Identifying RFI in Raw Voltage Data from uGMRT

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Giant Metrewave Radio Telescope

- Sensitive telescope operating between 120 to 1450 MHz. A national project of the Govt. of India
- Located 80 km north of Pune, 160 km east of Mumbai
- Array telescope: 30 antennas, each of 45 m diameter14 antennas in 1 sq. km. region, other spread in a Y-shaped array
- Central square (C00 – C14, except C07), E-arm (E02-E06), W-arm (W01-W06), S-arm (S01-S06, except S05)

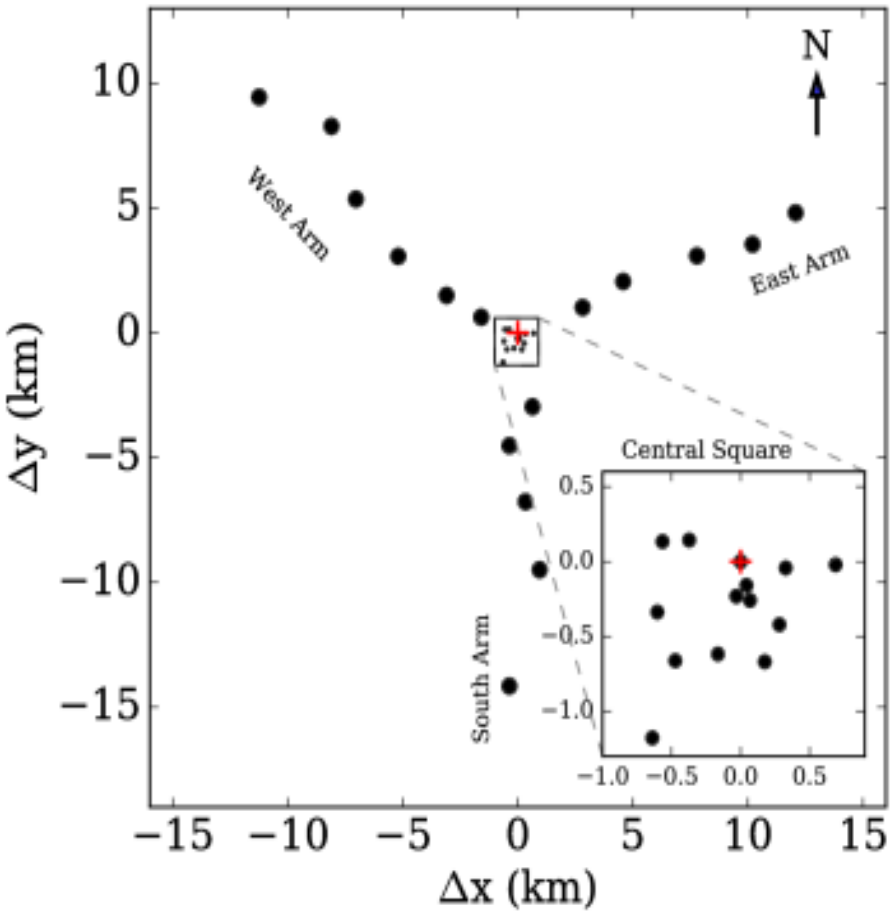
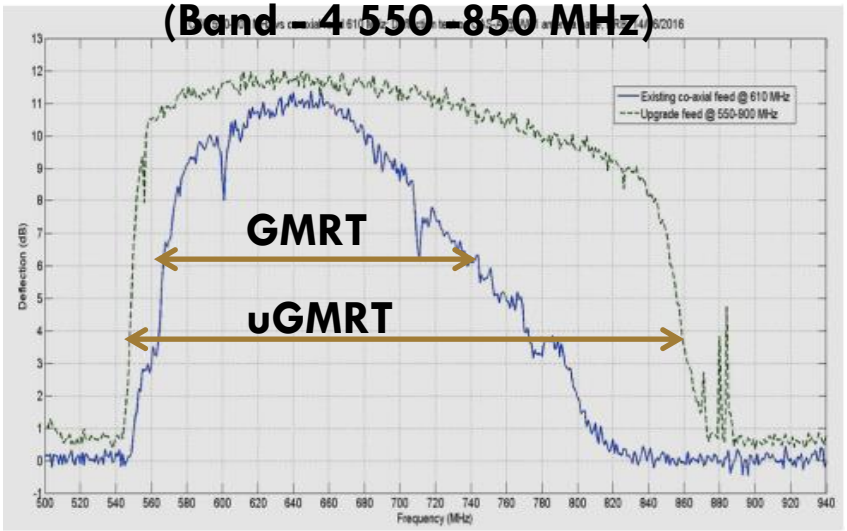


Image Courtesy: N. Patra

The Upgraded GMRT

- Near seamless observing (120 – 1450 MHz)
- Four observing bands:
  - Band -2 (120 – 240 MHz)
  - Band -3 (250-500 MHz)
  - Band -4 (550-850 MHz)
  - Band -5 (1050-1450 MHz)
- 400 MHz instantaneous bandwidth
- Improved sensitivity (P=kTB watts, for noise-like signals)



