Some Results from the Real-time RFI Excision System of uGMRT

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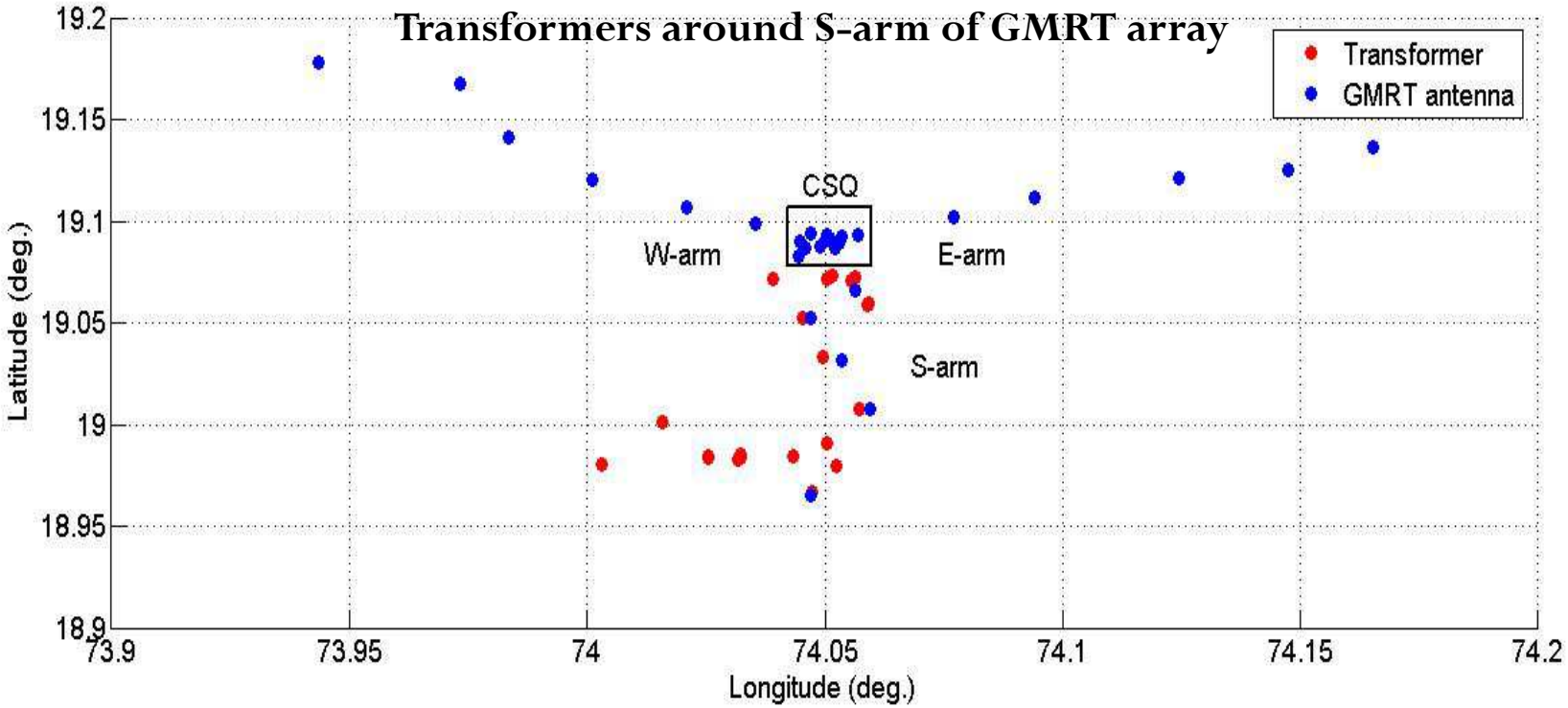
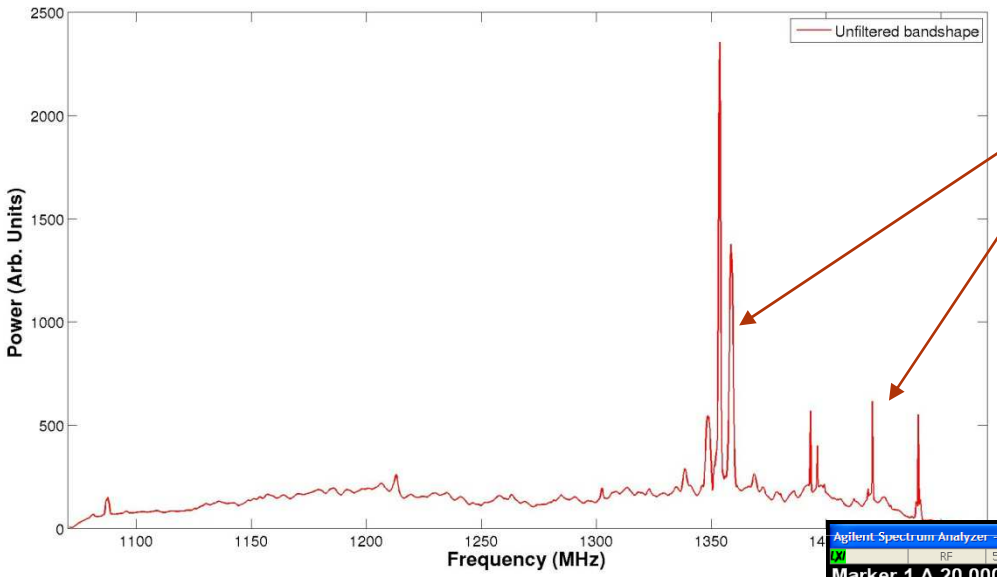
Major Sources of RFI at GMRT

- Broadband RFI
  - Sparking on power-lines
  - Corona Discharge
  - Automobile sparking
- Narrowband RFI
  - Communication transmitters
  - Broadcast TV / Radio
  - Satellites



Data Courtesy: Pravin Raybole, RFI Group, GMRT

RFI at GMRT

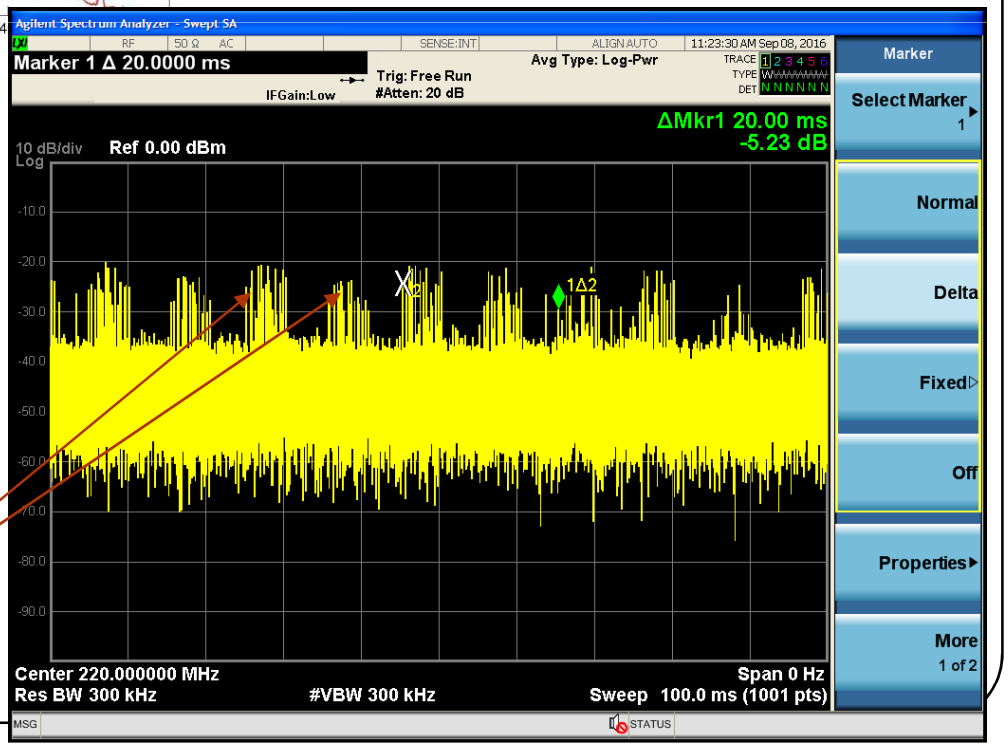


Narrowband RFI

RFI

Broadband RFI is stronger at lower radio frequencies

Broadband RFI



Examples showing impulsive time and frequency domain RFI observed at the GMRT

RFI is usually 30-40 dB stronger than the system noise

RFI

Why Real-time ?

