Real-time RFI Filtering for uGMRT Observations: Shared-risk Release and Optimal System Configuration

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The Upgraded GMRT (uGMRT)

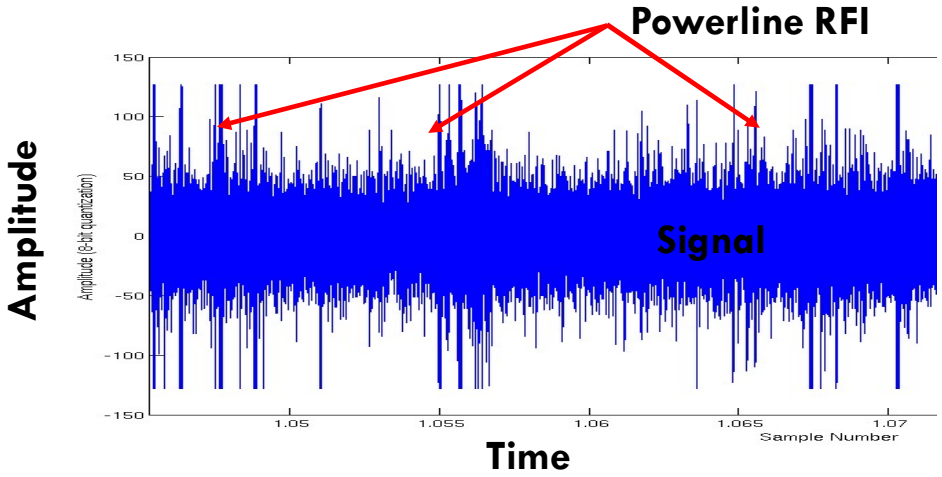
- uGMRT is a sensitive radio telescope array observing in:
  - Band -2 (120 – 240 MHz)
  - Band -3 (250-500 MHz)
  - Band -4 (550-850 MHz)
  - Band -5 (1050-1450 MHz)
- Maximum receiver bandwidth: 400 MHz
- Backend – 16 FPGA Boards + 16-node CPU-GPU cluster
- Pre-correlation Broadband RFI filtering

Gupta et. al, "The upgraded GMRT: opening new windows on the radio Universe", Current Science, Vol. 113, No. 4, August 2017

Powerline RFI at GMRT

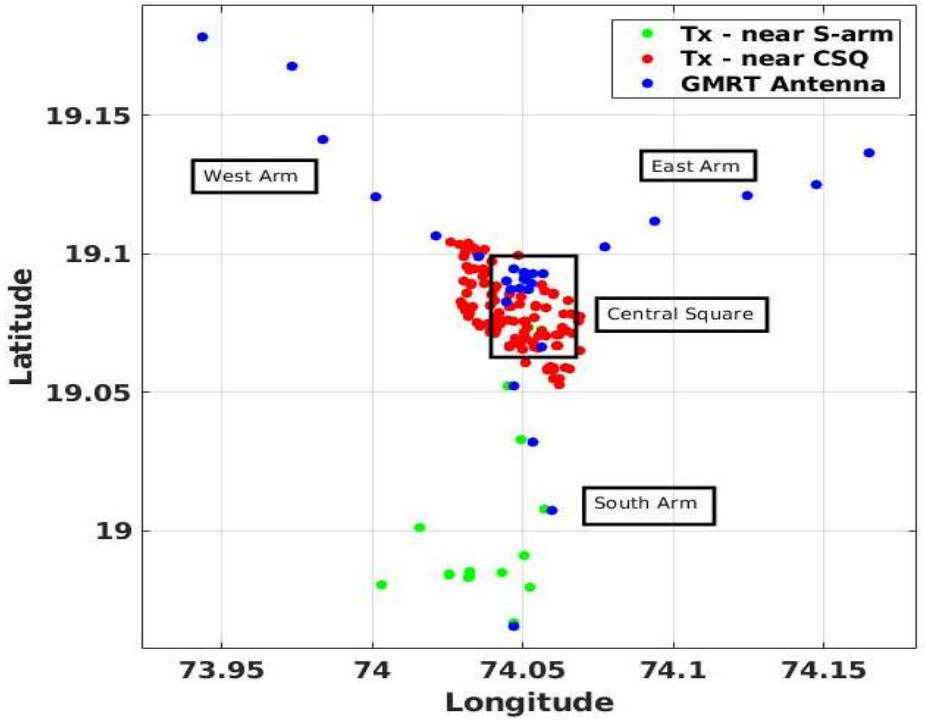
Broadband RFI (< 700 MHz)

- Sparking (gap discharge) on power-lines, transformers
- Corona Discharge
- Automobile sparking



Powerline RFI makes the Gaussian distribution of the astronomical signal heavy-tailed