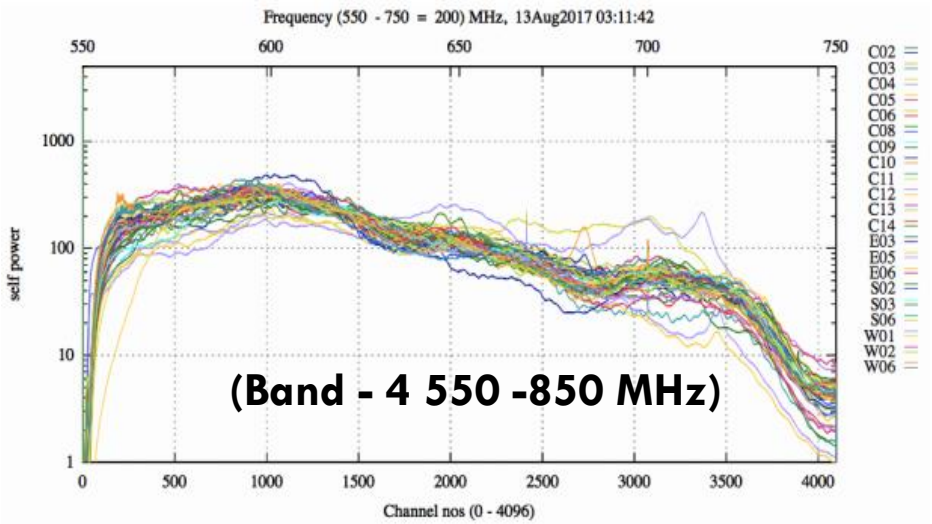


Image Courtesy: FE group + Control room

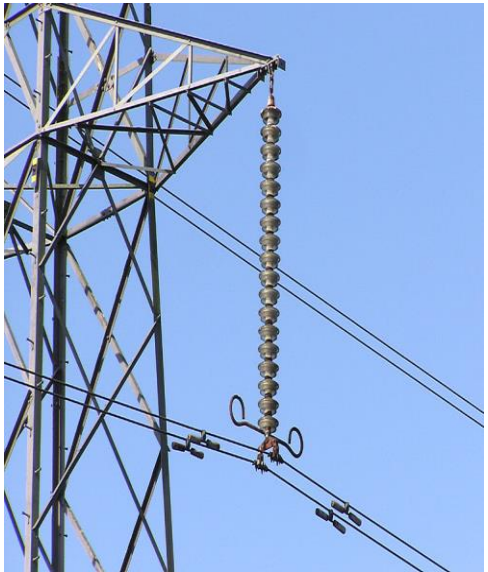
Radio Frequency Interference

- Radio Telescopes are passive instruments
- Due to large bandwidth and sensitive receiver systems, it is vulnerable to interference generated by various terrestrial and extra-terrestrial sources
- RFI is usually much stronger than the astronomical signal, may be 1000 or 10000 times (i.e. 30 to 40 dB)
- Adversely effects the sensitivity
- Biggest challenge for the contemporary/upcoming radio telescopes