- Temporally impulsive RFI: Energy spreads post-FFT hence excision is needed before FFT.
  - Power-line RFI: Low duty cycle but high spectral occupancy
  - RFI is correlated in closely spaced antennas
- Spectrally impulsive RFI: RFI excision useful for low time occupancy
- Best possible time resolution: reduction in loss of astronomical data due to flagging
- Leads to improvement in receiver sensitivity

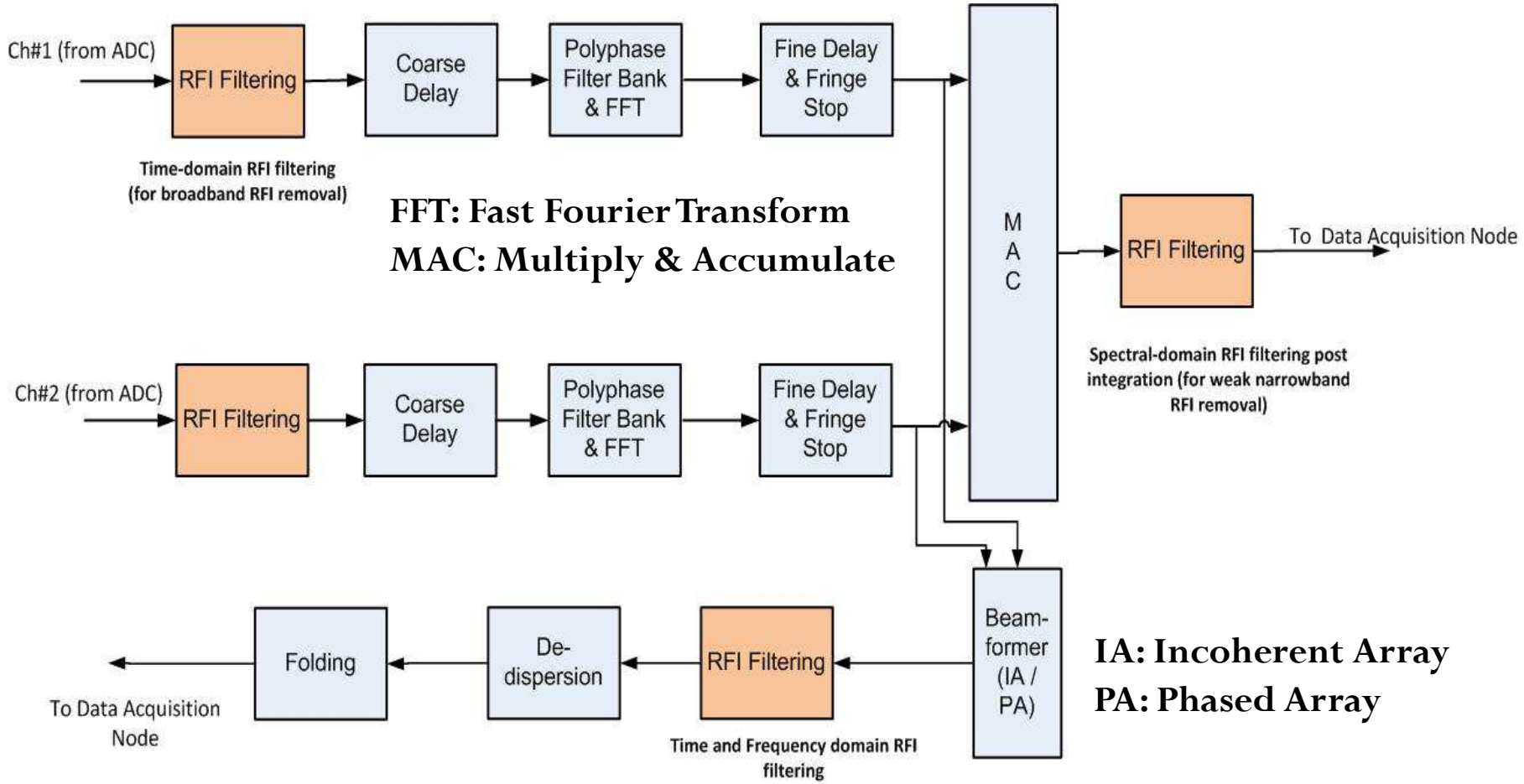
A stitch in (real) time saves nine !

RFI Excision for uGMRT

- RFI in astronomical data – outliers make Gaussian distribution heavy-tailed
- Excision assumes that RFI is much stronger than the astronomical signal
- Robust threshold using Median Absolute Deviation for RFI detection
- Excision by replacing the RFI affected samples by constant value or noise or threshold
    - Implemented in temporal and spectral domains

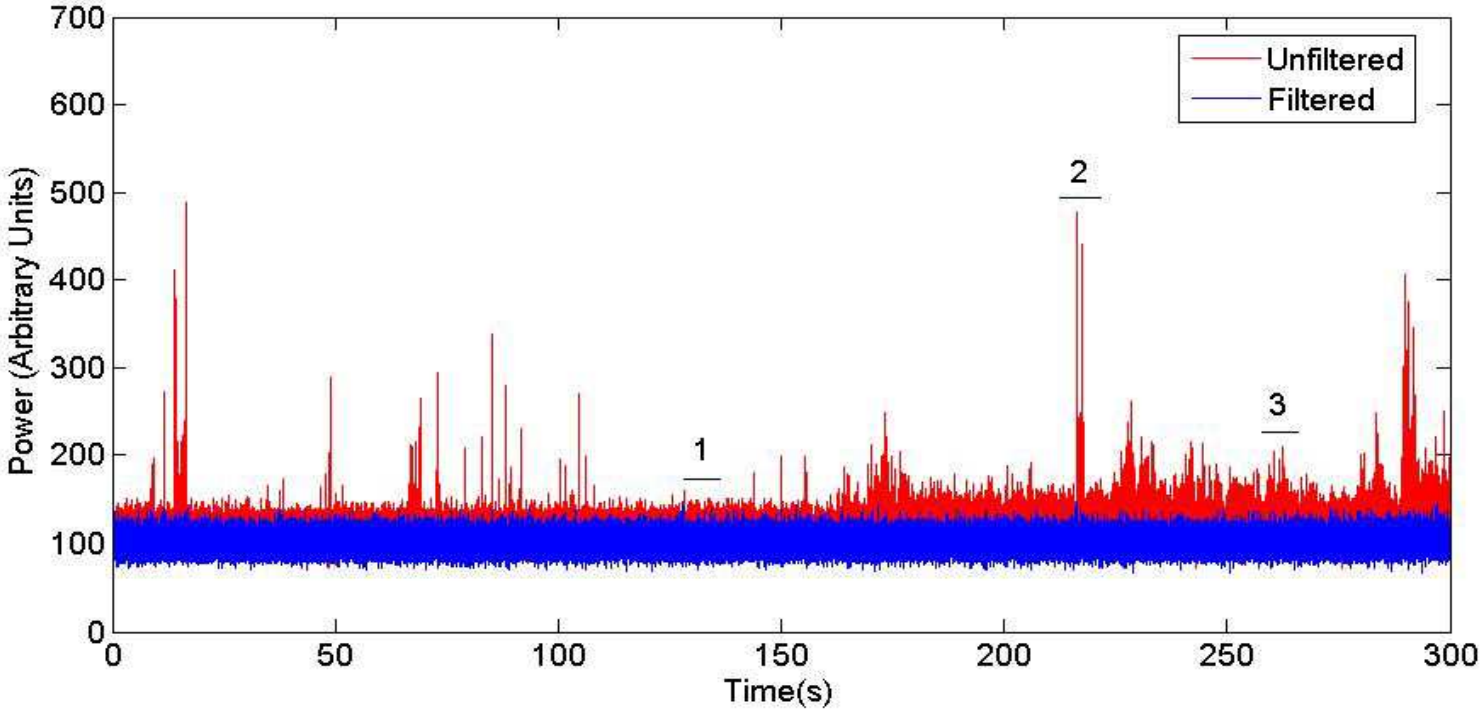
Buch et. al, "Towards Real-time Impulsive RFI Mitigation for Radio Telescopes", JAI Special Issue, 2017 http://www.worldscientific.com/doi/abs/10.1142/S225117171641018X
Buch et. al, "Real-time RFI excision for the GMRT wideband correlator", RFI-2016 conference proceedings, 2016 http://ieeexplore.ieee.org/abstract/document/7833523/