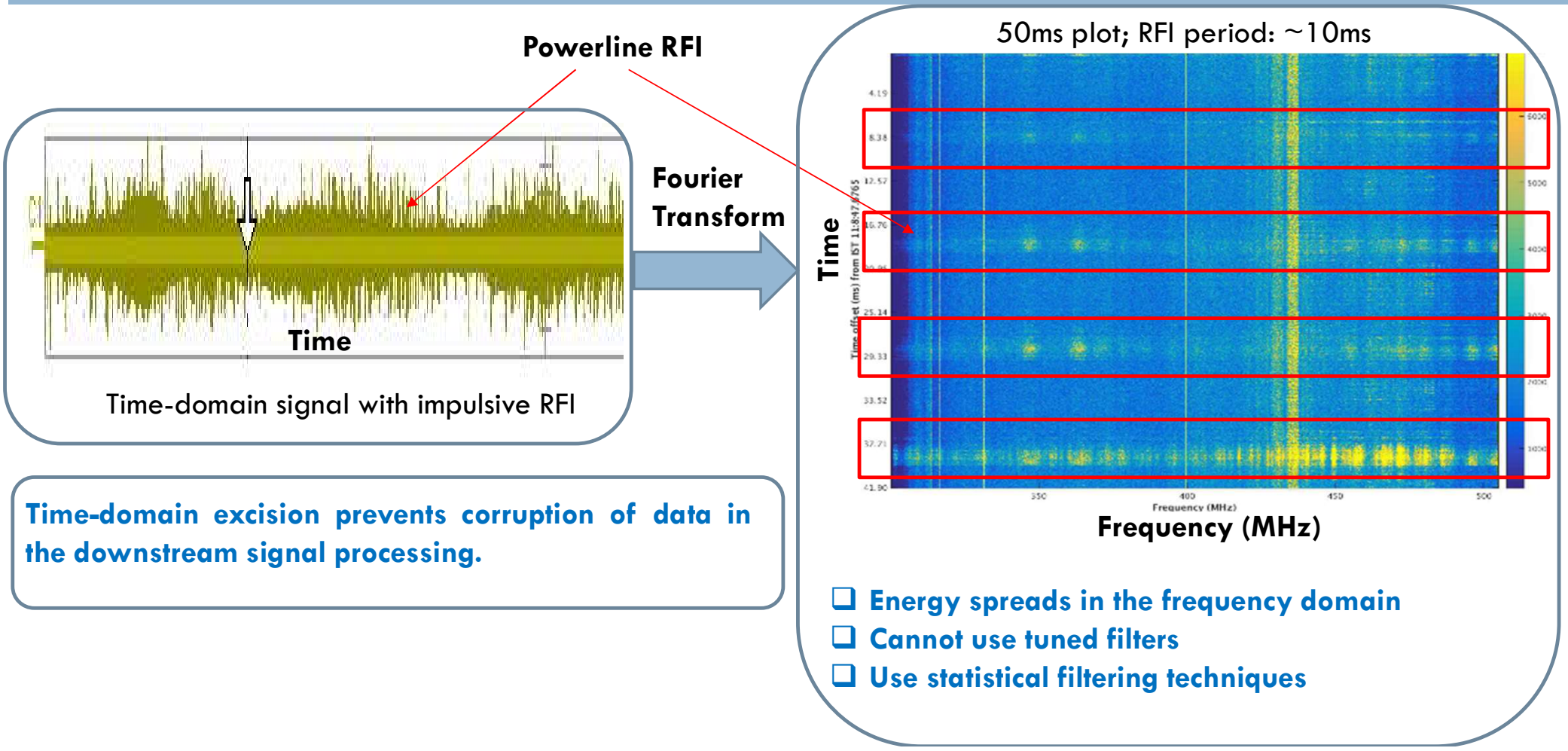
Potential Sources of Powerline RFI around Central Square and South-arm of GMRT



Data Courtesy: Pravin Raybole, RFI Group, GMRT

Power-line RFI can be seen as impulsive in time and correlated on short baselines