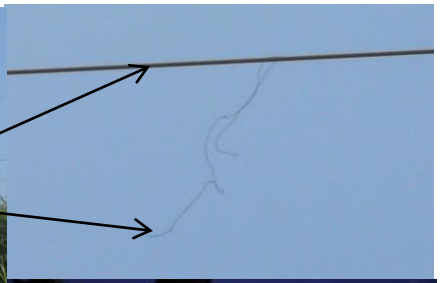
Sources of Radio Frequency Interference

Major Sources of RFI

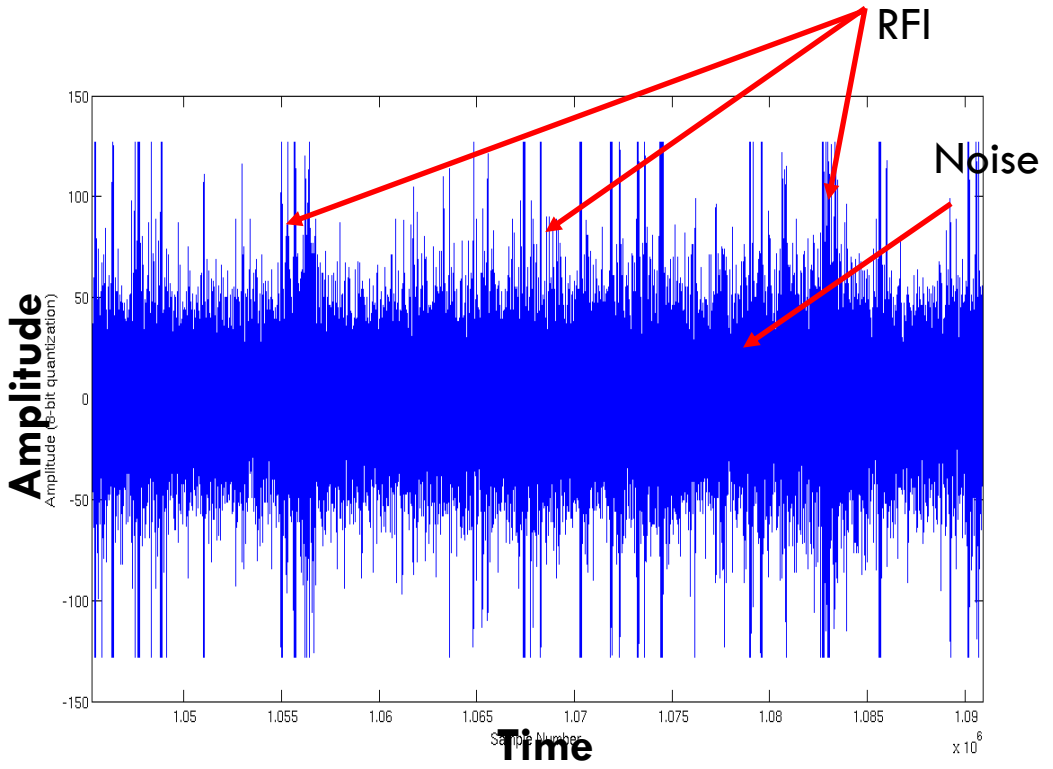
Image Courtesy: Wikipedia



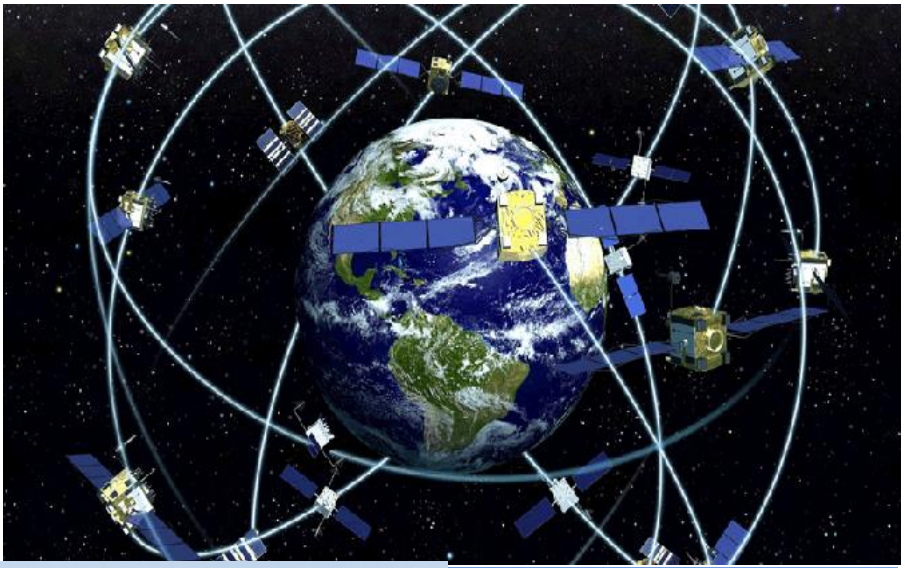
Broadband Powerline RFI



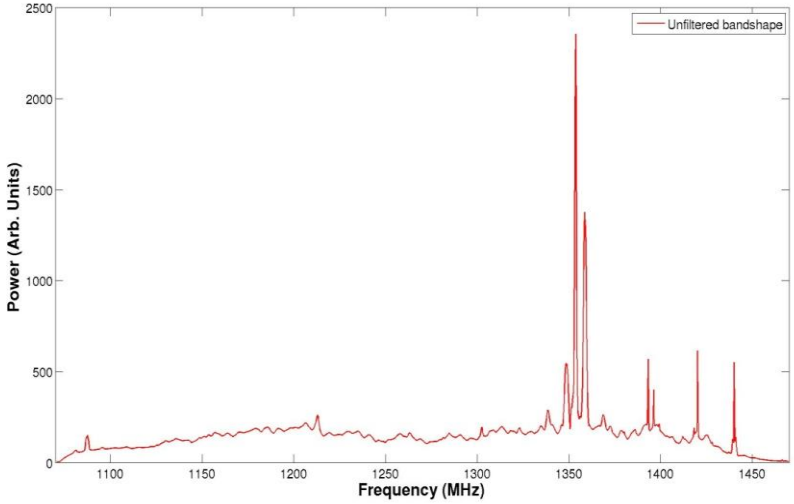
- Major source of interference below 800 MHz
- Cause: Gap discharge on HV transmission lines/distribution equipment
- Stronger than the signal of interest (noise)