RFI Mitigation in GMRT Wideband Backend



- Requires implementation at multiple locations in the processing chain to remove diverse types of RFI
- Broadband RFI filtering is carried out in real-time on Nyquist-sampled digital time-series (for each antenna) at 800 MHz

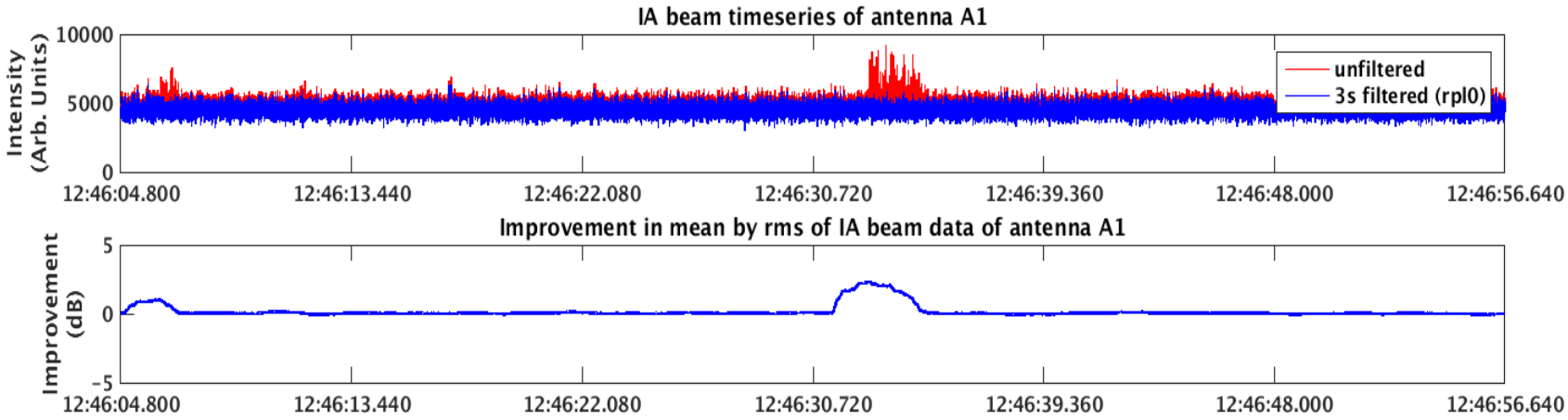
Quantitative Metric for filtering



Parameter	Unfiltered Output			Filtered Output		
	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Mean / RMS ratio	10.89934	4.7044	8.5987	11.9863	11.9689	10.9659

Theoretical: √(B*T) =√ ((200e6/2048)*1.31ms) = 11.31

Test Results (Antenna signals)



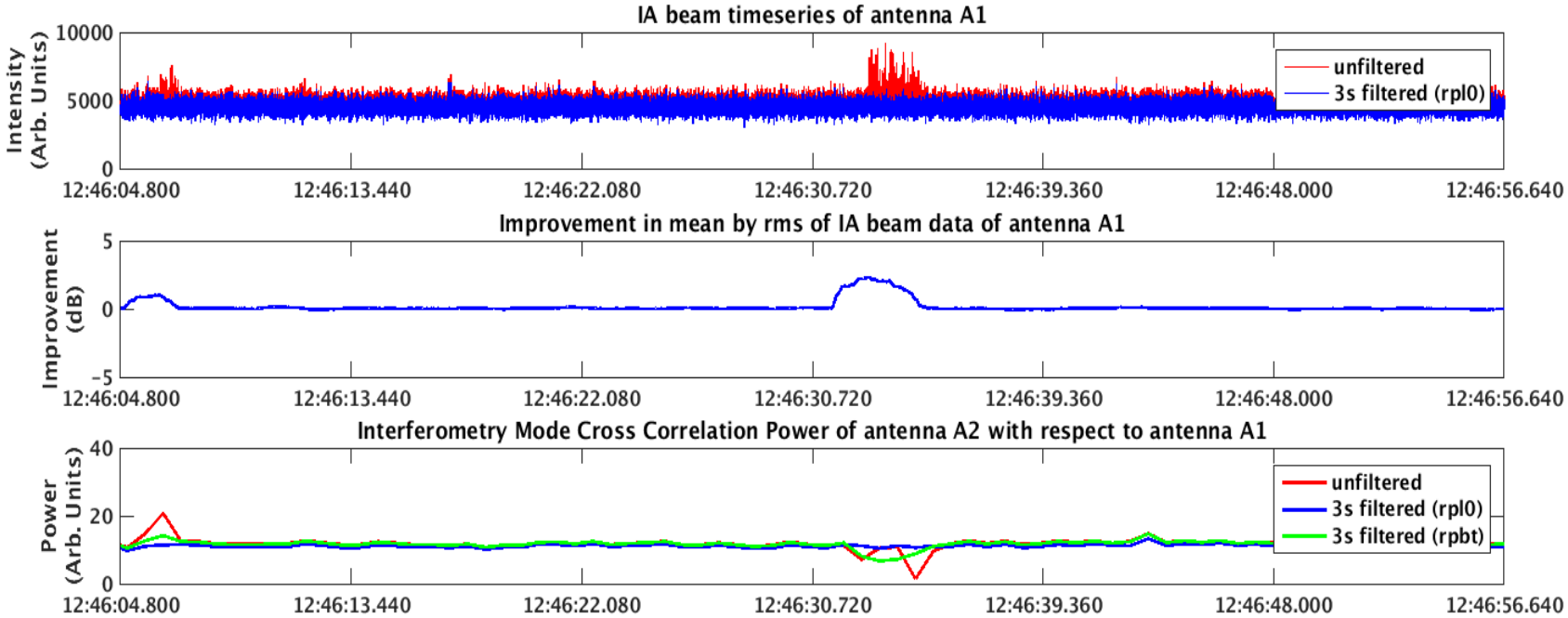
Single spectral channel (650 MHz) plot over time (Incoherent Array mode) at 1.3 ms time resolution for filtered and unfiltered outputs

Improvement (dB):

$$I = 10\log(MR\_F/MR\_U)$$

MR_F and MR_U are the mean/rms ratio for filtered and unfiltered signal respectively. Running mean/rms calculated over 1024 samples of IA beam output

Test Results (Antenna signals)