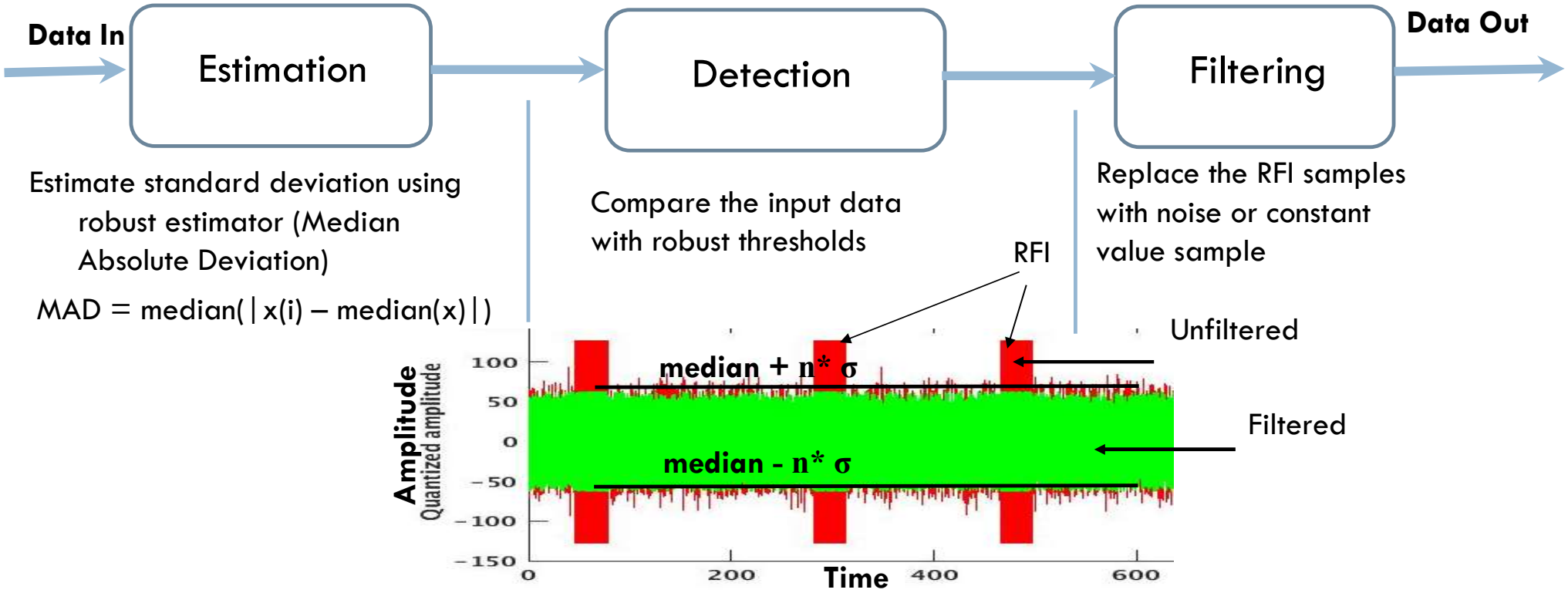
Need for Real-time Excision



Time-domain excision prevents corruption of data in the downstream signal processing.

- ❑ **Energy spreads in the frequency domain**
- ❑ **Cannot use tuned filters**
- ❑ **Use statistical filtering techniques**

The Filtering Algorithm – Detecting and Removing Outliers



Computing recursive median in real-time is the most challenging aspect of this system

Buch et. al, "Real-time MAD-based RFI Excision on FPGA ", JAI Special Issue on Interference Mitigation in Radio Astronomy, Vol. 8, No. 1, January 2019

Optimized Algorithm for Longer RFI Bursts

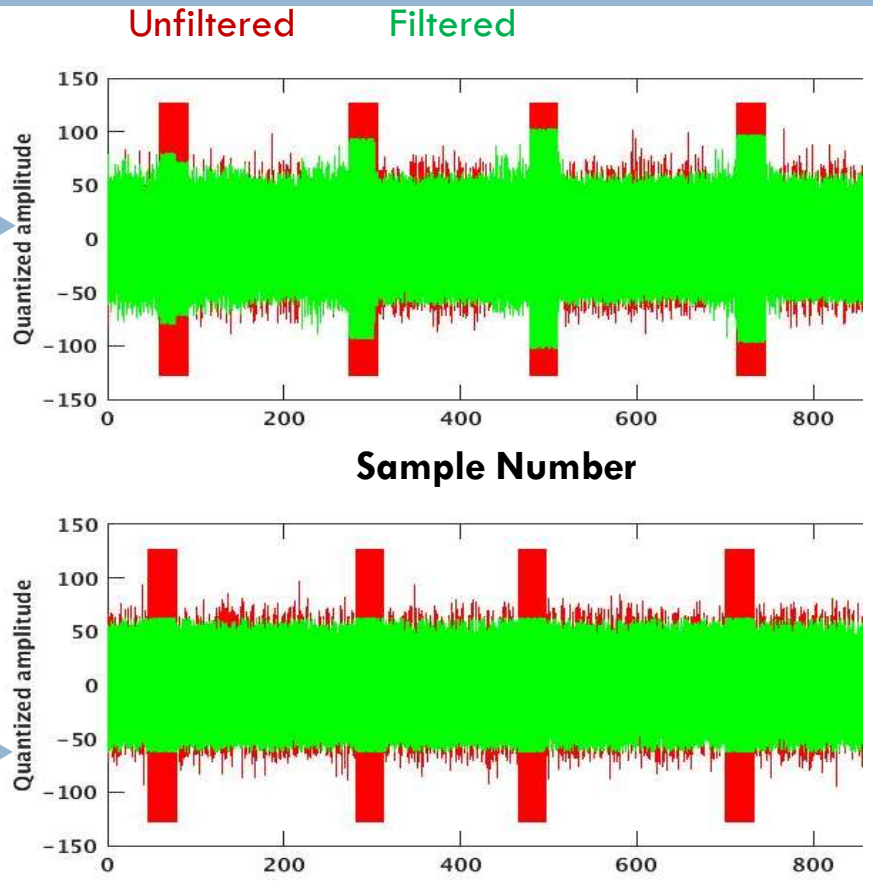
Need 50% healthy samples for an unbiased estimation of the signal dispersion