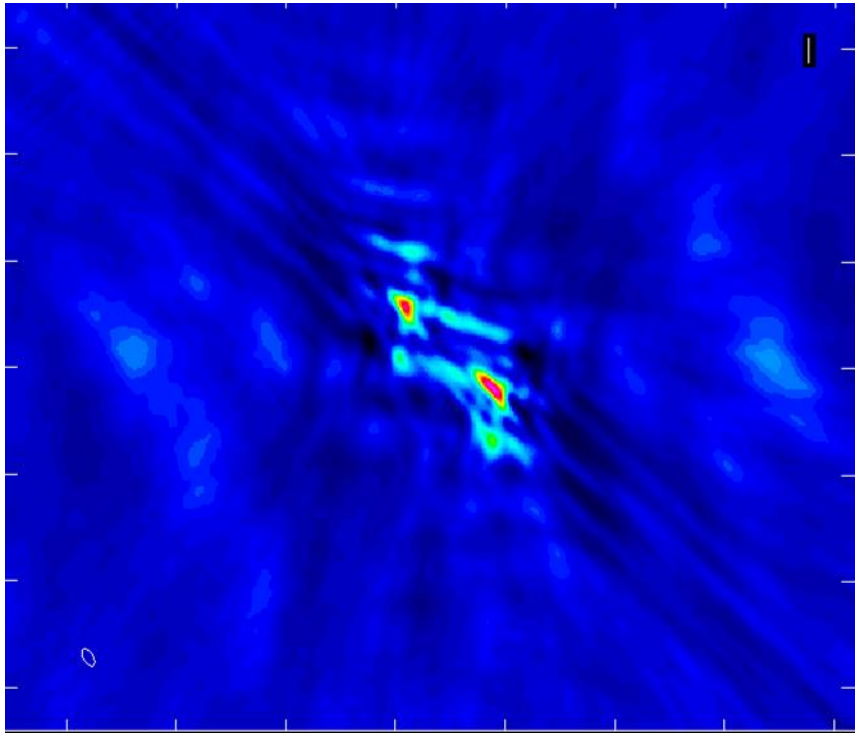
Narrowband RFI

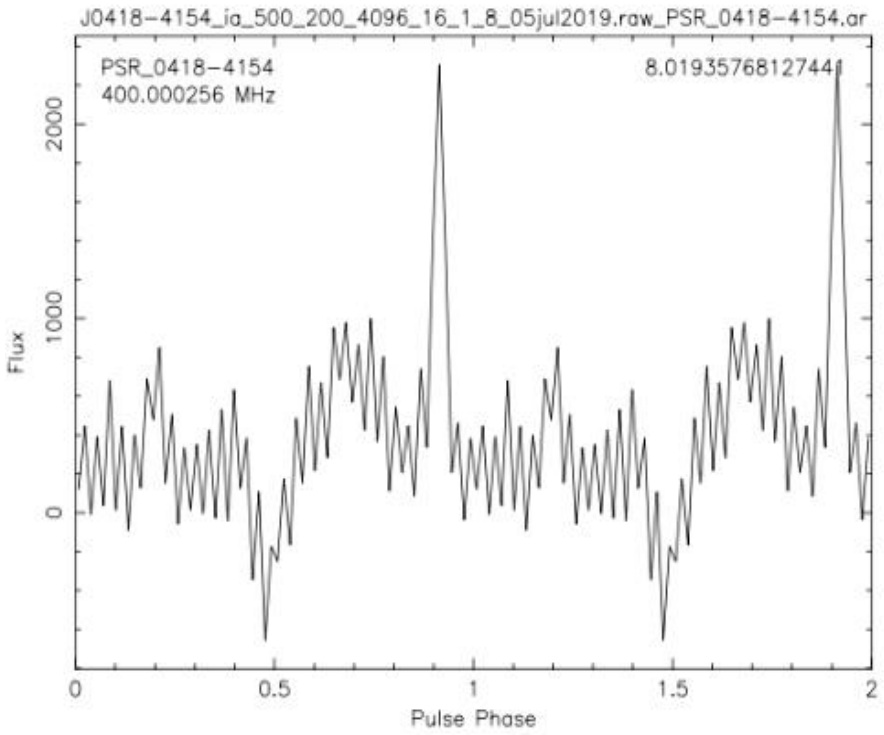


- Spectrally (and at spatially) confined
- Communication transmitters – terrestrial and extra-terrestrial
- Stronger than the signal of interest (noise)



