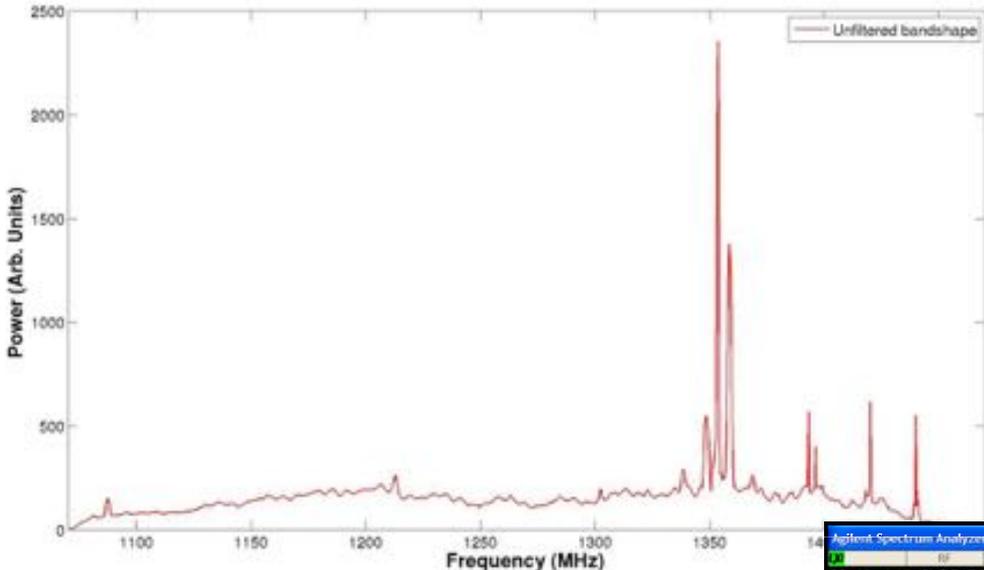


Results from Real-time RFI Excision System for uGMRT

Kaushal D. Buch
Yashwant Gupta, Ajithkumar B.

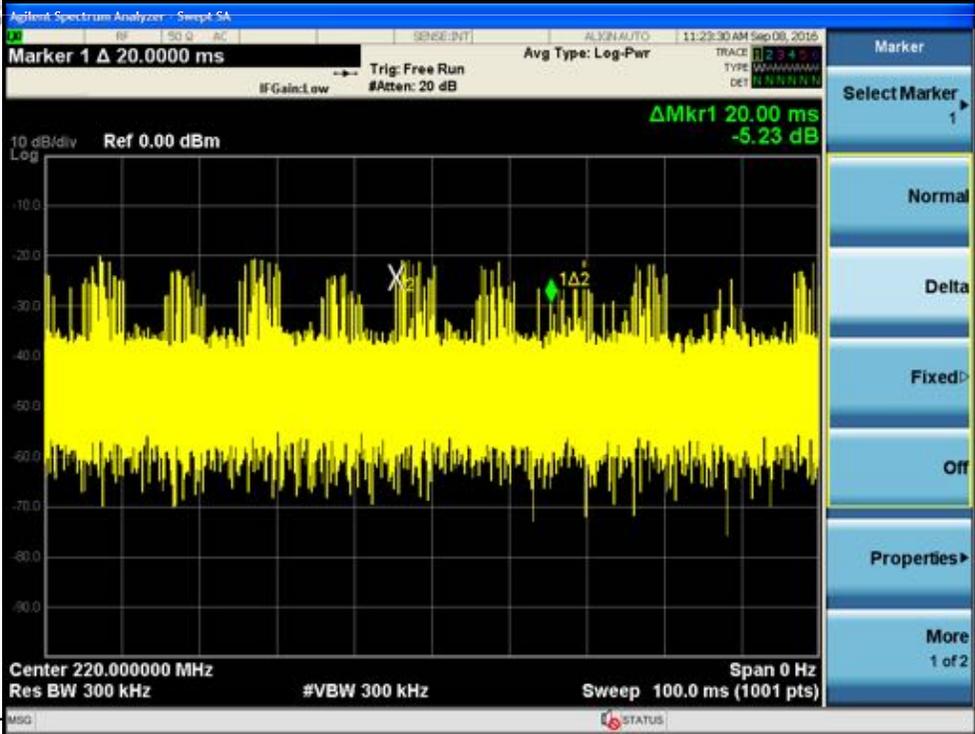
Digital Backend Group,
Giant Metrewave Radio Telescope
NCRA-TIFR, Pune, India
kdbuch@gmrt.ncra.tifr.res.in

RFI at GMRT



Narrowband RFI

Broadband RFI



RFI

Why Real-time ?

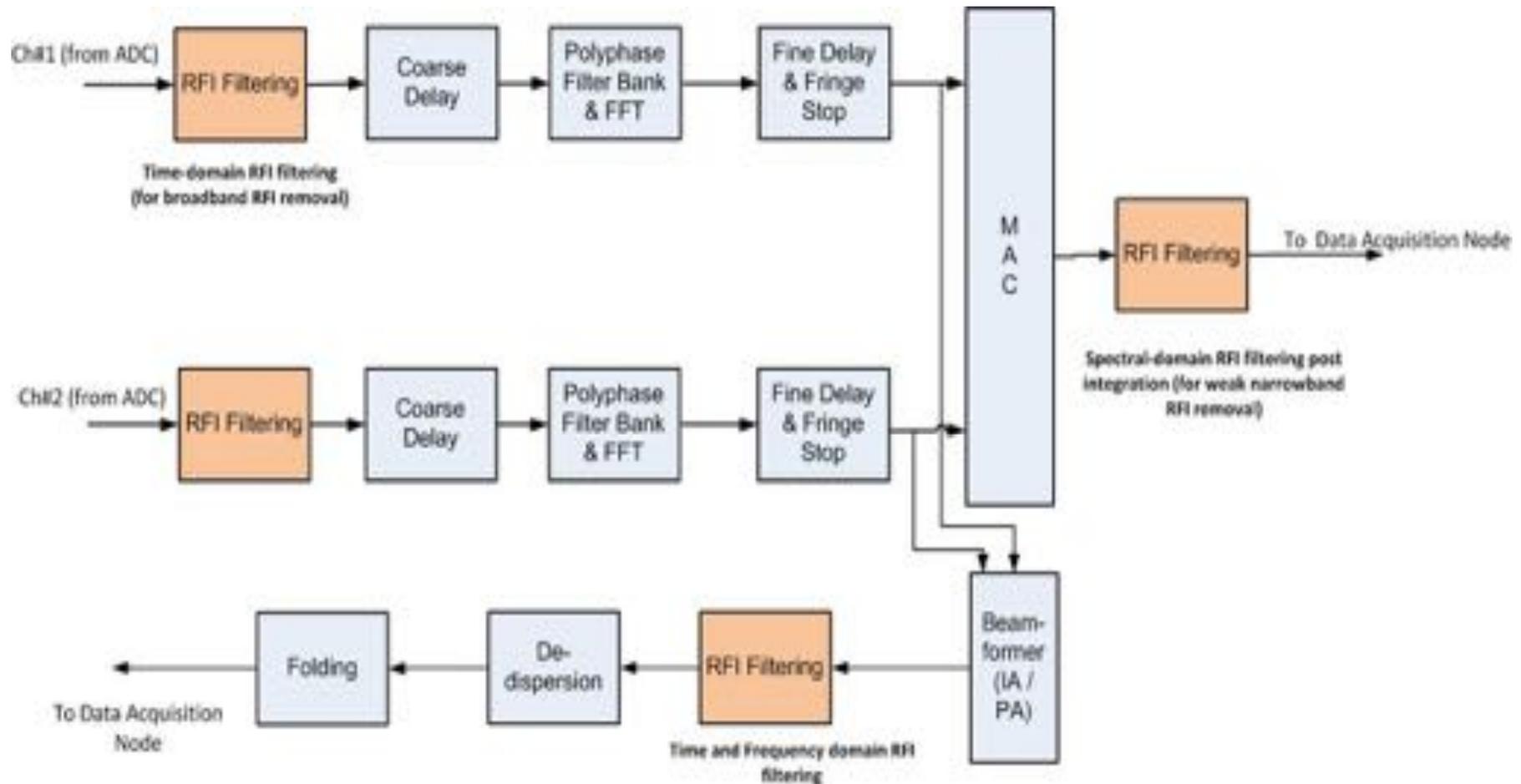
- Temporally impulsive RFI: Energy spreads post-FFT hence excision is needed before FFT.
 - Power-line RFI: Low duty cycle but high spectral occupancy
 - RFI is correlated in closely spaced antennas
- Spectrally impulsive RFI: RFI excision useful for low time occupancy
- Best possible time resolution: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

A stitch in (real) time saves nine !