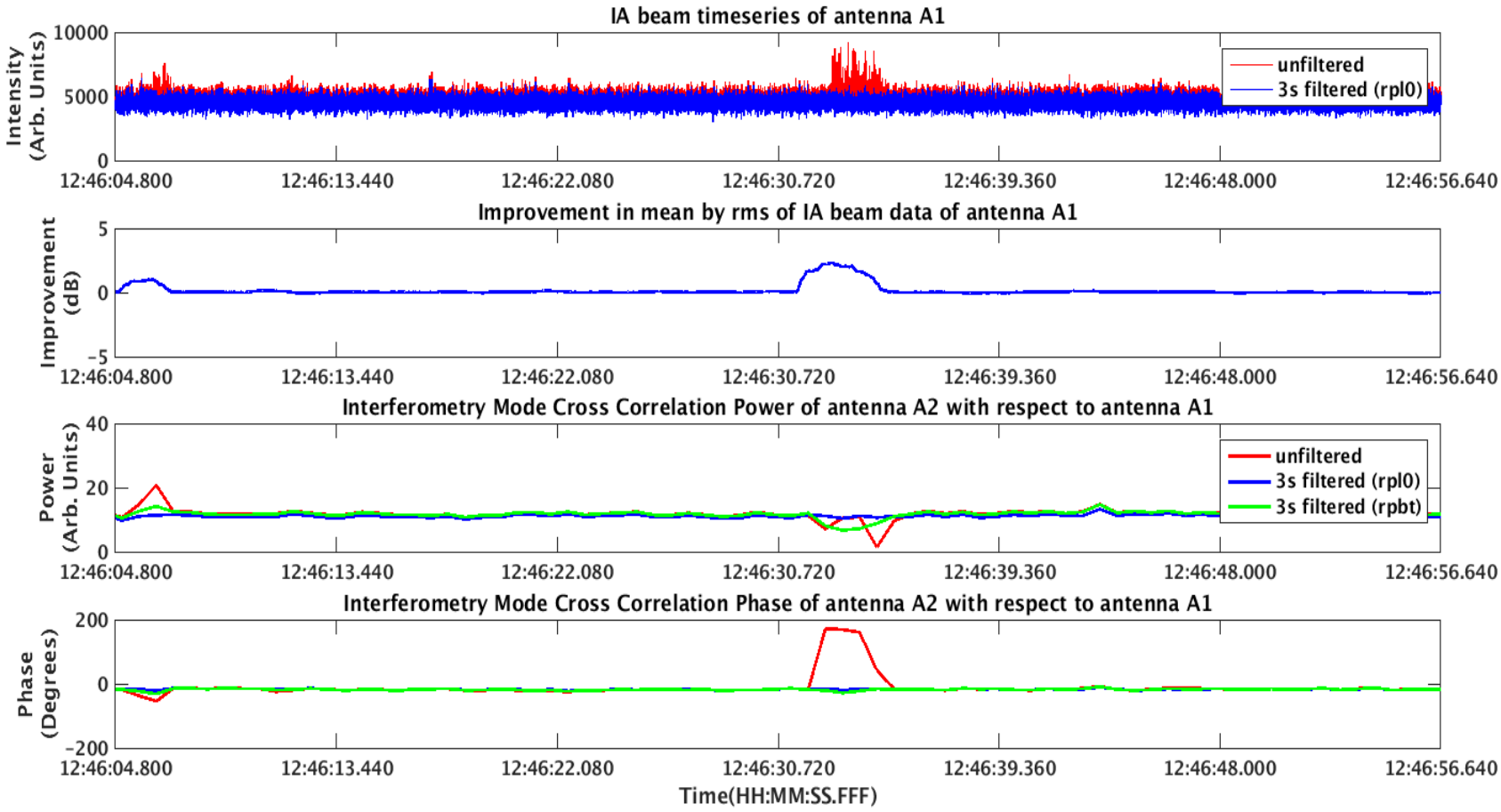


Coarse time resolution (671 ms)

Cross-correlation magnitude (unnormalized)– options – filtered vs filtered, and unfiltered vs unfiltered for short baseline

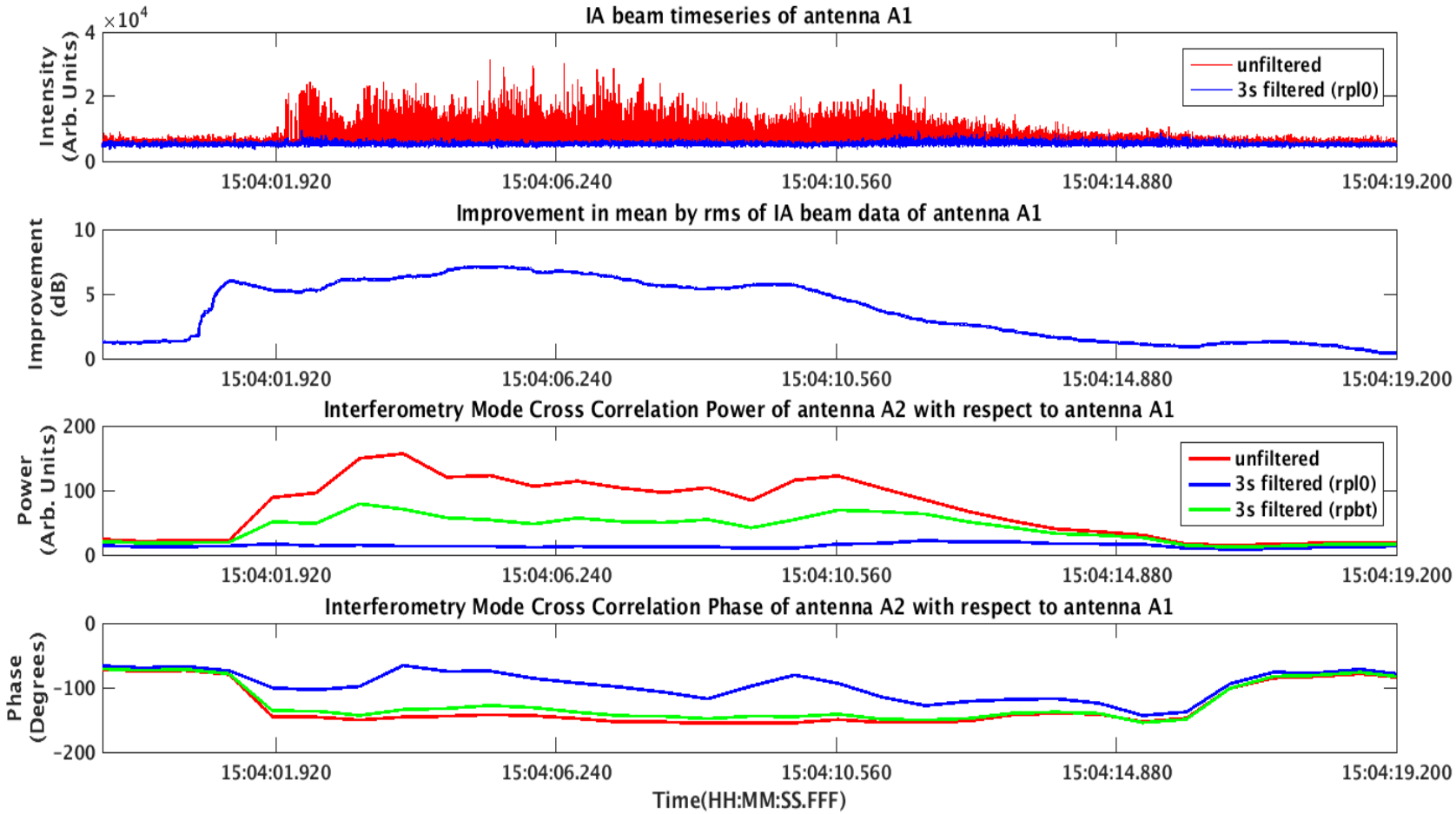
Beam and correlator output of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

Test Results (Antenna signals)



Beam and correlator output of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