Effects on astronomical data



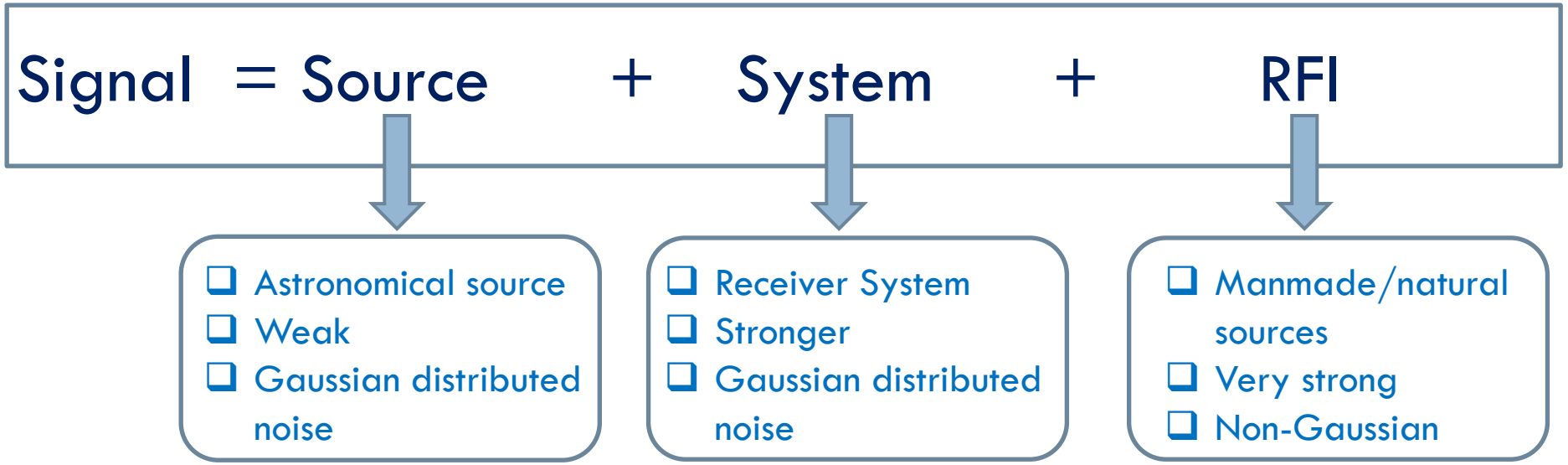


Band-4 uGMRT, extragalactic field, data affected by RFI

Band-3 uGMRT, Pulsar data, data affected by RFI

Adversely effects the sensitivity, detection, and astronomical imaging

Signal Model



RFI can be identified using non-Gaussian behavior in the data or finding outliers

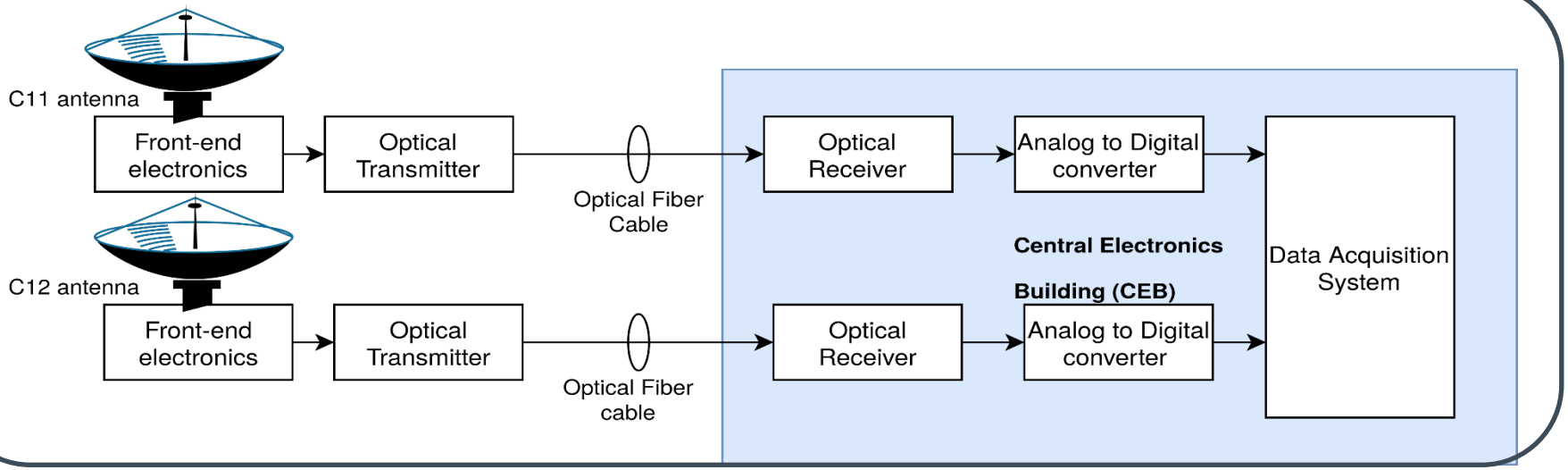
Aims of the experiment

- Examine and compare the statistical properties of the voltage time series data of uGMRT bands 3 and 5.
- Construct a power spectrum and dynamic spectrum from the data.
- Construct auto-correlation and cross-correlation spectra.
- Identify RFI in the data at bands 3 and 5.