RFI Excision

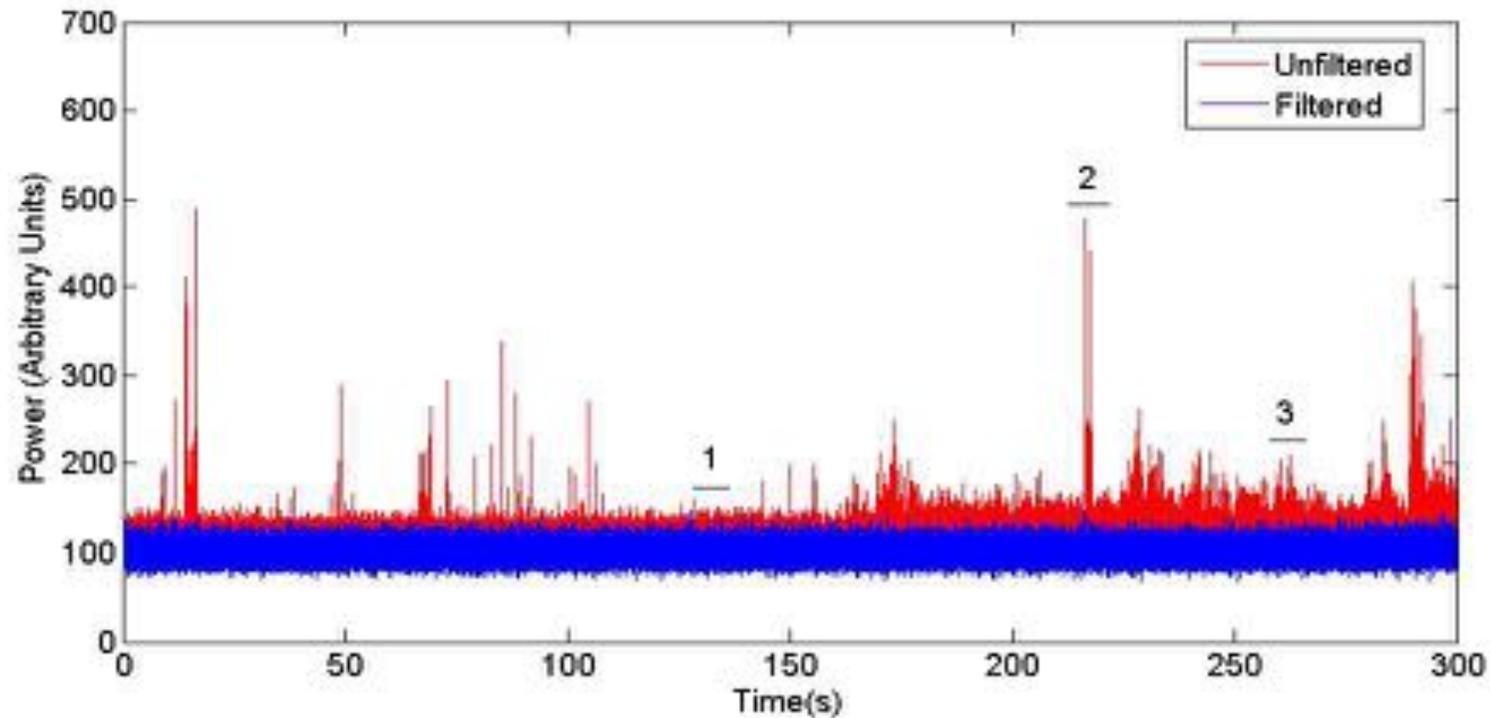
- RFI in astronomical data – outliers make Gaussian distribution heavy-tailed
- Excision assumes that RFI is much stronger than the astronomical signal
- Robust threshold using Median Absolute Deviation for RFI detection
- Excision by replacing the RFI affected samples by constant value or noise or threshold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

RFI Mitigation for GWB



❑ Requires implementation at multiple locations in the processing chain to remove diverse types of RFI

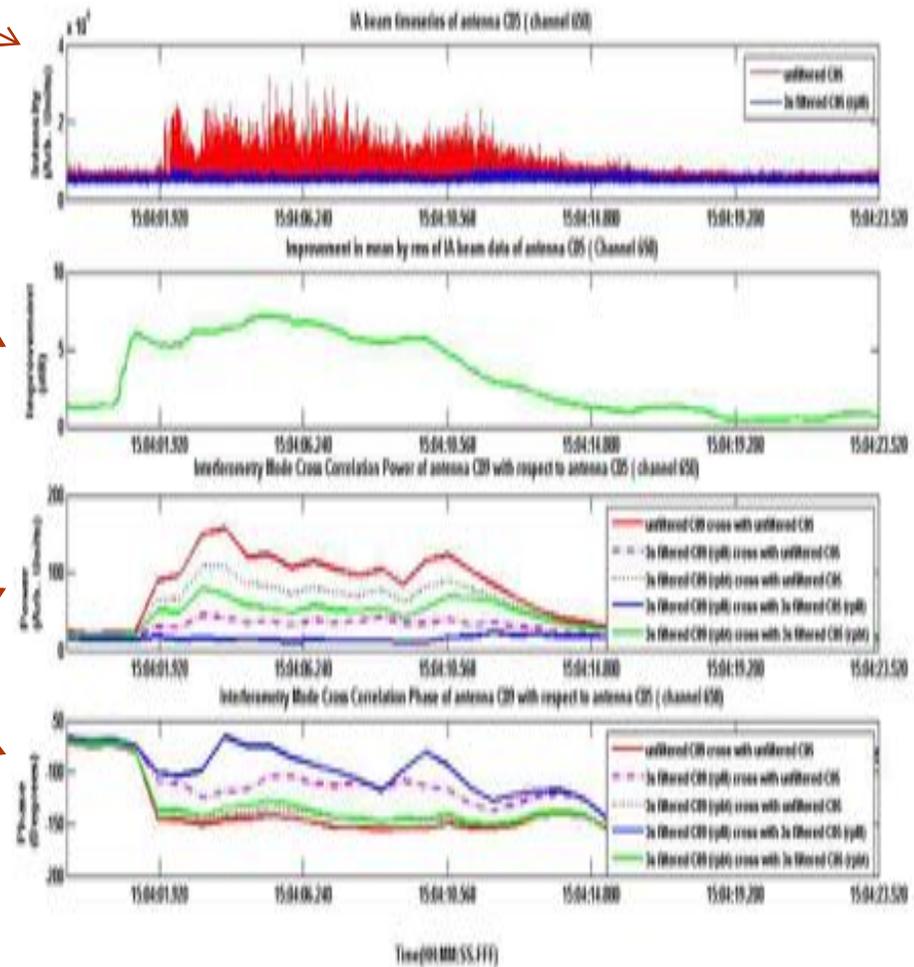
Quantitative Metric for filtering



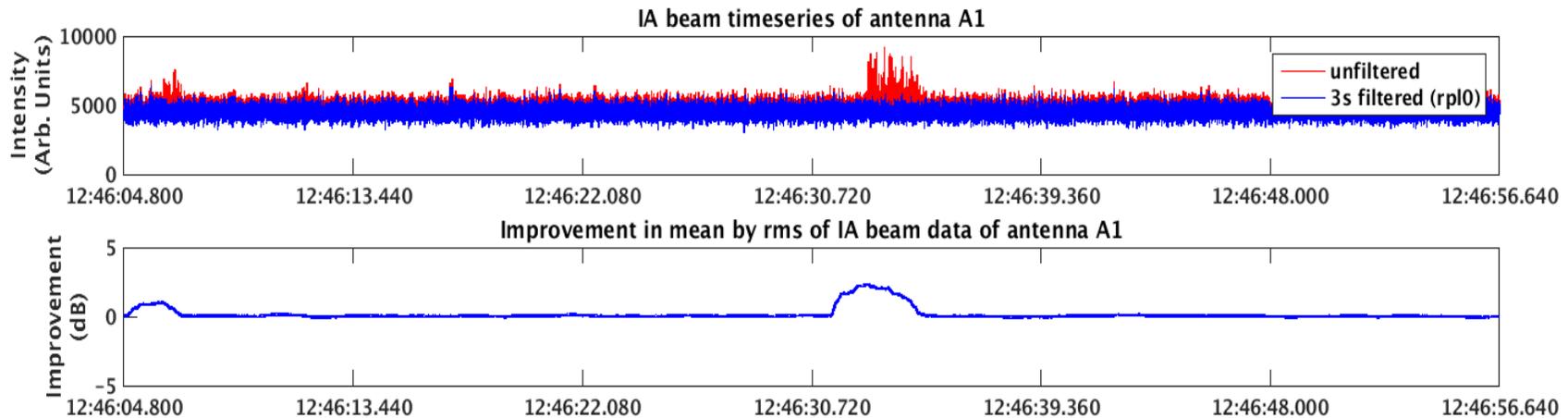
Parameter	Unfiltered Output			Filtered Output		
	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Mean / RMS ratio	10.89934	4.7044	8.5987	11.9863	11.9689	10.9659