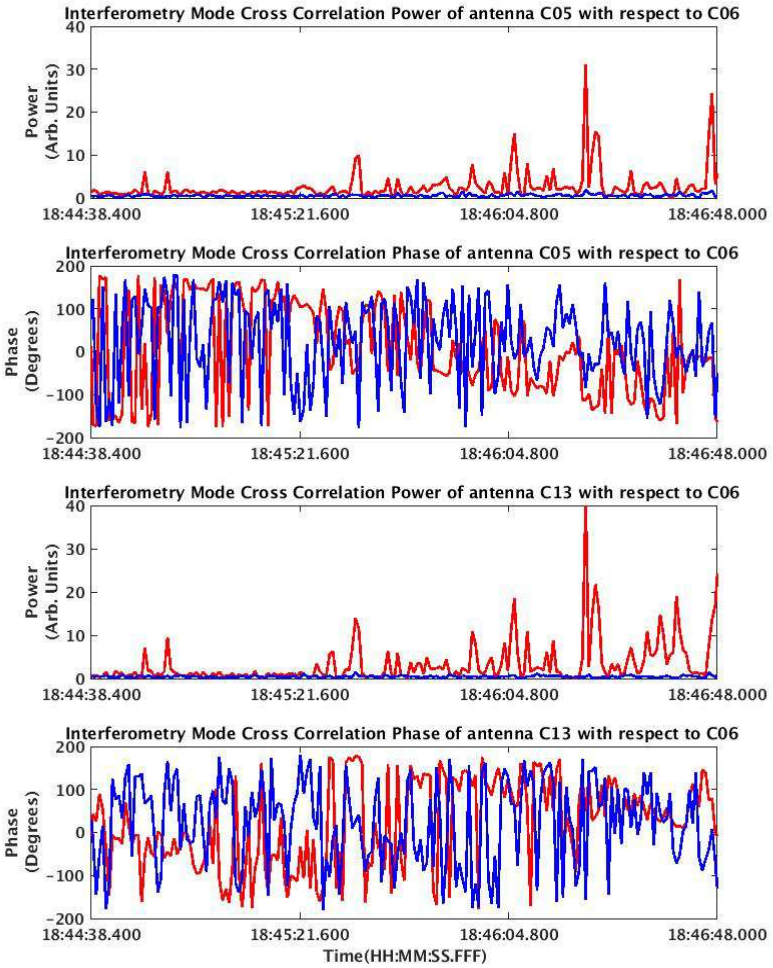
Test Results



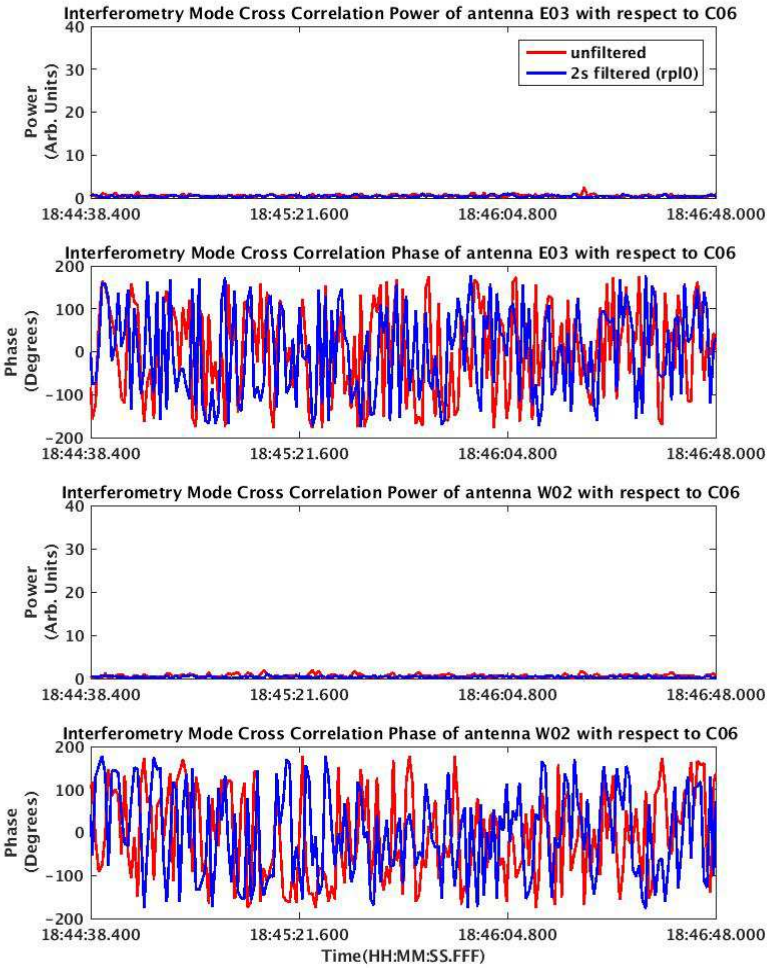
Beam and correlator data of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

Off-source tests (250-500 MHz)

Shorter Baselines (magnitude and phase)



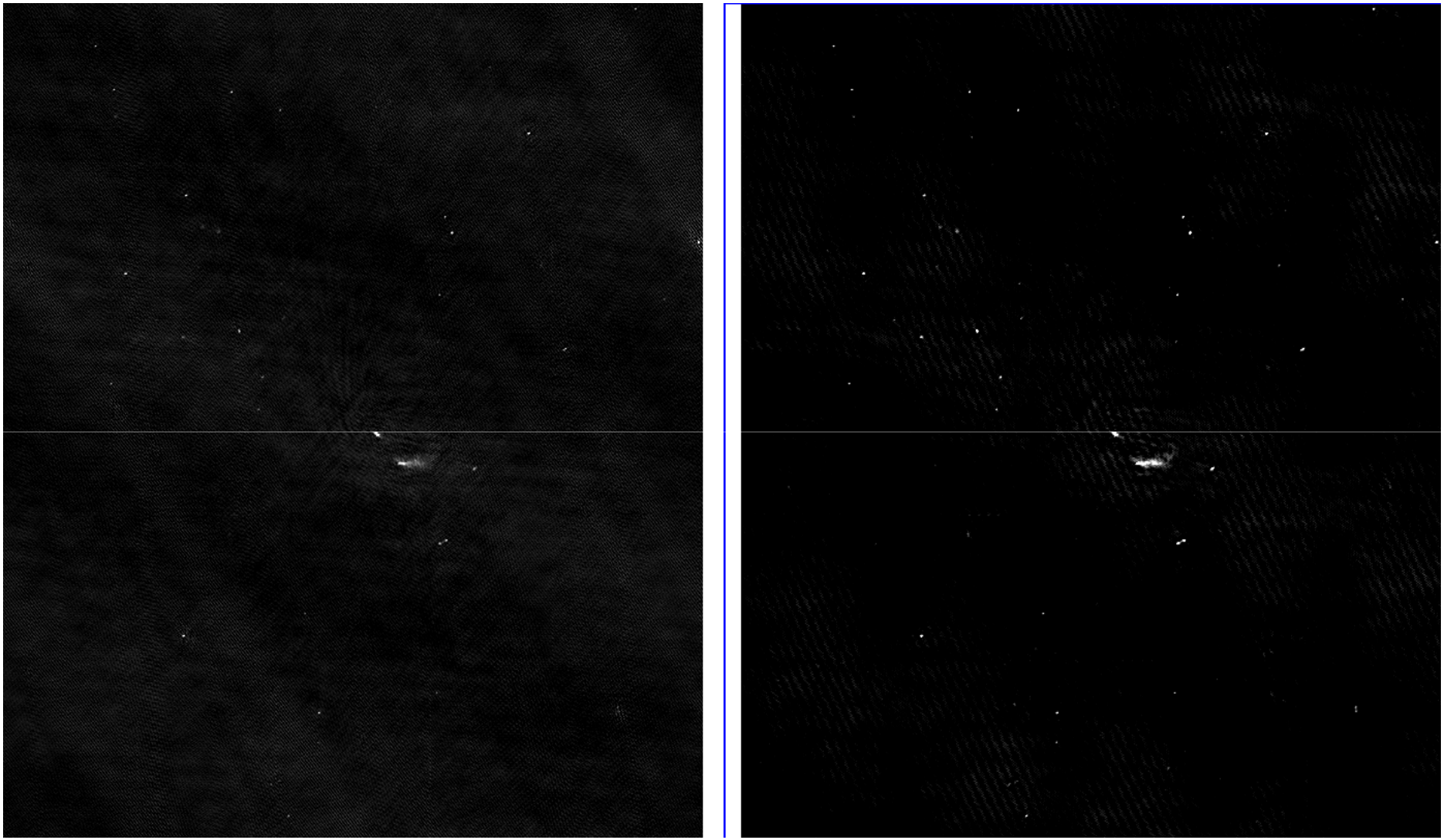
Longer Baselines (Magnitude and phase)