<u>Tools required</u>

Any programming language to analyze and plot the data

Radio Telescope: Overall Picture



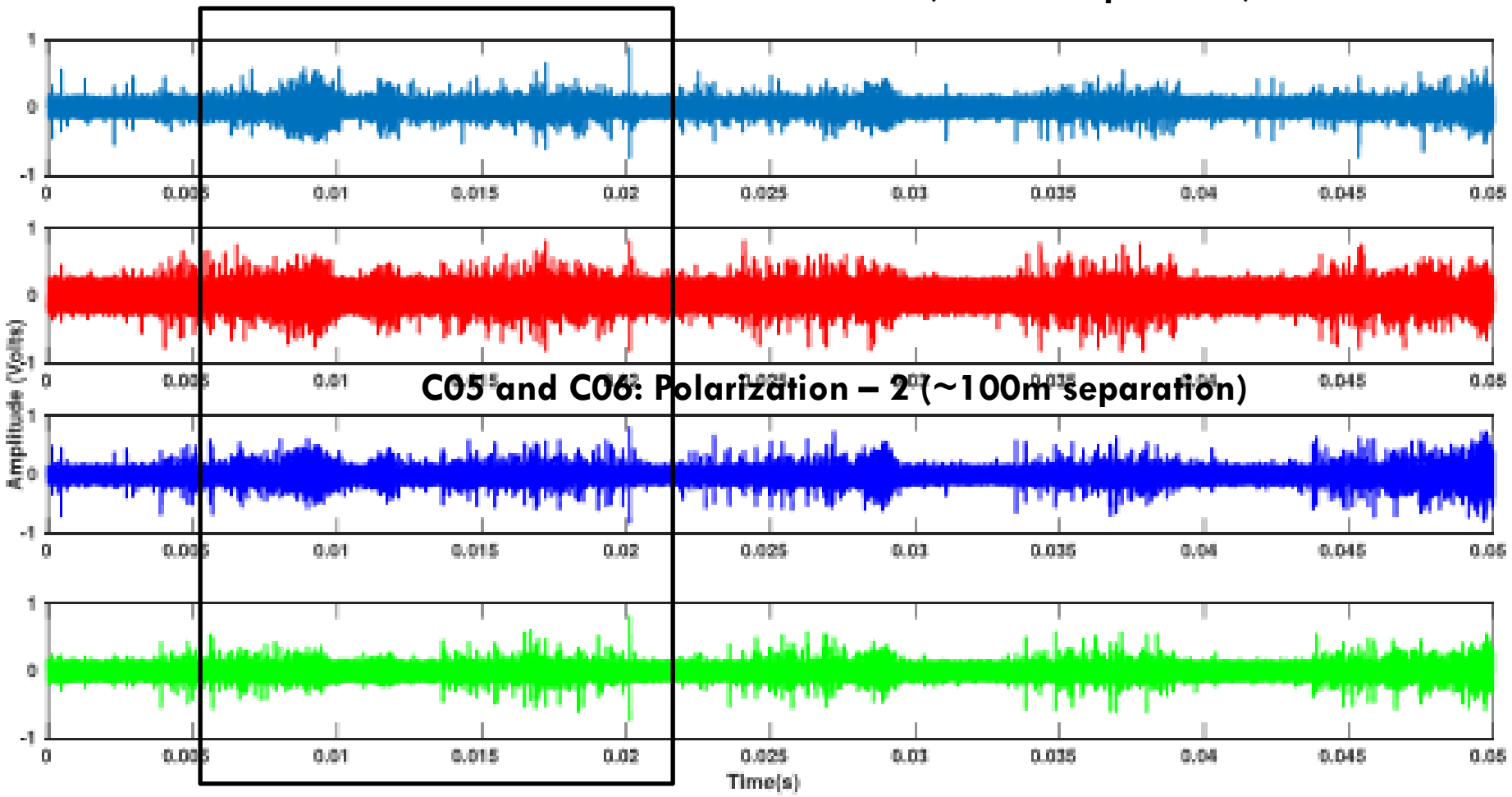
- ❑ Converting EM to electrical signals
- ❑ Signal Conditioning (amplification, filtering, frequency down-conversion)
- ❑ Signal transport (optical fiber) to a common location
- ❑ Digitization
- ❑ Signal Processing
- ❑ Data Acquisition

Some Short Spacing Antennas of GMRT

Shortest spacing ~ 100m; largest spacing ~ 25km

Image Courtesy: NCRA Archives

Powerline RFI is correlated over shorter baselines



Needs mitigation before correlation

Data

- Observations for band 3 (300 - 500 MHz) and band 5 (1050 - 1450 MHz)
- Bandwidth of 200 MHz => sampling at 400 MHz => 2.5 × 10−9 s per sample
- Data => 4194304 numbers.
- 8-bit, ASCII format data

uGMRT Band	C11 data	C12 data
3	C11_1024_Packets_ B3.out	C12_1024_Packets_ B3.out
5	C11_1024_Packets_ B5.out	C12_1024_Packets_ B5.out