Longer bursts of RFI

Compute the median i.e. median of MAD (MoM) values (M_m)

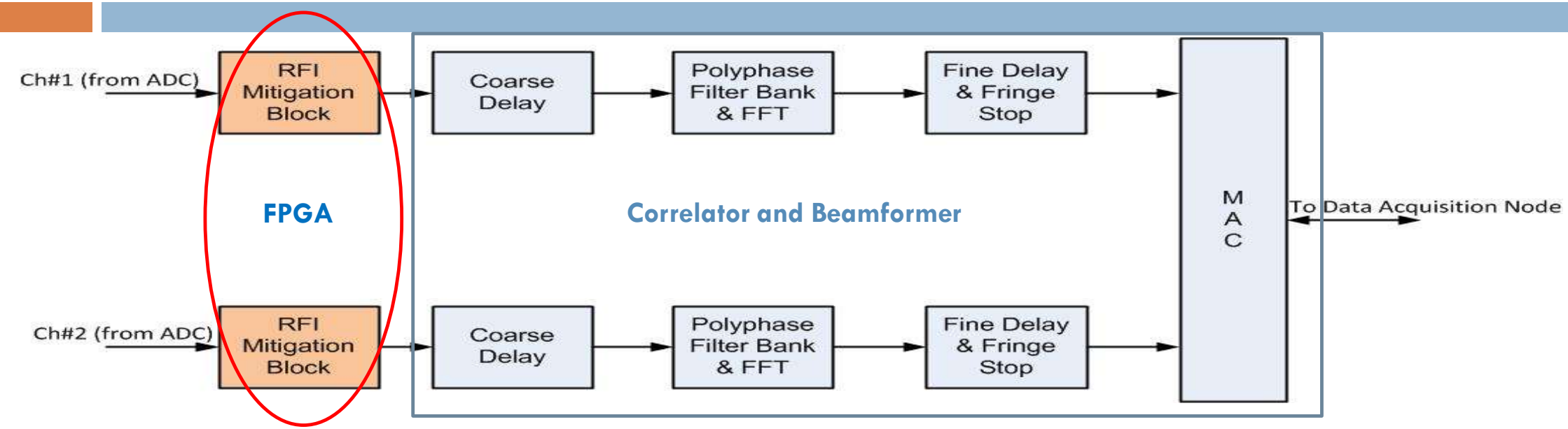
$$M_m = \text{median}(MAD_1, MAD_2, \ldots, MAD_n)$$

Hardware-optimized solution



Buch et. al, "Real-time MAD-based RFI Excision on FPGA ", JAI Special Issue on Interference Mitigation in Radio Astronomy, Vol. 8, No. 1, January 2019

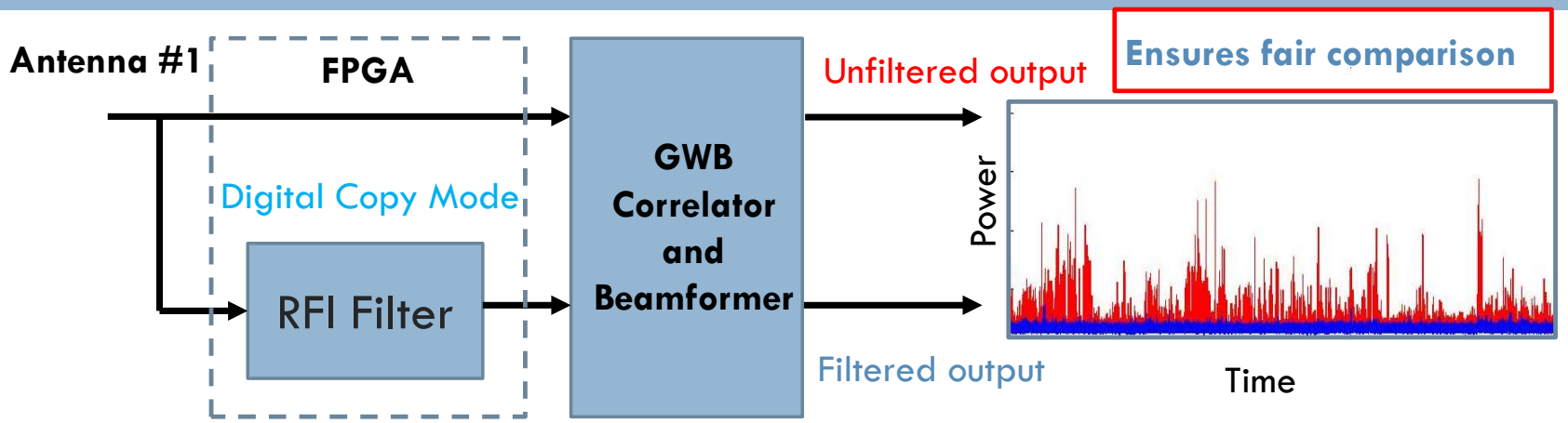
Real-time Mitigation in GMRT Wideband Backend