5 degrees off-source, shows correlated RFI, Filtering at 2 sigma threshold (replaced by zero), unfiltered in red color, filtered in blue color

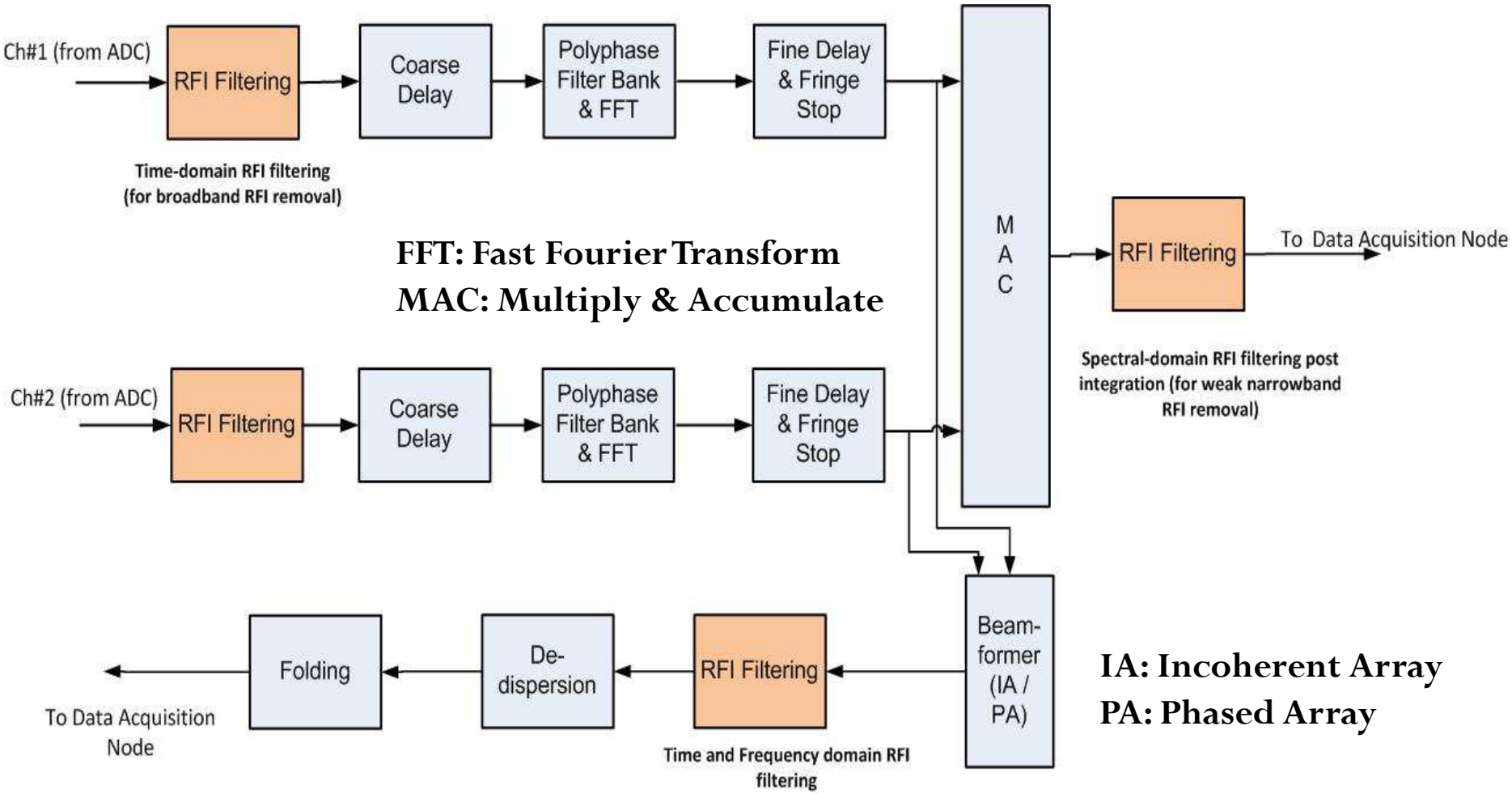
First Image

Image Courtesy: Dharam Vir Lal



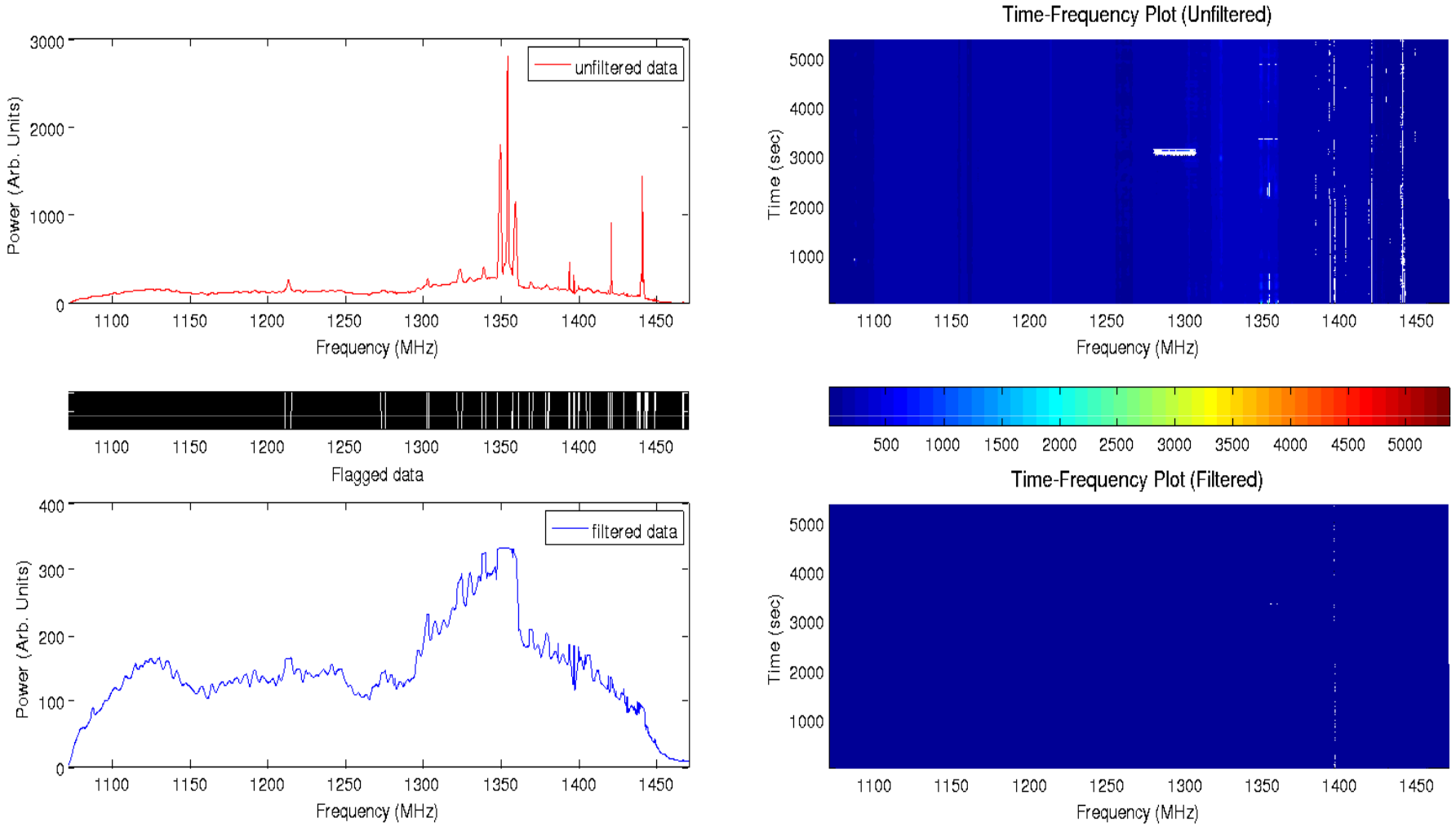
250-500 MHz, 16 antennas, Pol.-1 (left, without filter) & Pol.-2 (right, with broadband RFI filter), factor of two improvement post-filtering