Signal Correlation

Radio Source

$$R_{xy}(\tau) = \sum_{n=0}^{T} x[n]y[n+\tau]$$

Digitized signal from Antenna#1

Digitized signal from Antenna#2

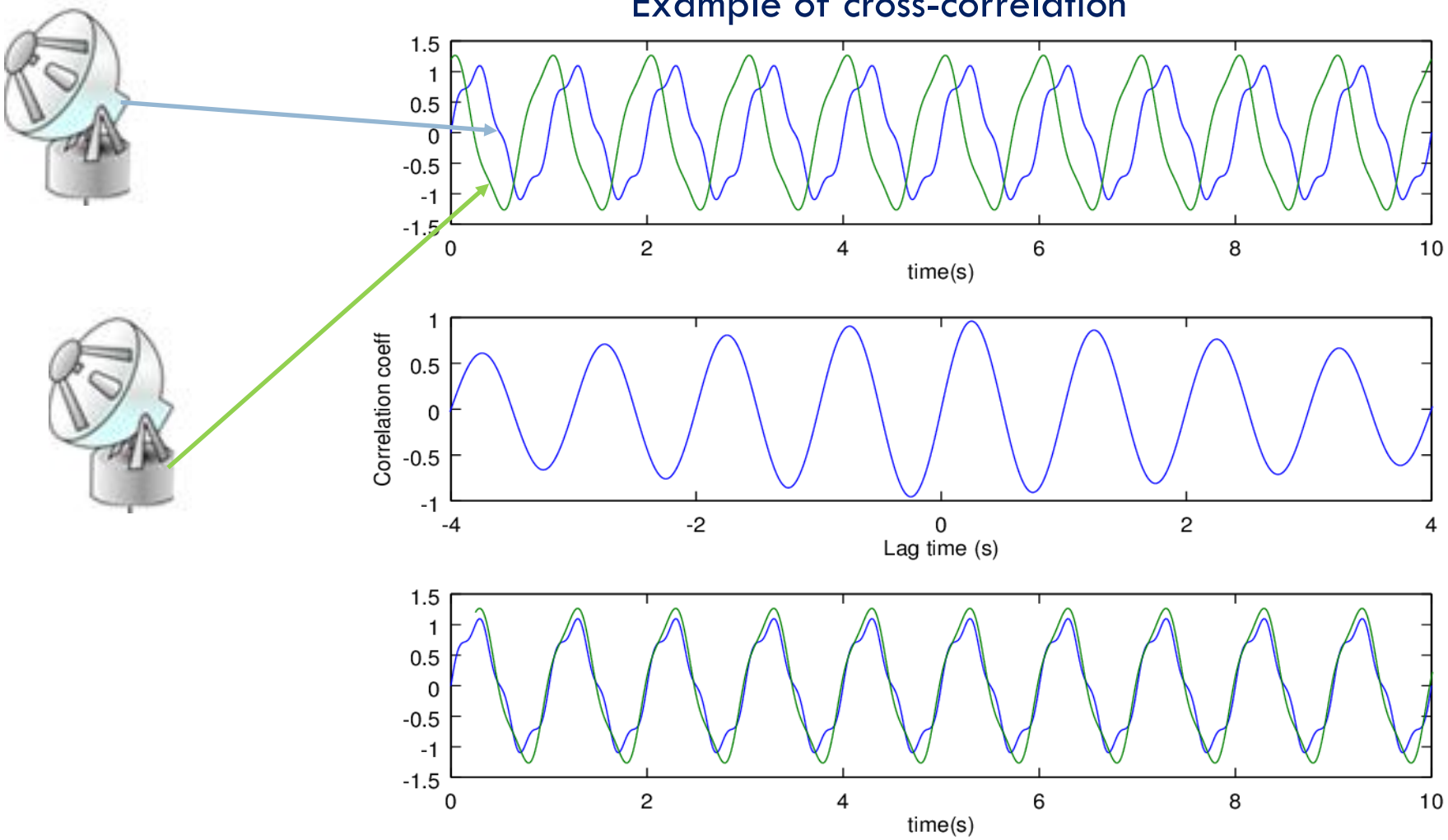
Correlation gives information about the similarity between two signals - the common component contributed by the source

Cross correlate signals from antennas after correcting for the delay between them (τ).

In this case, the delay between C11 and C12 is very less and can be ignored

A computationally efficient method is to transform signals to frequency domain and multiply