Test Results

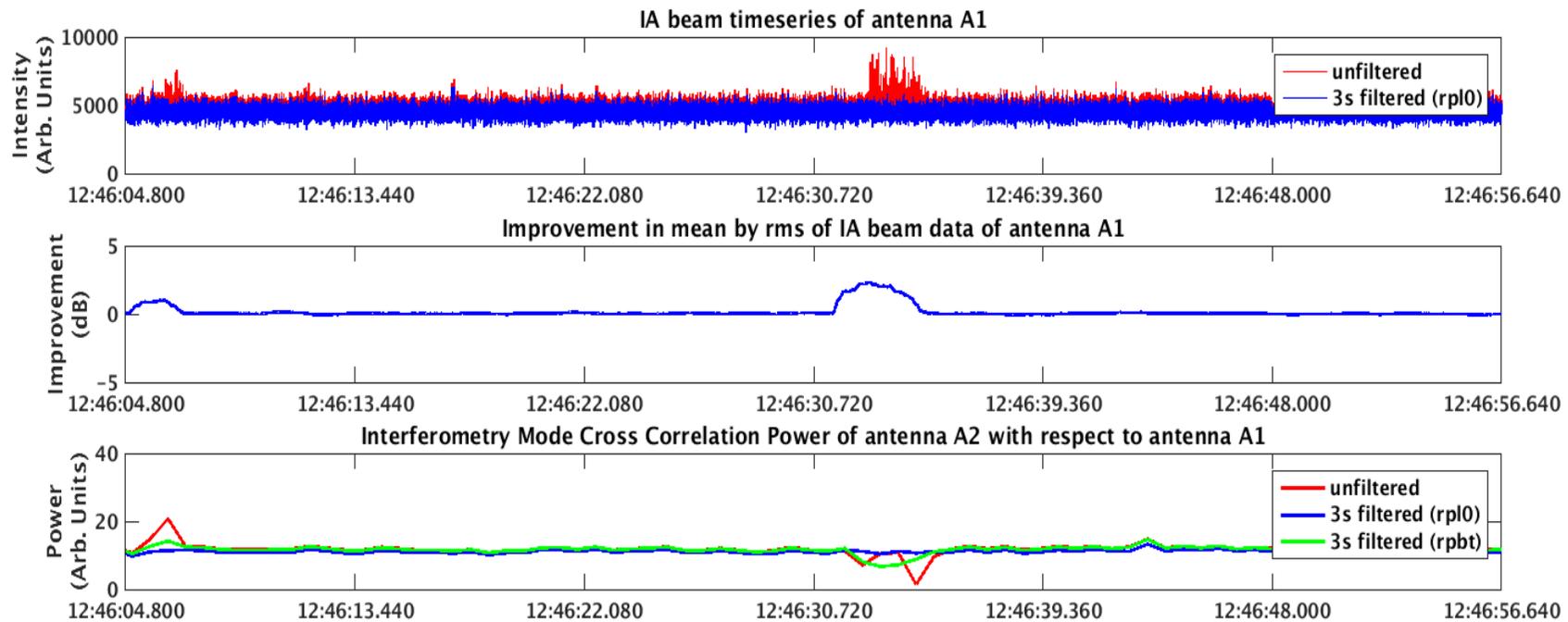
- **High time resolution:**
Single spectral channel (650 MHz) plot over time (IA mode) from the GWB at 1.3 ms time resolution for filtered and unfiltered outputs
- **Improvement (dB)**
 $I = 10\log(MR_F/MR_U)$
where MR_F and MR_U are the mean/rms ratio for filtered and unfiltered signal respectively. Running mean/rms calculated over 1024 samples of IA beam output
- **Coarse time resolution (671 ms):**
Cross-correlation magnitude (unnormalized) and phase – options – filtered vs filtered, and unfiltered vs unfiltered for short baseline



Test Results (Antenna signals)

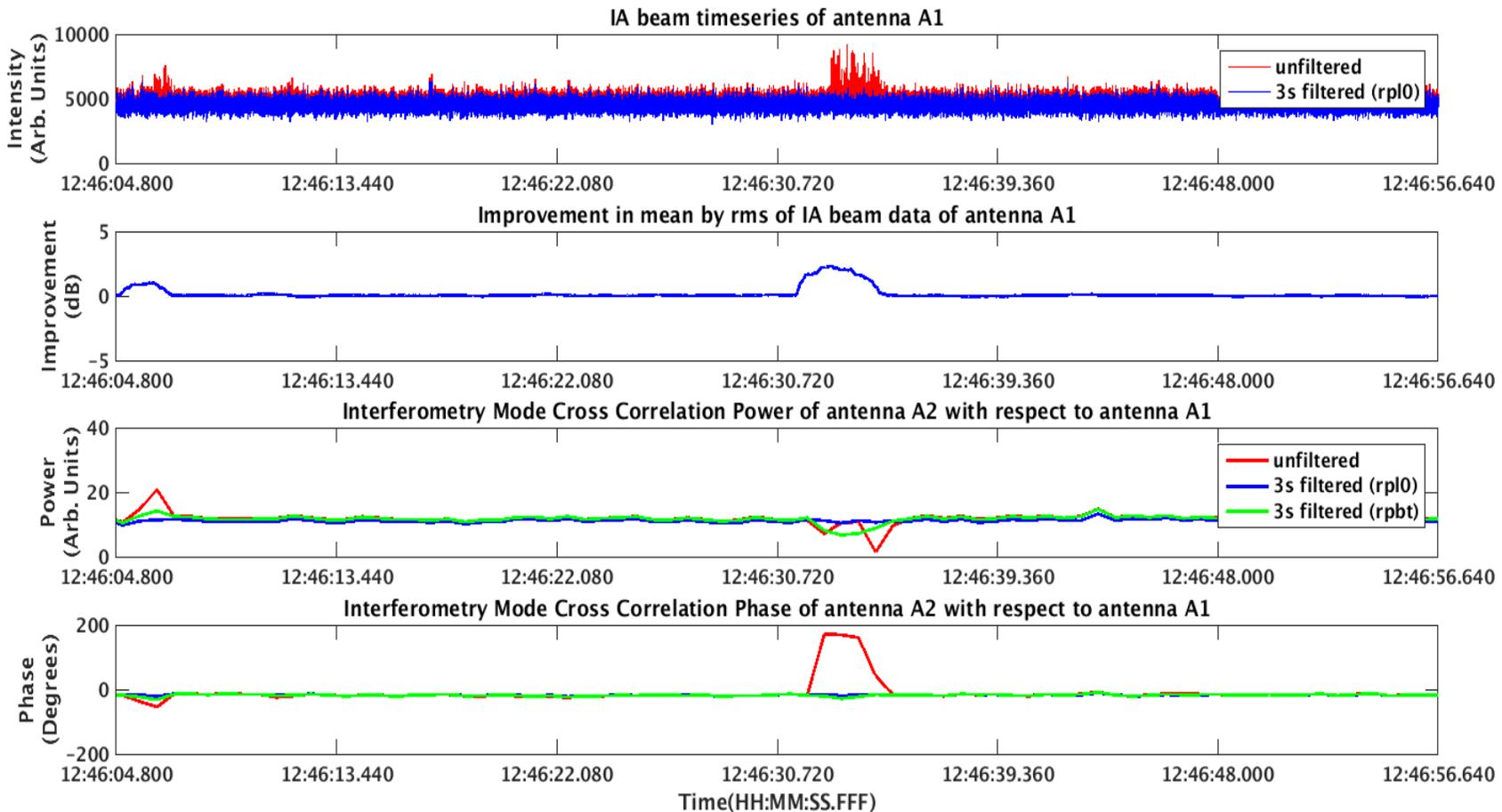


Test Results (Antenna signals)