Spectral Domain RFI Filtering



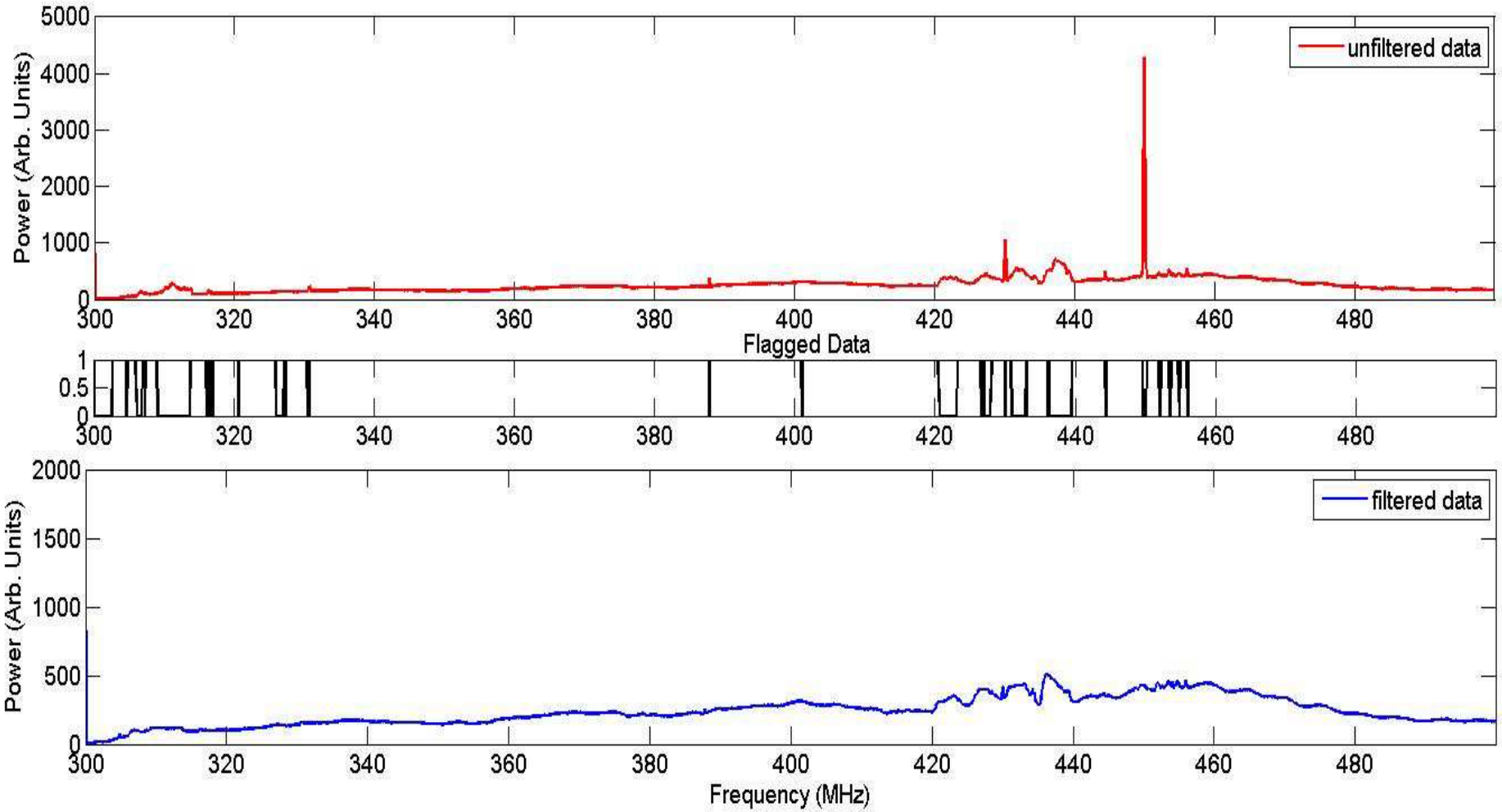
Real-time Narrowband RFI Mitigation is carried out post-integration at 0.671s integration on visibilities