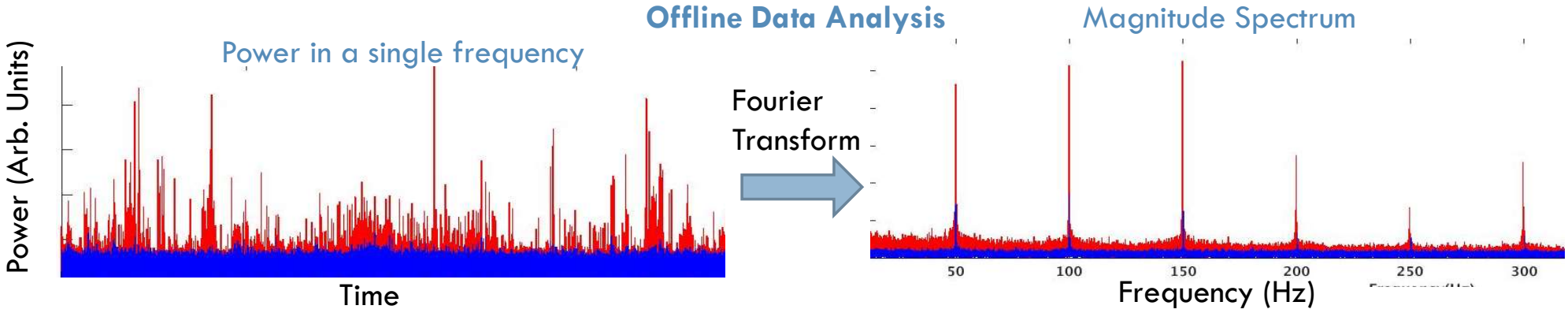


- Operates in time-domain for each antenna (and polarization)
- Implementation challenge: Real-time on Nyquist sampling rate of 800 MHz (400 MHz bandwidth)
- Pre-correlation detection and mitigation

Buch et al., "Towards Impulsive RFI Mitigation for Radio Telescopes", Journal of Astronomical Instrumentation, Vol. 5, No. 4, 2016