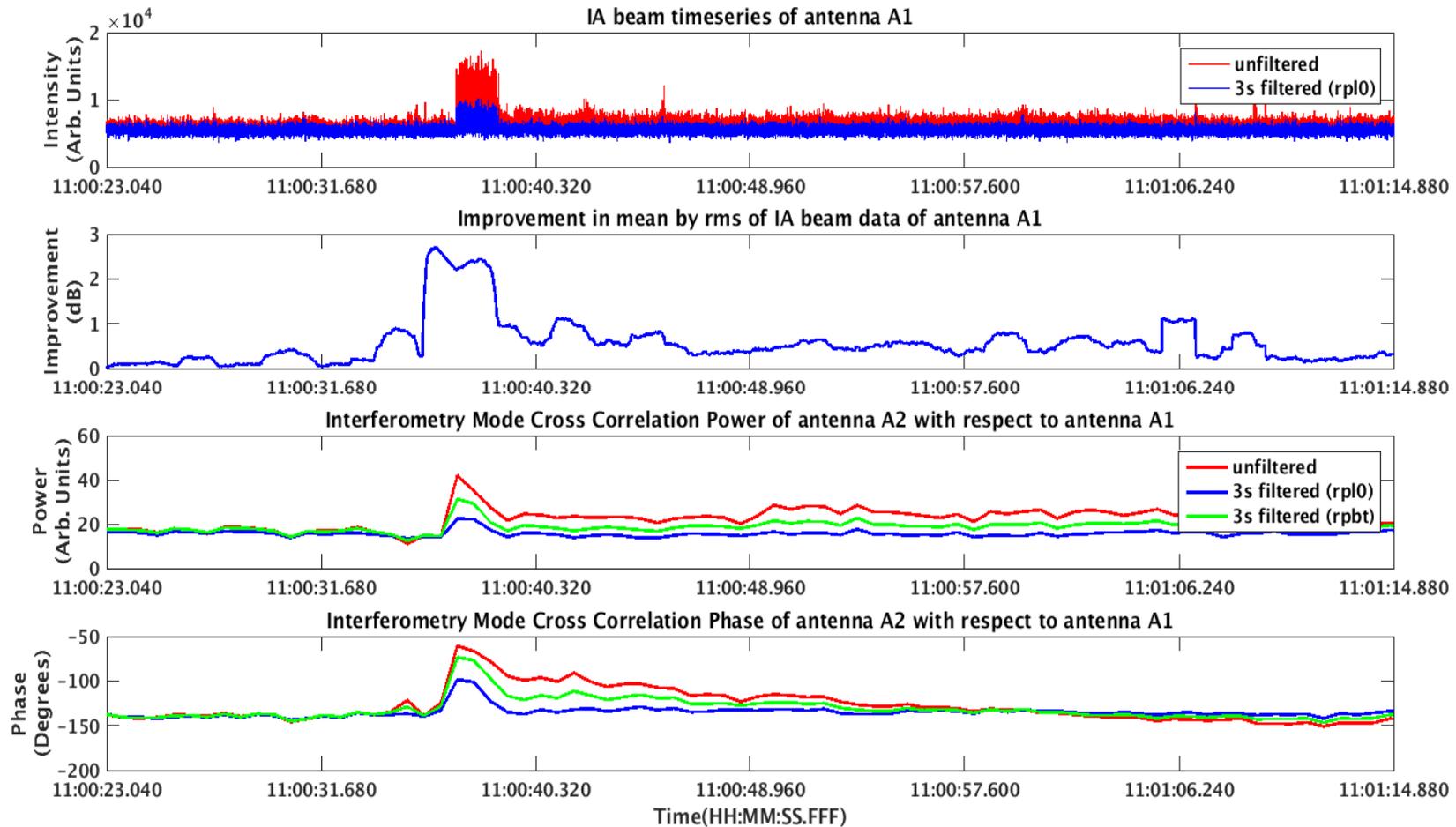
Beam and correlator output of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

Test Results (Antenna signals)



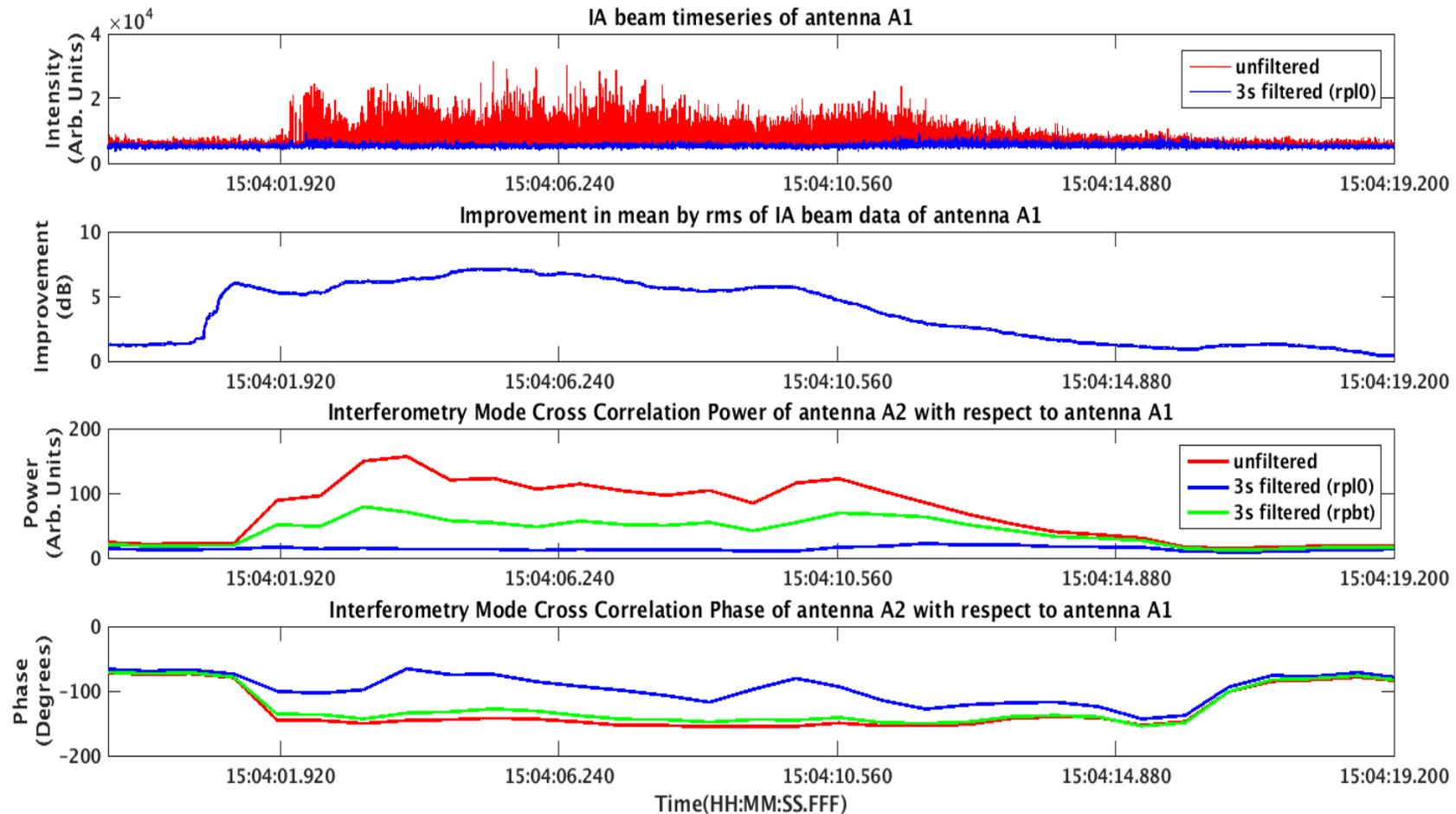
Beam and correlator data of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

