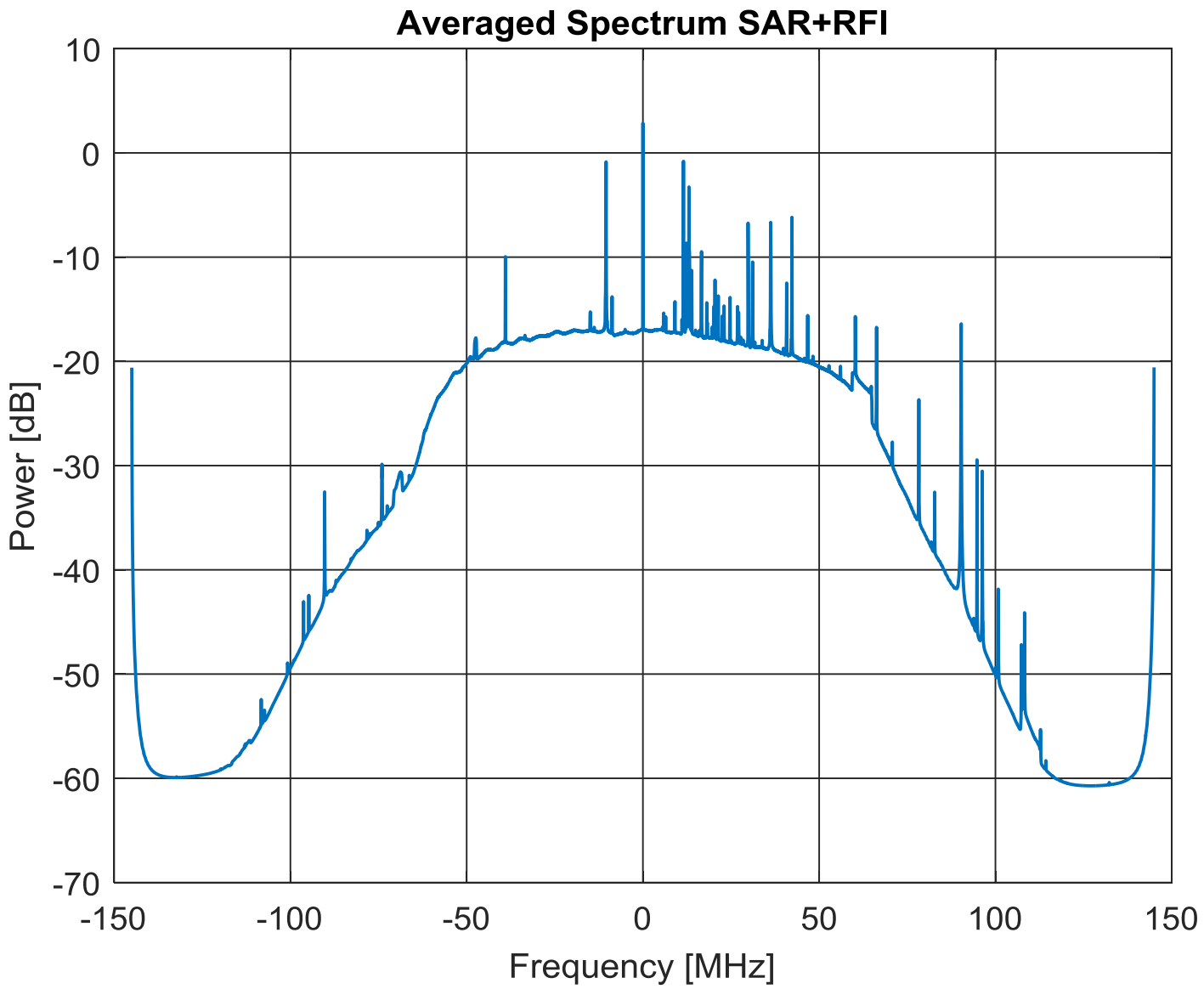
Costa Rica on March 31st 2014

HH, different wings (Proc3P1), 3 antenna elements, side lobes subtracted



Costa Rica on March 31st 2014

RFI Mitigation Test (HV-Channel)



