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)
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

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-continuous RFI sources

RFI @ 424.63MHz

RFI @ 459.72MHz
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
IDEA: If the RFI signal at this frequency comes from one dominant source:
→ Signal should only differ in phase due to spatial antenna element separation
   (And magnitude due to calibration)

Without antenna pattern knowledge:

RFI signal in a frequency bin at 4 different channels

Channel Comparison

Complex Magnitude

Azimuth-Time Sample
(Timespan 88s)
Without antenna pattern knowledge:

1. Estimate AoA at each frequency bin
2. Steer to AoA
   \[\rightarrow\] Extracts reference signal of RFI, noise
   and SAR from same direction
3. Subtract this reference from each channel
   with phase shift according to AoA

IDEA: If the RFI signal at this frequency comes from one dominant source:
\[\rightarrow\] Signal should only differ in phase due to spatial antenna element separation
(And magnitude due to calibration)
Resulting antenna pattern for this method

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
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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

Estimated DoA

Channel Comparison

Entire Spectrum

Bin 2204

Suppression CH: 20.3074dB
Suppression Spectrum: 16.5224dB

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

RAW SAR Data → SCORE → Downlink → Focusing → RFI Filtered

RAW Sniffing Pulse (or listening before first return) → Threshold Bins → AoA → Ref-Signal → Downlink → Create RFI RAW

Subtract

Focusing

SCORE
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 $2k$ percent** (respectively to the transmission 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)
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)

Nadir Nulled, No RFI Filter

Costa Rica on March 31st 2014
RFI Mitigation Test (HV-Channel)

Costa Rica on March 31st 2014
RFI Mitigation Test (HV-Channel)