Simultaneous Testing: Digital Copy Mode

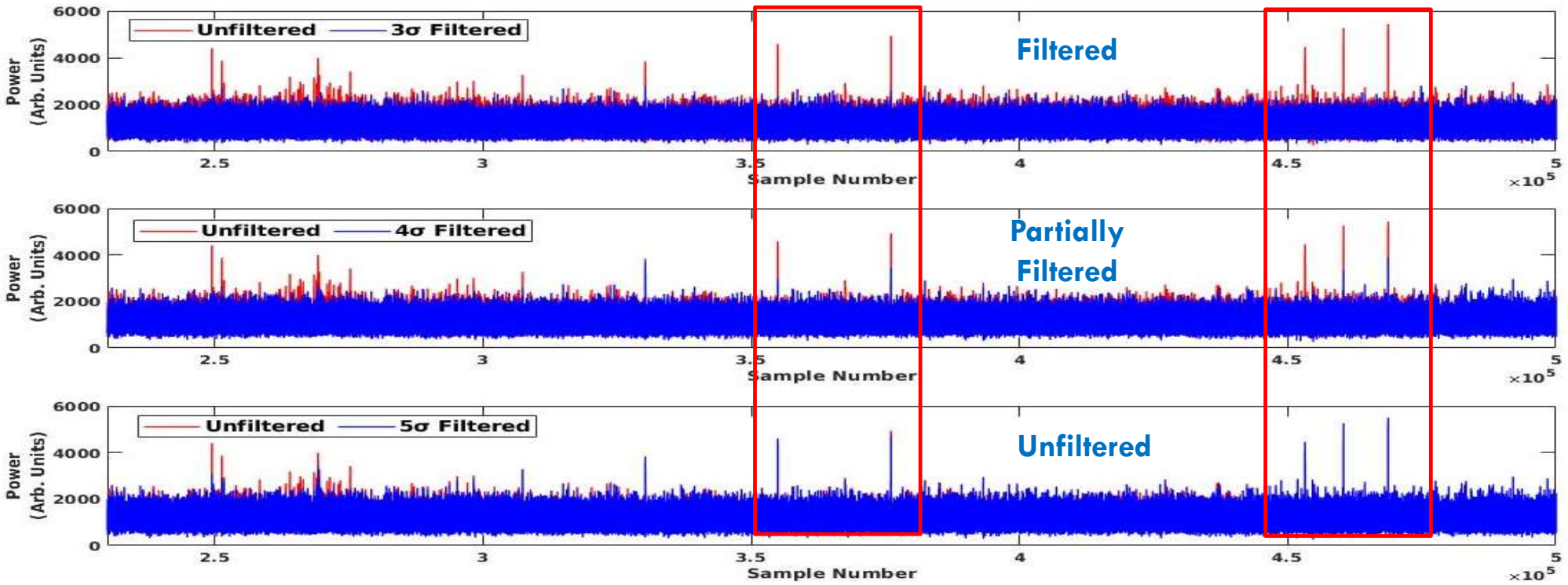




Buch et al., "Implementing and Characterizing Real-time Broadband RFI Excision System for the GMRT Wideband Backend", IETE Technical Review, Taylor and Francis, May-June 2019

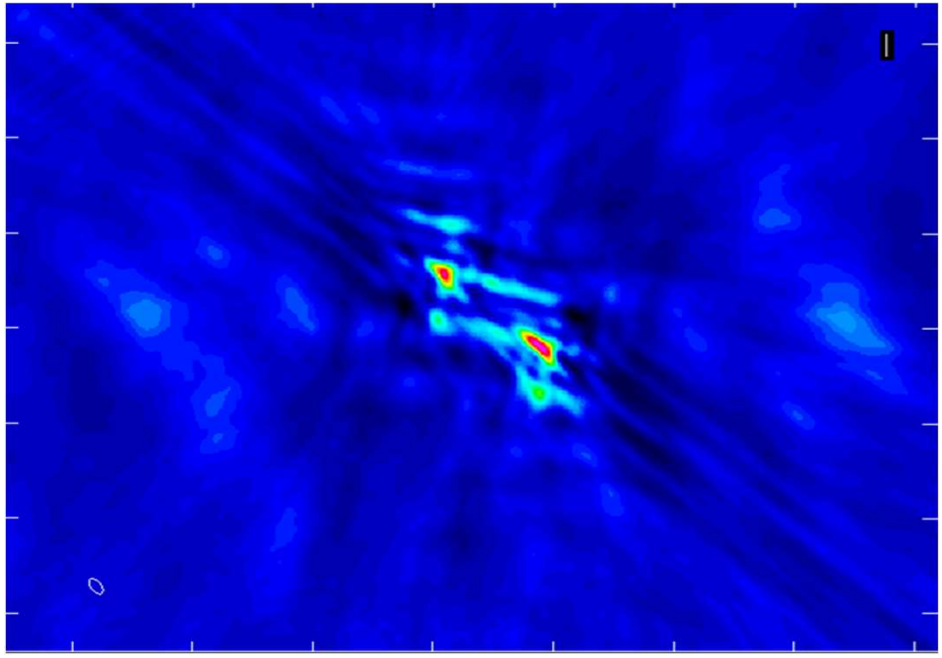
Trade-off between threshold and data loss – single frequency trace over time

- Flagging at 3 sigma threshold – Band-2 (5%), Band-3(2%), Band-4(1%), Band-5(<0.5%)
- 3 sigma threshold – an appropriate trade-off for all the bands, shows good improvement in the SNR
- Similar analysis for replacement options – digital noise, threshold, constant value (zero)