Test Results

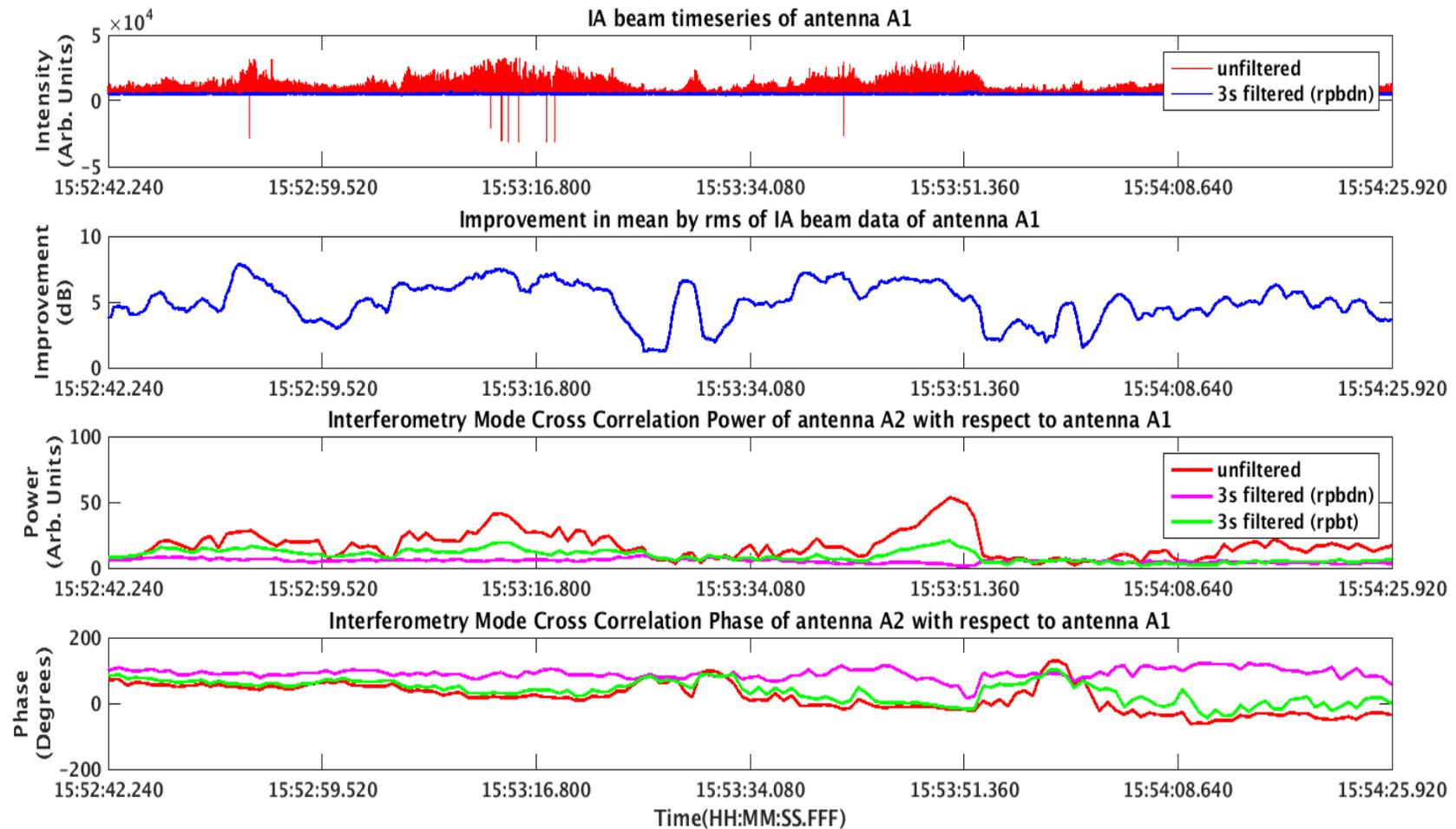


Beam and correlator data of a spectral channel showing filtering at 3σ threshold – replacement with zero and threshold

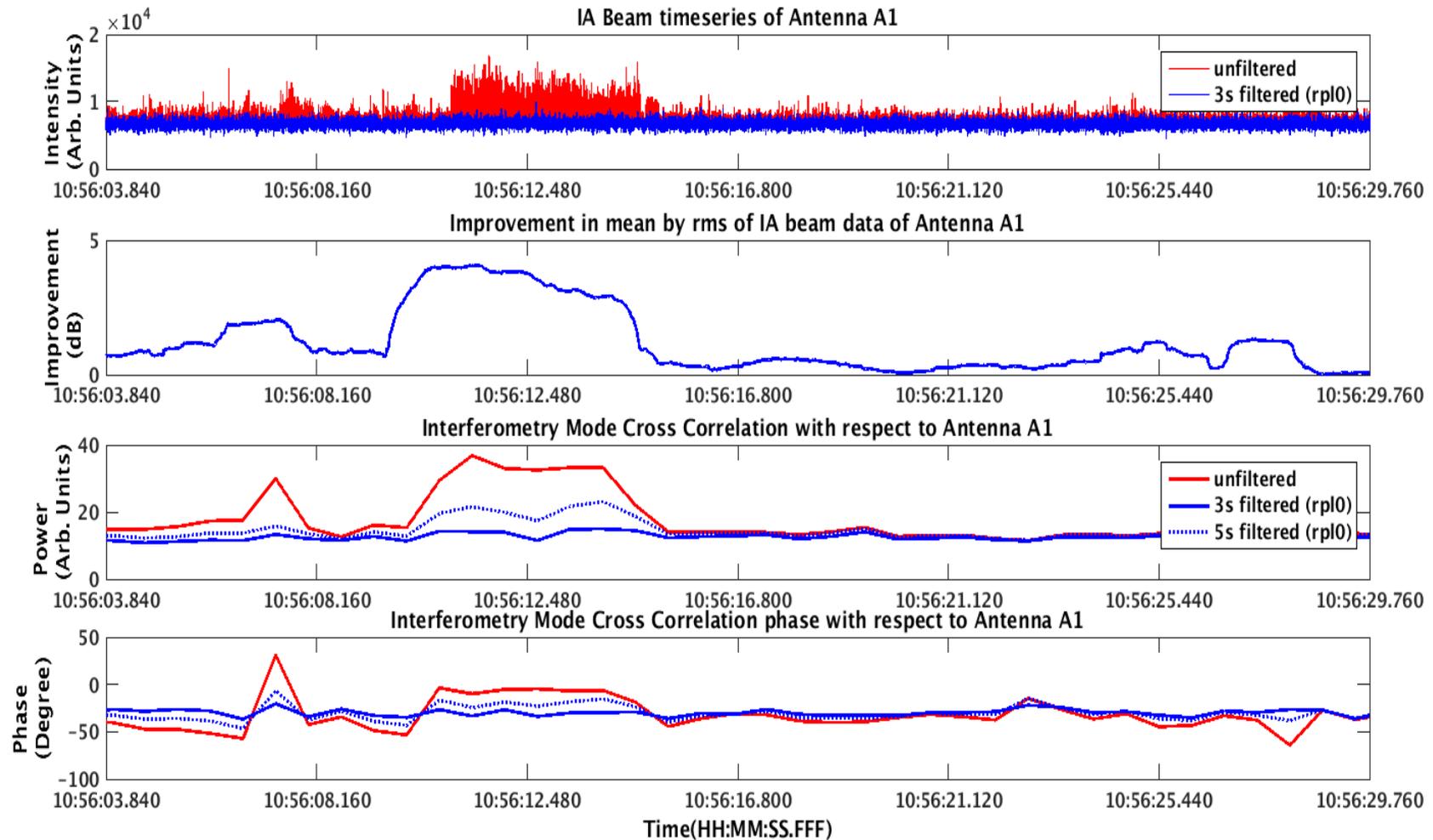
Test Results



Test Results



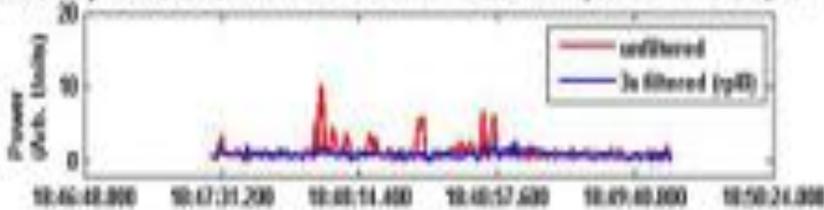
Test using different thresholds



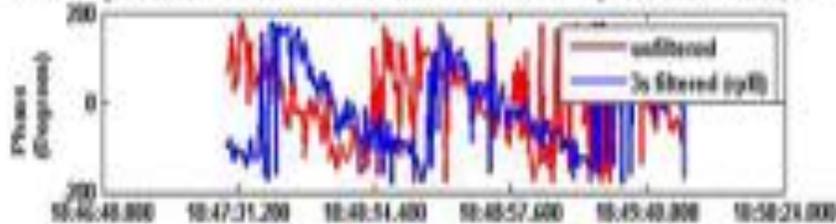
Beam and correlator data of a spectral channel showing filtering at 3σ and 5σ threshold – replacement with zero