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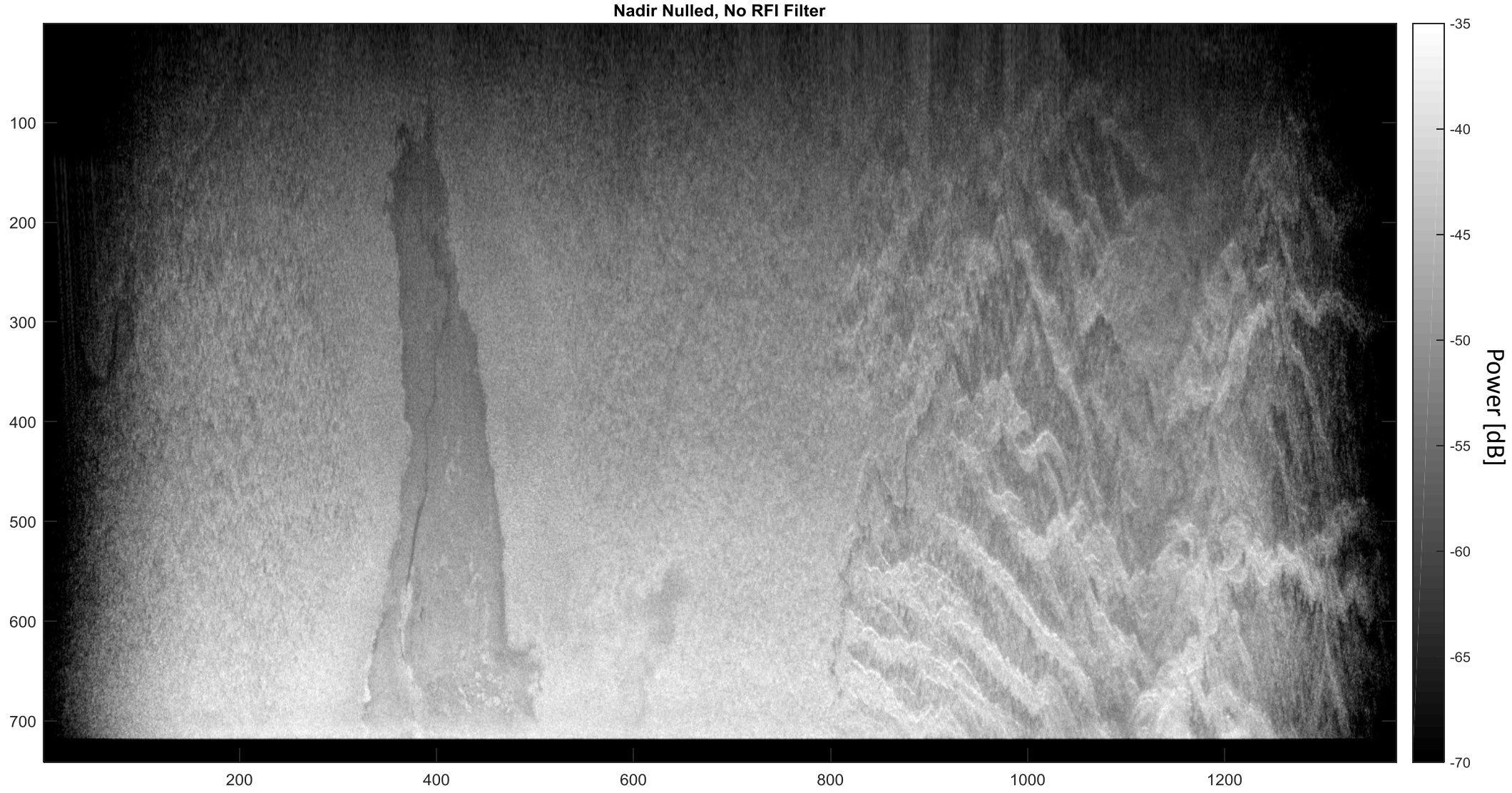