Narrowband filtering on GWB data

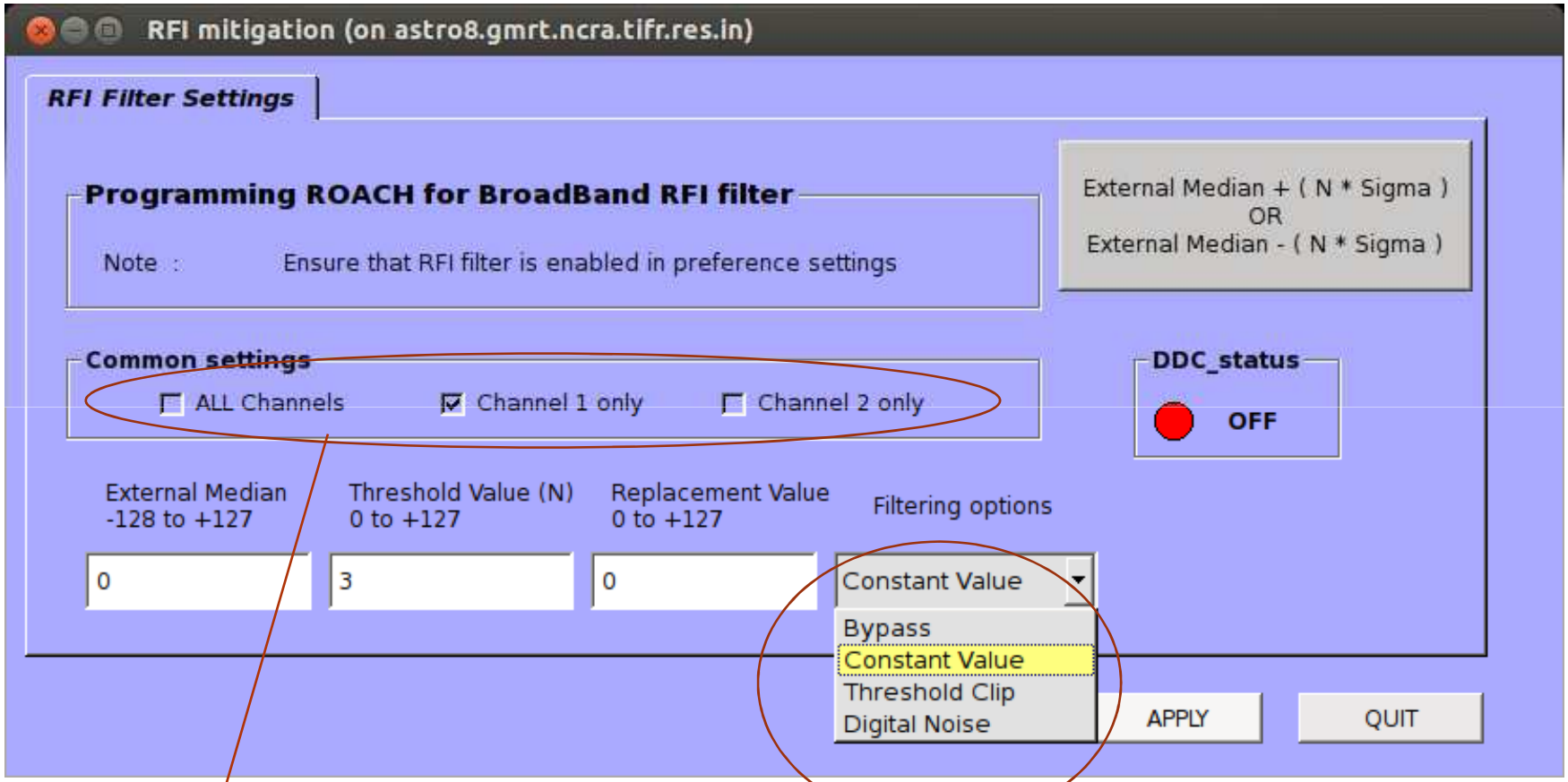


Narrowband RFI filtering on GWB-3 recorded data (L-band)
5000 s data single-antenna plot

Narrowband RFI filtering (250-500 MHz)



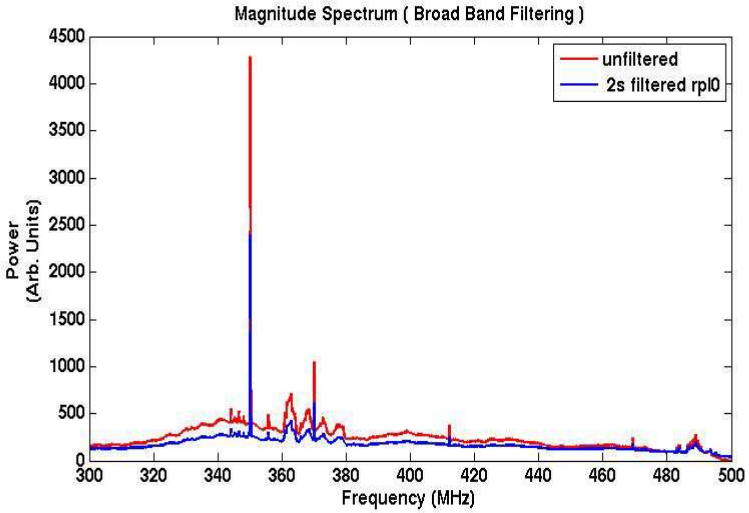
Real-time RFI Filtering: Features

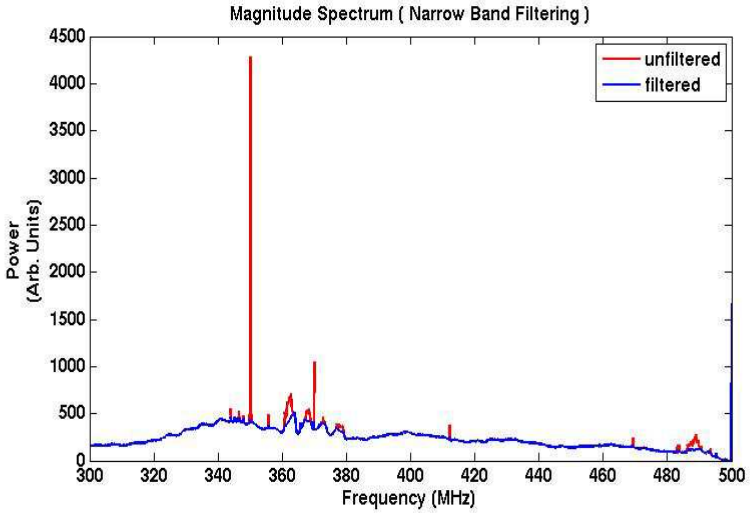


Can filter one or both polarizations

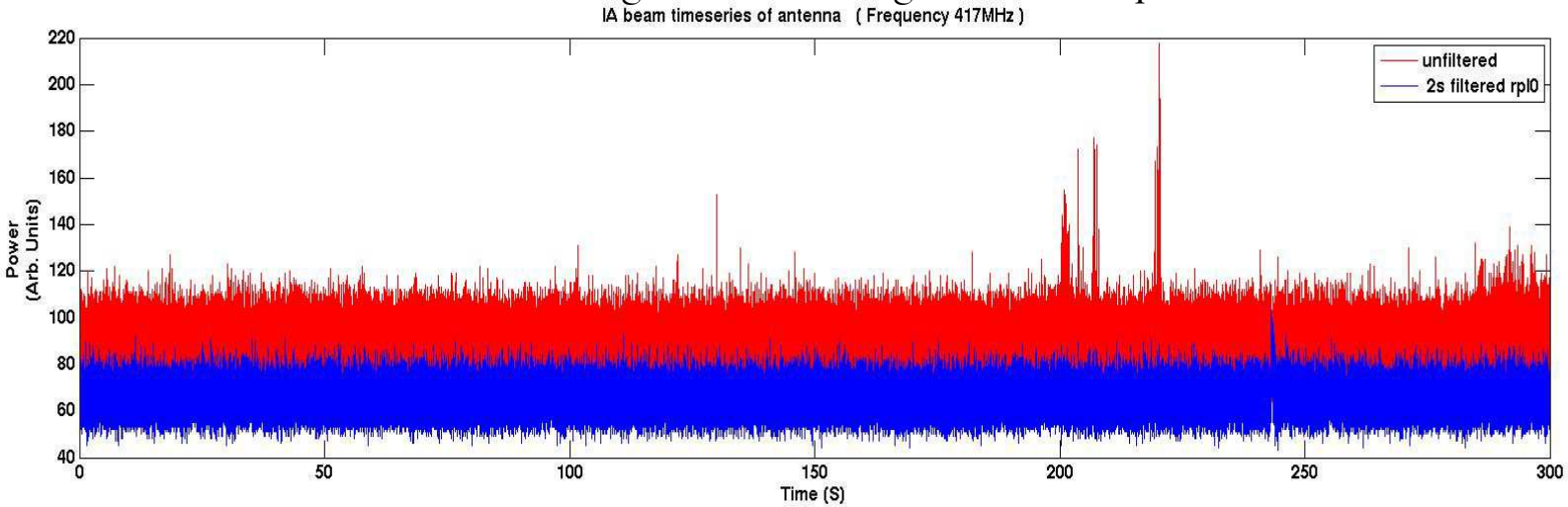
Includes option to bypass the filter

What to look for ?





Narrowband filtering removes strong lines in the spectrum



Broadband filtering affects total power in the spectrum as seen in the spectral time-series

Current Status & Plans

- Long-term experiments show about 10-12 dB improvement in signal-to-noise ratio; work going on to find the best sample replacement strategy for filtering
- Broadband RFI filtering – released and available for testing
- Facility to keep track of flagged samples (broadband RFI filtering) – March 2017
- Real-time narrowband RFI filtering along with weights per spectral channel for each visibility output – April 2017

Antenna	Timestamps	Total Count	Flag Count
C09	Mon 06-02-17 10:36:43:034387 IST	400000000	200000000
C09	Mon 06-02-17 10:36:43:054802 IST	0	0
C09	Mon 06-02-17 10:36:43:075124 IST	2458736	1762648
C09	Mon 06-02-17 10:36:48:668962 IST	400000000	200000000

Example window showing the total count and flag count for a particular antenna at a given time instance (zero in the count indicates a 'reset' to the counter)

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Tushar Sawadekar
Shriram Nerkar
Nishit Baburaj


Thank You!
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