Off-source tests (250-500 MHz)

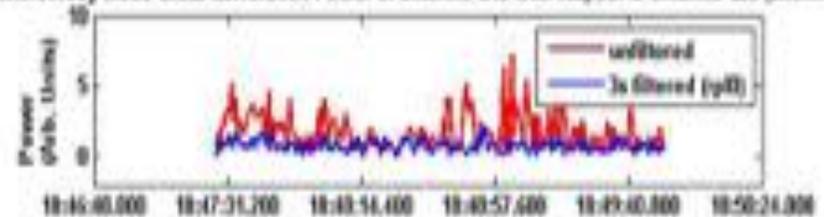
Interferometry Mode Cross Correlation Power of antenna C03 with respect to antenna C06 (channel B50)



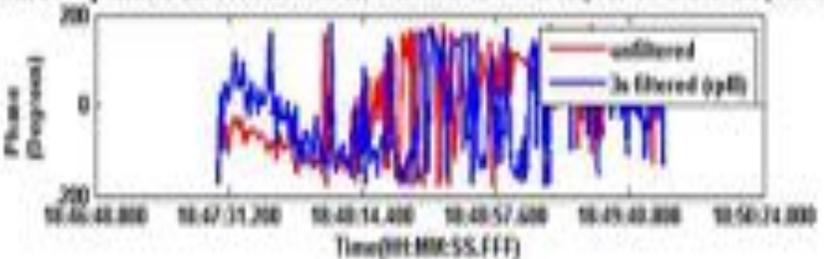
Interferometry Mode Cross Correlation Phase of antenna C03 with respect to antenna C06 (channel B50)



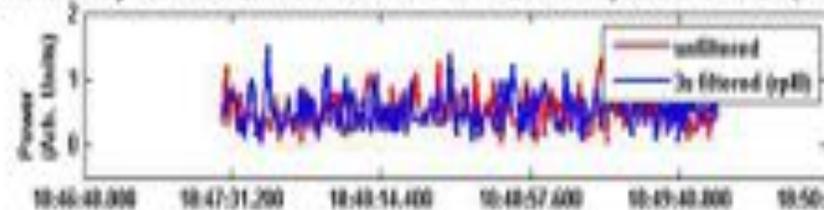
Interferometry Mode Cross Correlation Power of antenna C13 with respect to antenna C06 (channel B50)



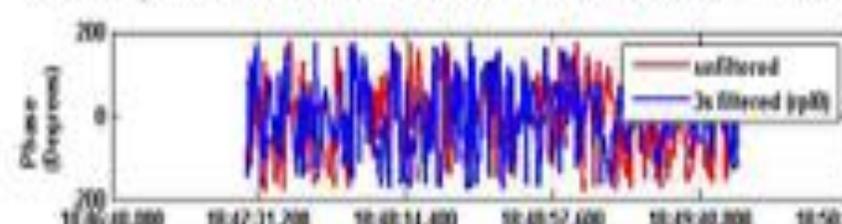
Interferometry Mode Cross Correlation Phase of antenna C13 with respect to antenna C06 (channel B50)



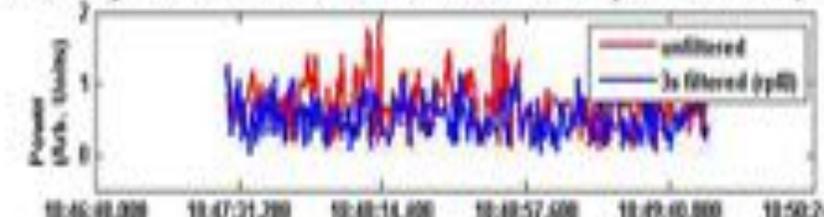
Interferometry Mode Cross Correlation Power of antenna E03 with respect to antenna C06 (channel B50)



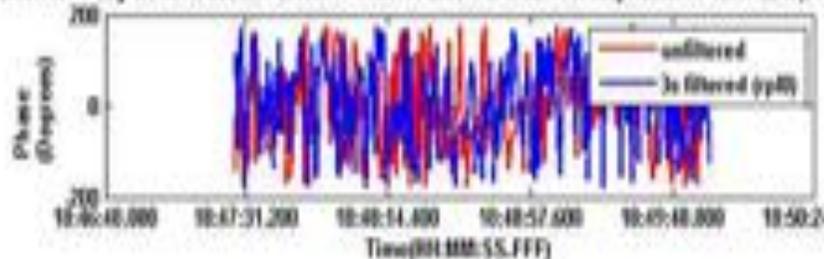
Interferometry Mode Cross Correlation Phase of antenna E03 with respect to antenna C06 (channel B50)



Interferometry Mode Cross Correlation Power of antenna W02 with respect to antenna C06 (channel B50)

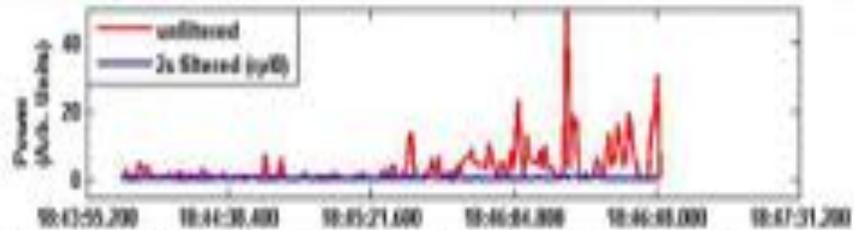


Interferometry Mode Cross Correlation Phase of antenna W02 with respect to antenna C06 (channel B50)

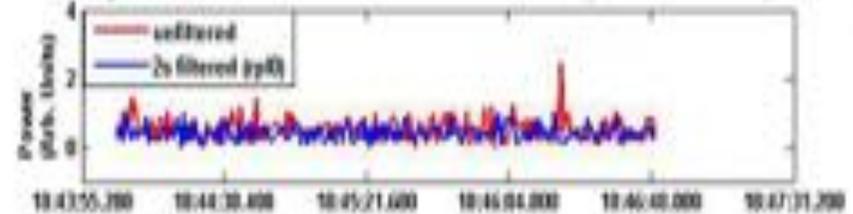


Off-source tests (250-500 MHz)

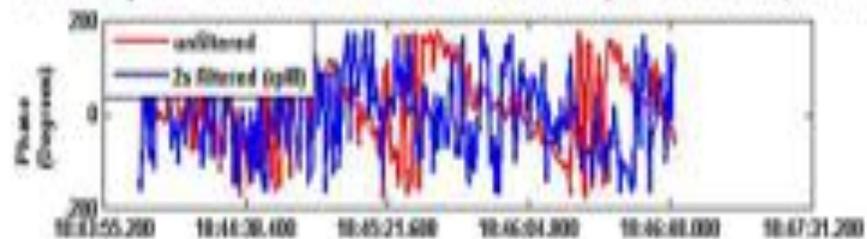
Interferometry Mode Cross Correlation Power of antenna C08 with respect to antenna C06 (channel B56)



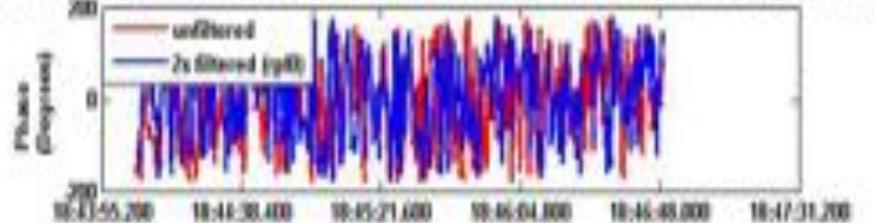
Interferometry Mode Cross Correlation Power of antenna E03 with respect to antenna C06 (channel B56)



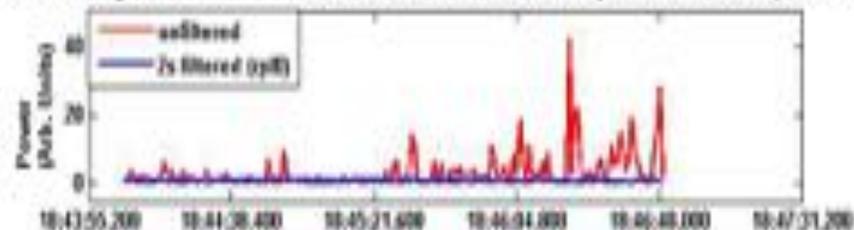
Interferometry Mode Cross Correlation Phase of antenna C08 with respect to antenna C06 (channel B56)