Costa Rica on March 31st 2014

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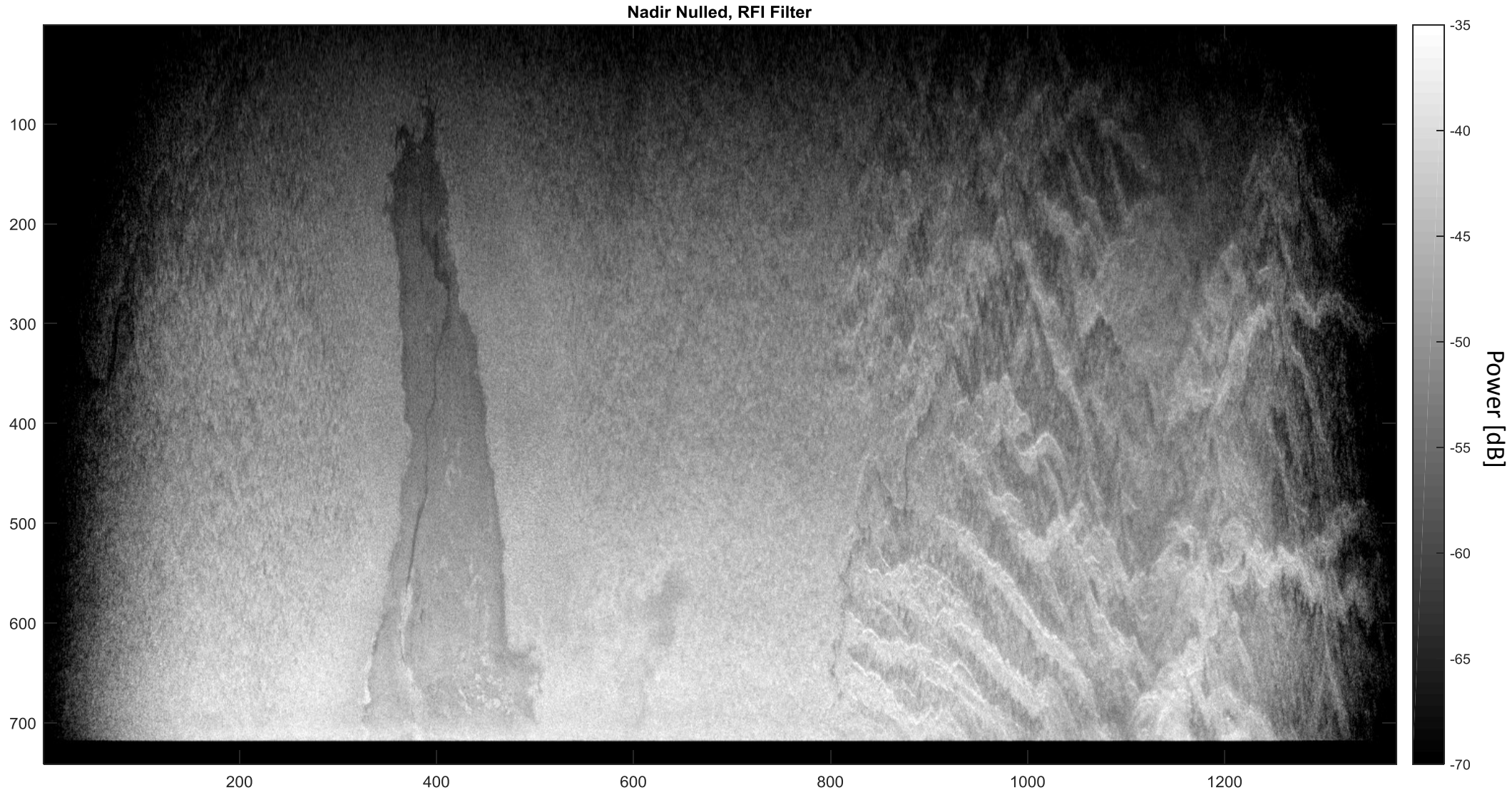