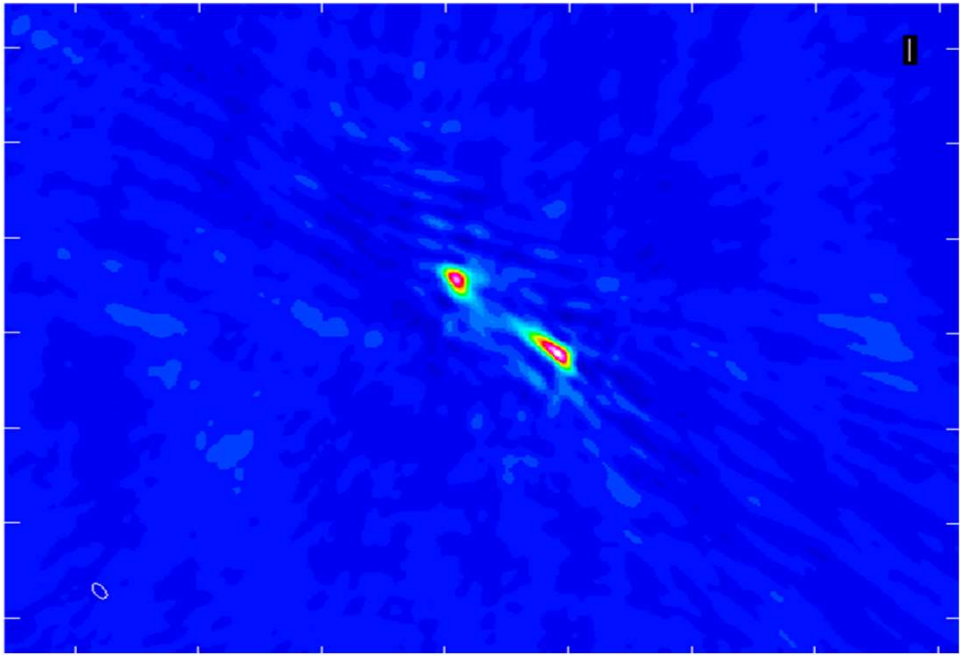


Imaging: Extended Source

Unfiltered



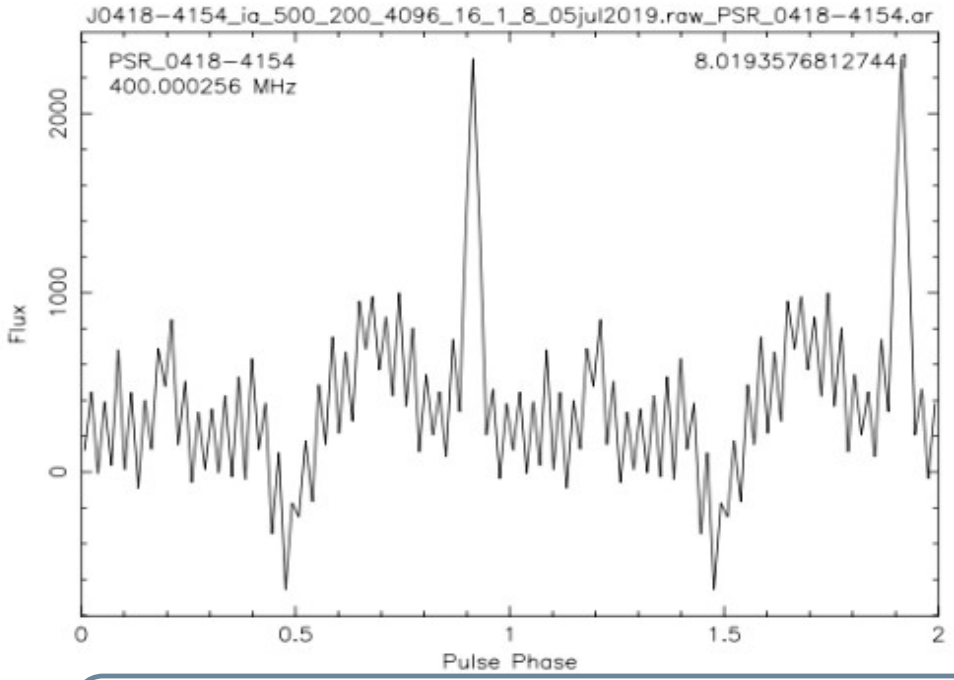
Filtered



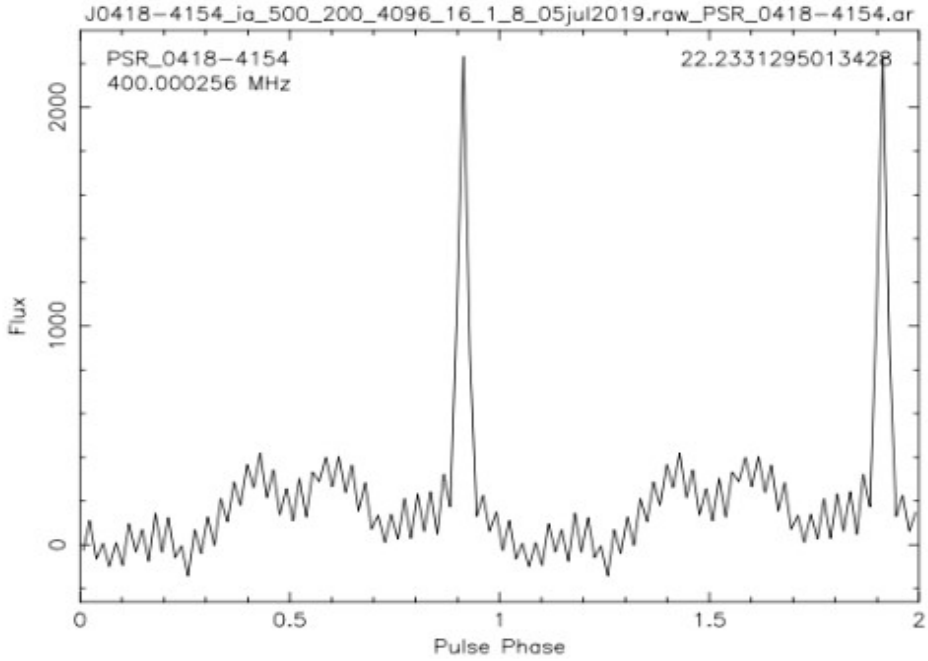
- uGMRT Band-3, 550-850 MHz , 200 MHz RF bandwidth, 2048 spectral channels
- Imaging for baselines < 1 kilolambda (~0.5 km)
- Noise RMS - 1.6 mJy/beam (Unfiltered) 0.52 mJy/beam (Filtered)
- Average Flagging: ~2.5-3%