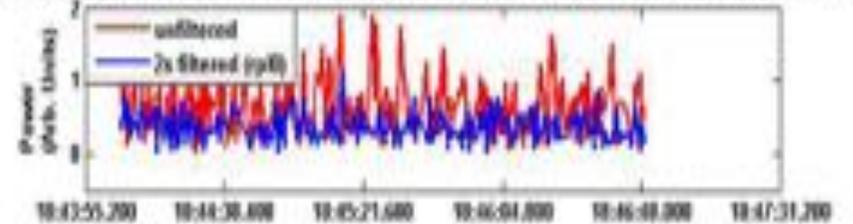
Interferometry Mode Cross Correlation Phase of antenna E03 with respect to antenna C06 (channel B56)



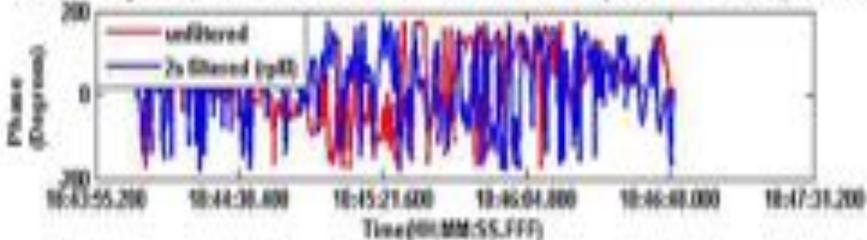
Interferometry Mode Cross Correlation Power of antenna C13 with respect to antenna C06 (channel B56)



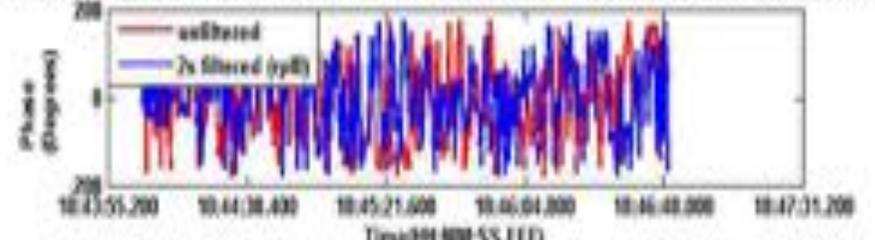
Interferometry Mode Cross Correlation Power of antenna W02 with respect to antenna C06 (channel B56)



Interferometry Mode Cross Correlation Phase of antenna C13 with respect to antenna C06 (channel B56)

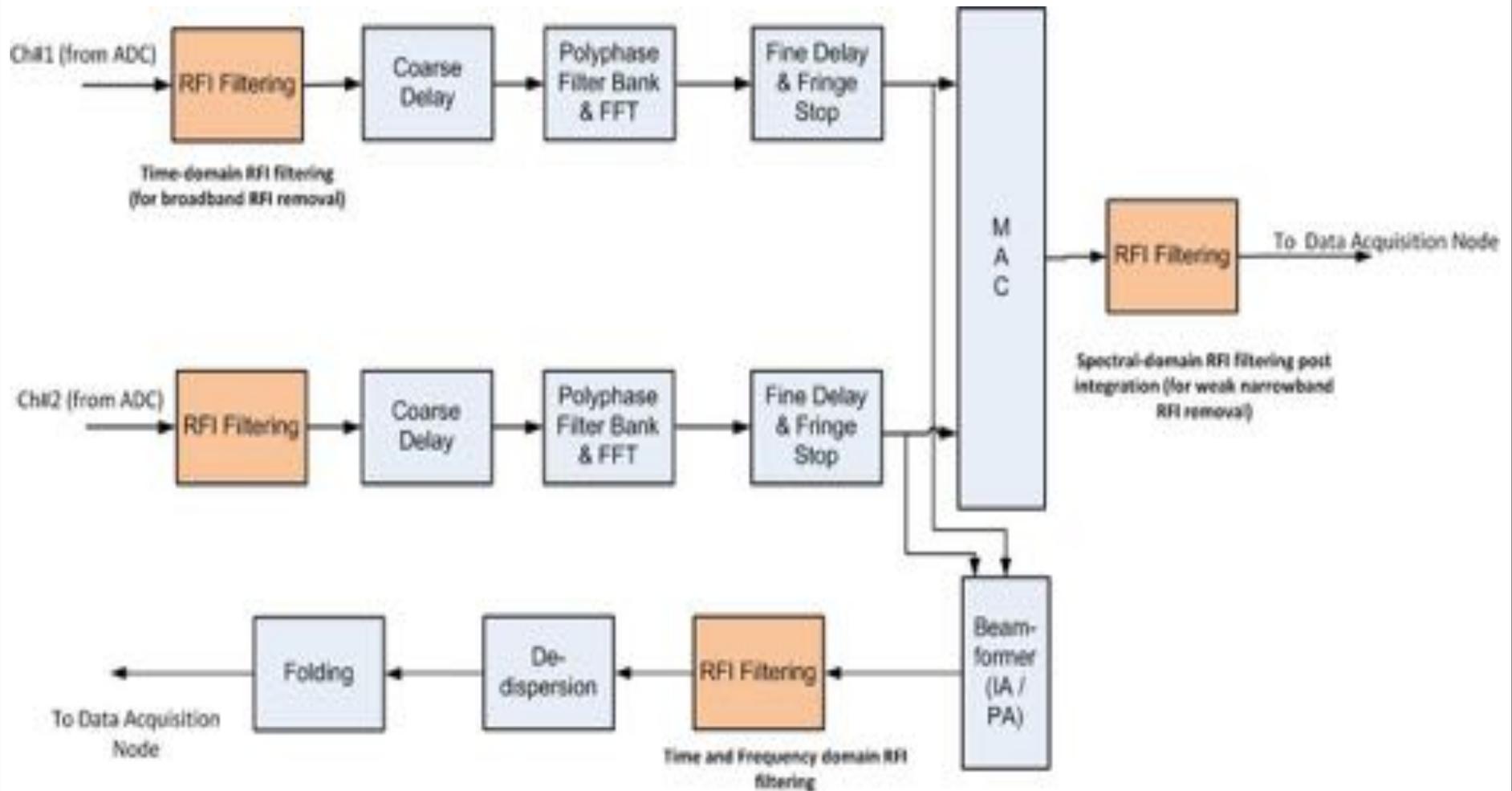


Interferometry Mode Cross Correlation Phase of antenna W02 with respect to antenna C06 (channel B56)