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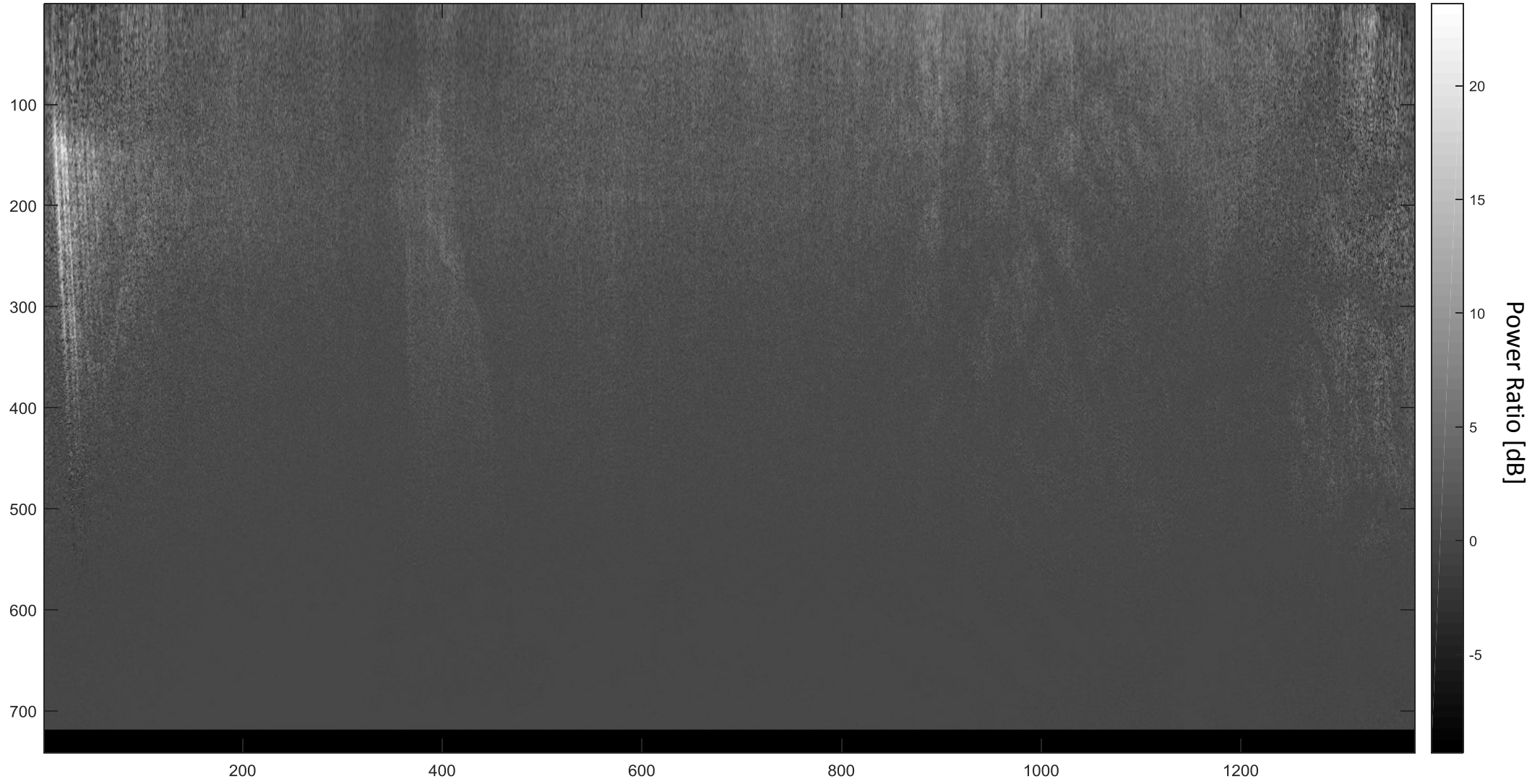