Time-domain Astronomy

Unfiltered



Filtered



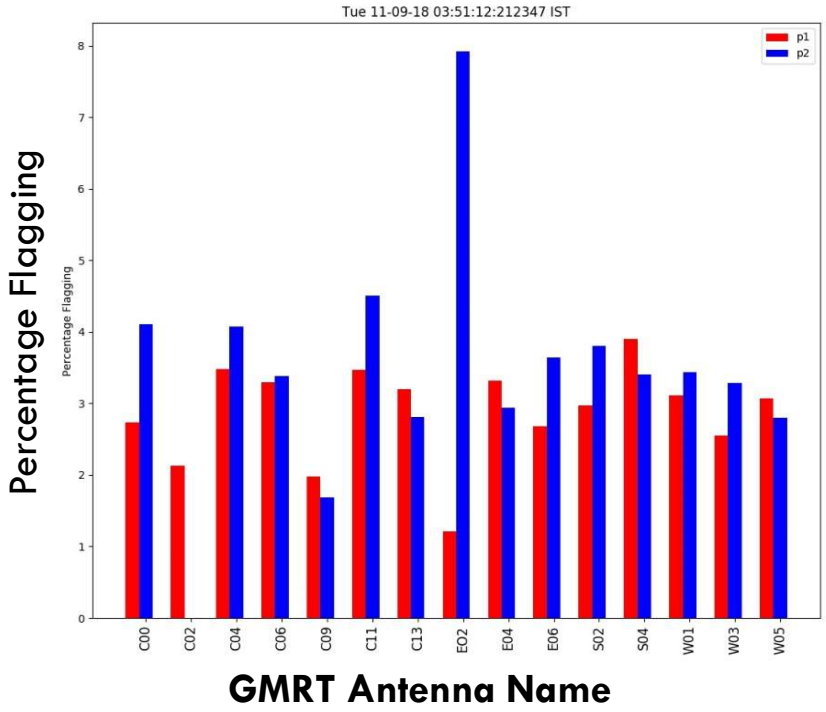
- Pulsar (J0418-4154) profile comparison: Incoherent Array beam - 4096 spectral channels 327.68μs integration time.
- SNR improvement by factor of 3; Average Flagging ~3%

Image Courtesy: J. Roy and B. Bhattacharyya, NCRA

Filtering System: Release Features

- Estimation interval: ~1.3s
- Filtering threshold, replacement option are user-defined
- Replacement options – digital noise, threshold, zero, constant value
- Observation command file can include options for recording the flagging count
- Recommended options:
  - 3σ (pulsar), 4σ (continuum)
  - Replacement by digital noise
  - Recording counter every five minutes

Typical counter plot showing antenna-wise flagging percentage



http://www.gmrt.ncra.tifr.res.in/~kdbuch/counter_page/counter_flagging.html

Summary

- Released for the uGMRT users (since May 2020) on shared-risk and full release from April 2022
- Used for continuum and time-domain astronomy (Pulsar and FRB) observations in uGMRT Bands-2,3, and 4
- Improvement in SNR (~4-6 dB) and imaging performance
- Typical flagging 0.5% - 5% at 3σ threshold
- Refinements to the filtering and flagging technique - in progress

GMRT Observing Cycle 40 (April – October 2021)

Band	RFI Filtering Usage (hours)	Total Duration (hours)
2	24	30
3	203	418

GMRT Observing Cycle 41 (Nov 2021 – March 2022)
(till Feb 15th 2022)

Band	RFI Filtering Usage (hours)
2	34
3	136
4	99

Release document: http://www.ncra.tifr.res.in/ncra/gmrt/gmrt-users/online-rfi-filtering