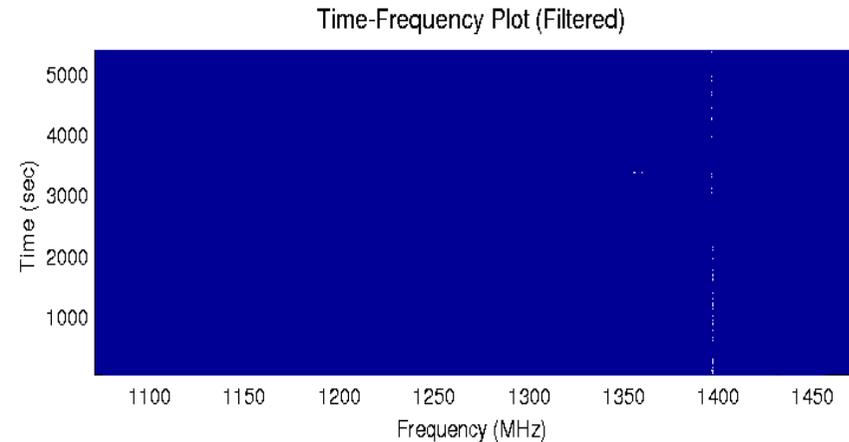
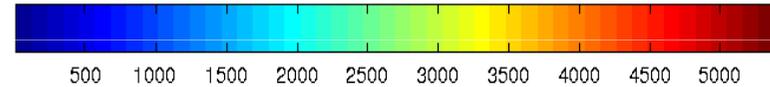
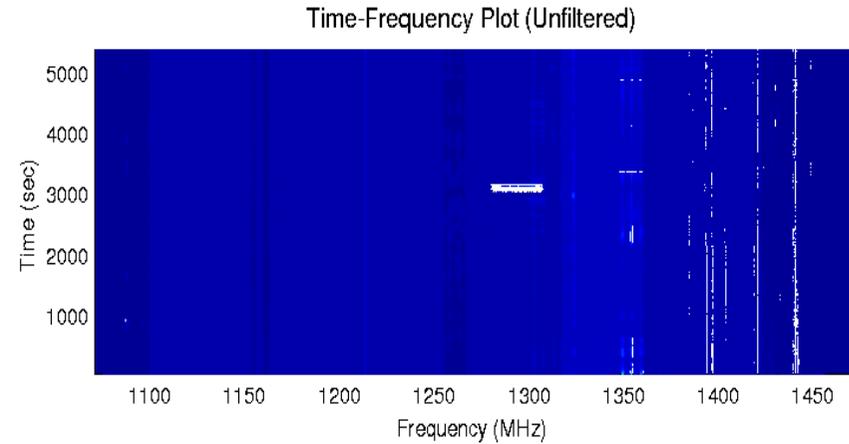
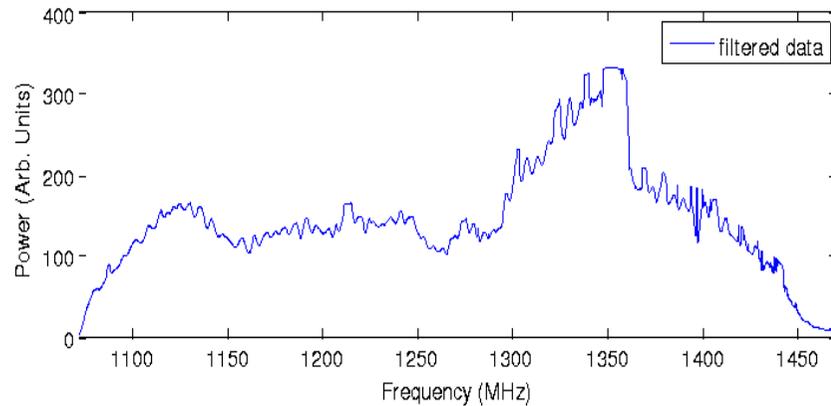
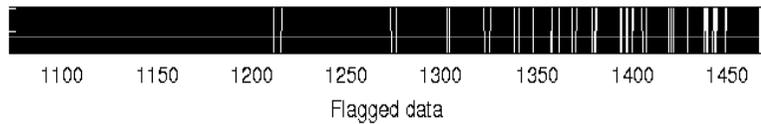
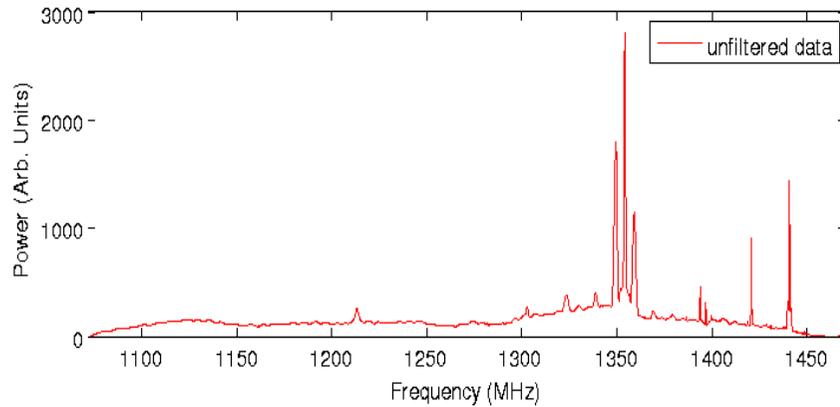
5 degrees off-source, shows correlated RFI, Filtering at 2 sigma threshold (replaced by zero)

Spectral Domain RFI Filtering



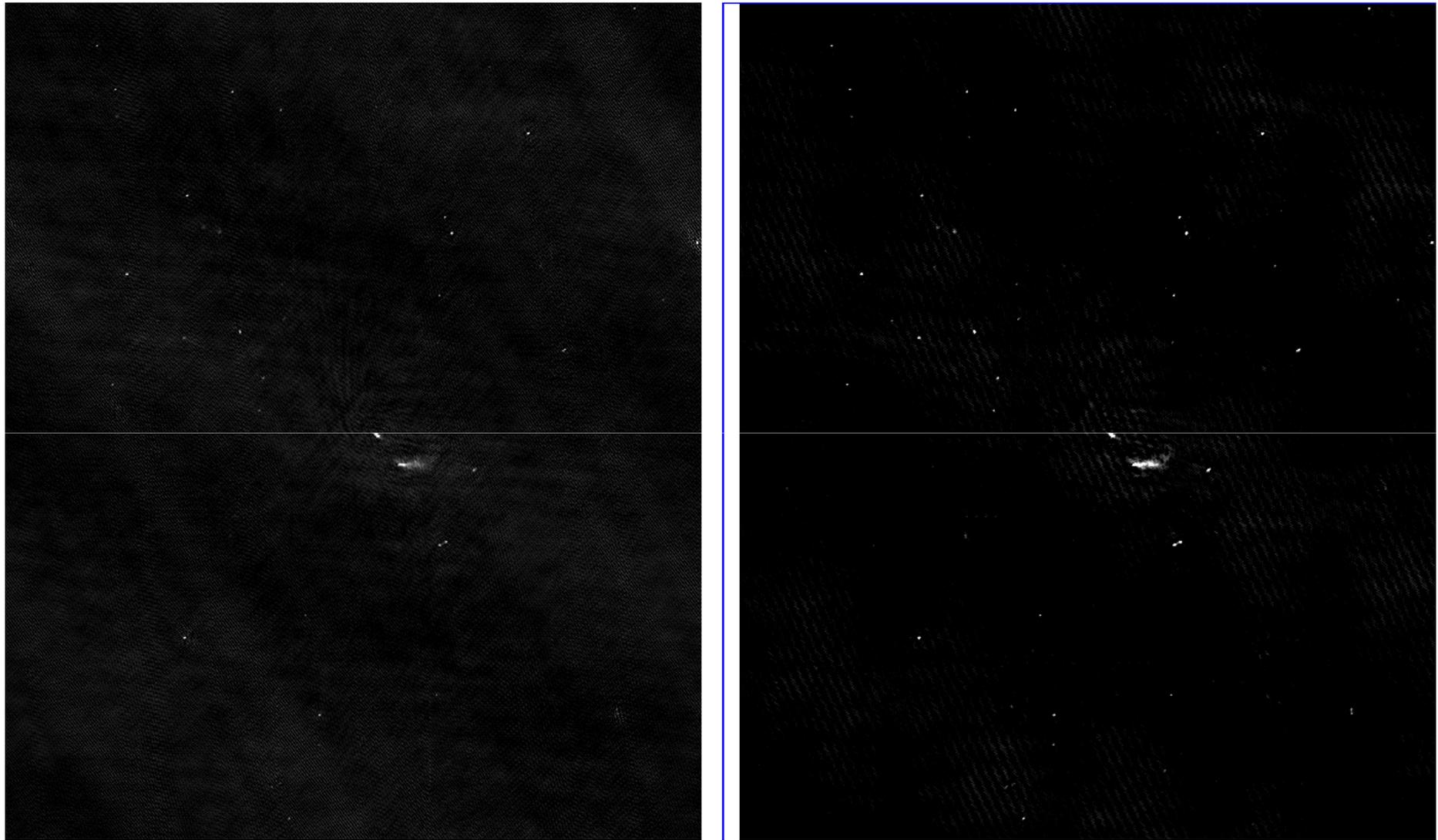
Real-time Narrowband RFI Mitigation is carried out post-integration (depending on the strength of the RFI relative to the overall noise).

Narrowband filtering on GWB data



First Image

Image Courtesy: Dharam Vir Lal



Real-time RFI Filtering: Features

- Possible to set fractional filtering threshold (in steps of 0.1)
- Various filtering options available (constant values, threshold, digital noise)
- Filtering possible in Ch-1 or Ch-2 or both
- ‘Bypass’ option is also available
- Filtering for 200 or 400 MHz mode as well as narrowband modes of GWB-3
- Number of samples flagged per antenna for a given scan
 - % RFI can be calculated as this feature provides total number of samples and the number of flagged samples

Summary

- Broadband RFI mitigation using MAD-based filtering in real-time is available for the uGMRT user community.
- Various tests carried so far show an improvement of 10-12 dB in the post-filtering signal-to-noise ratio.
- Long-term RFI filtering tests to understand the effect of filtering on power spectrum and cross-correlation are being carried out
- Narrowband RFI mitigation has been demonstrated on recorded visibilities.

Acknowledgements

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Nishit Baburaj



Thank You!