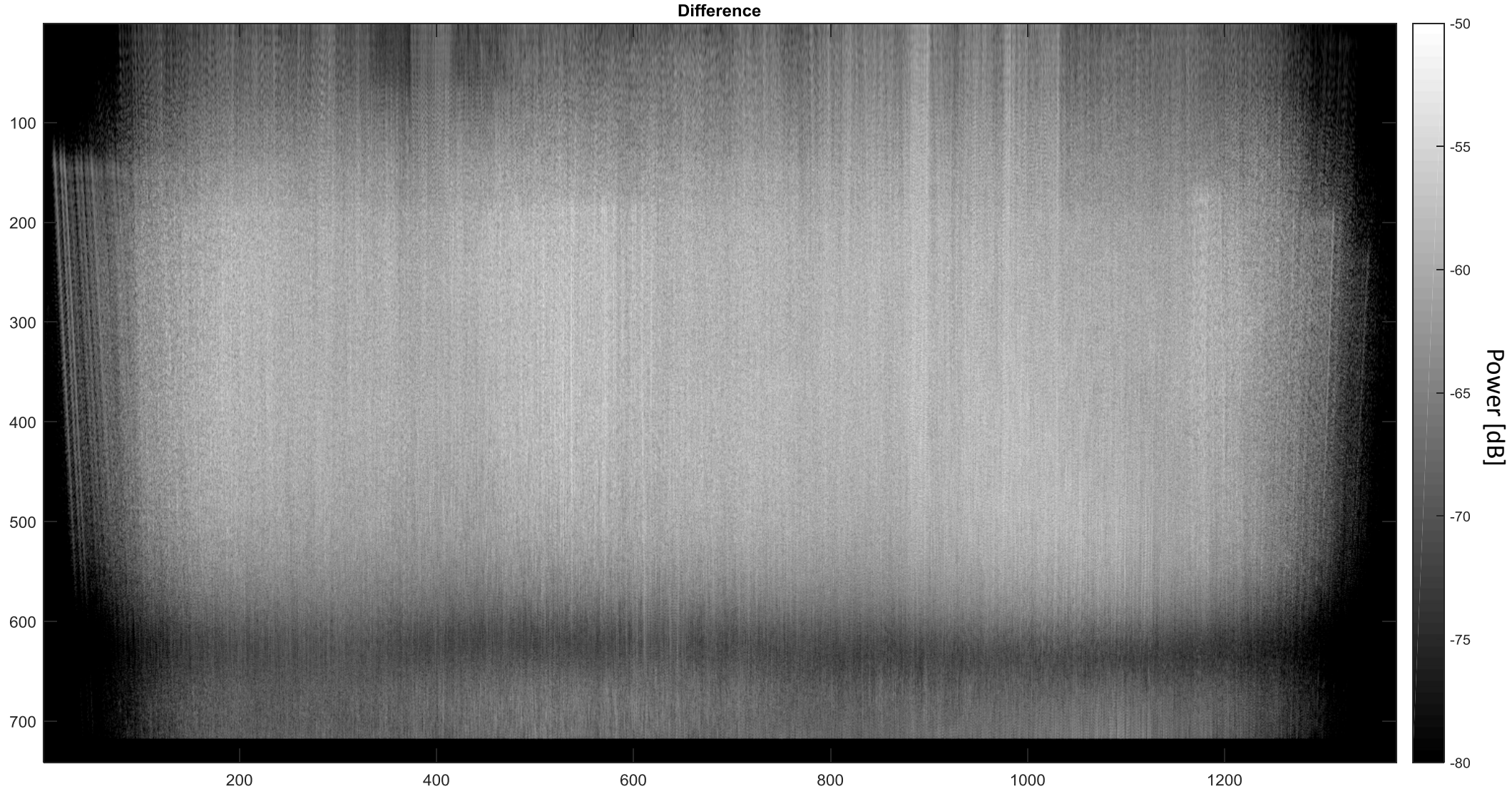


Ratio (before/after)

RFI Mitigation Test (HV-Channel)



RFI Mitigation Test (HV-Channel)