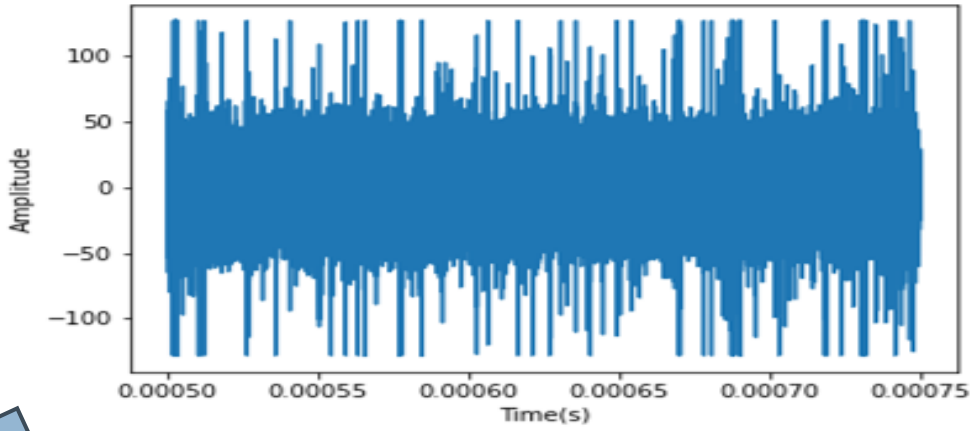
Correlation as a function of lag



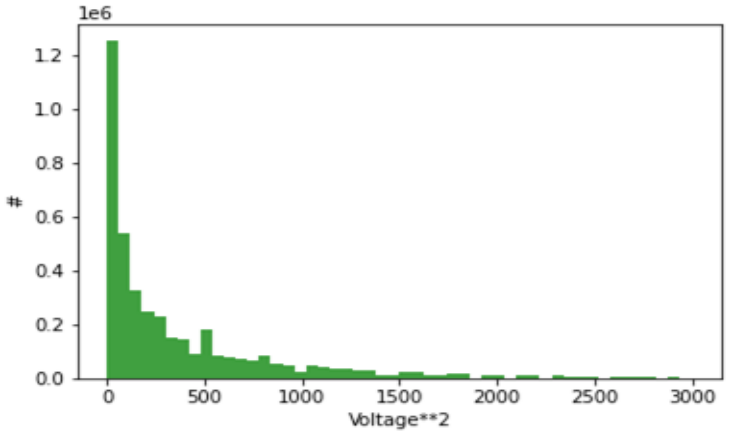
Raw Voltage

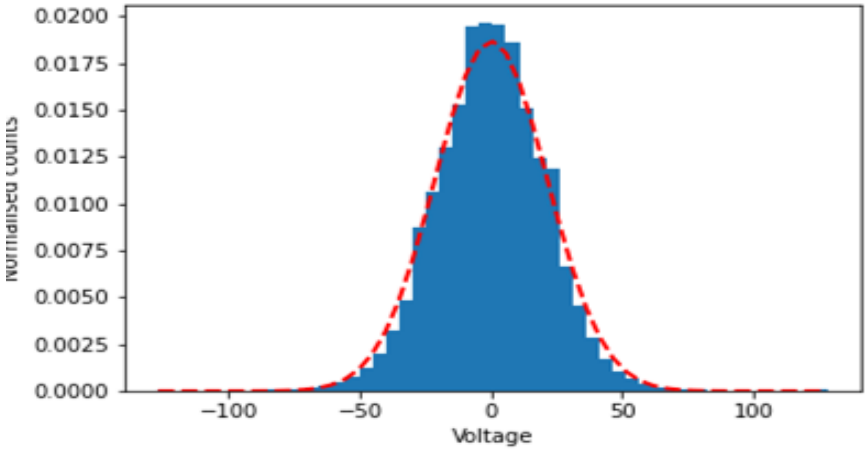
Raw Voltage Data

C11 or C12



V^2





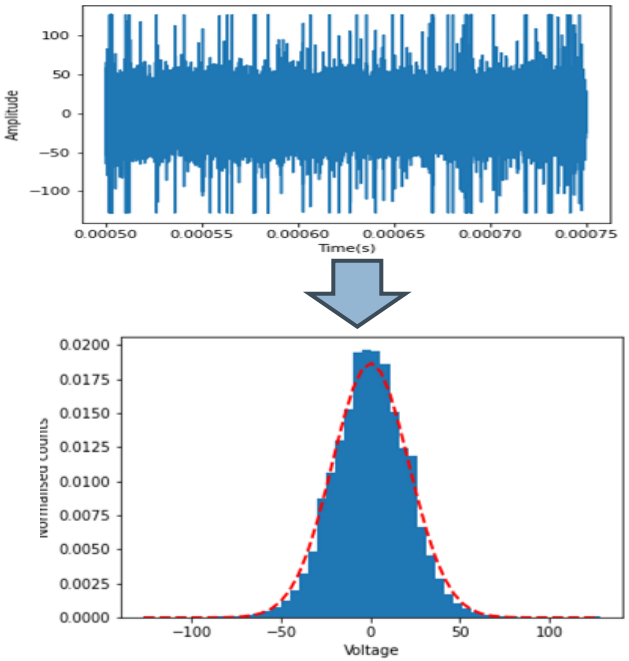
Raw Voltage and Autocorrelation

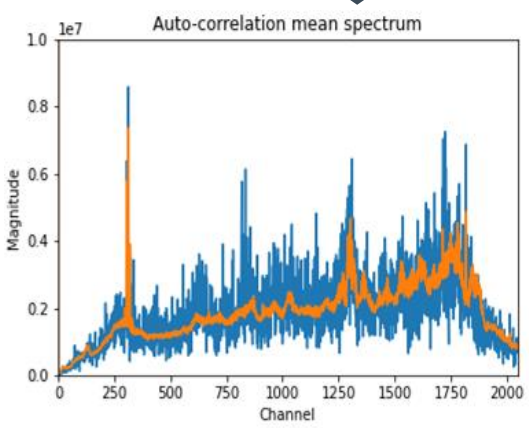
Raw Voltage Data
C11 or C12

FFT

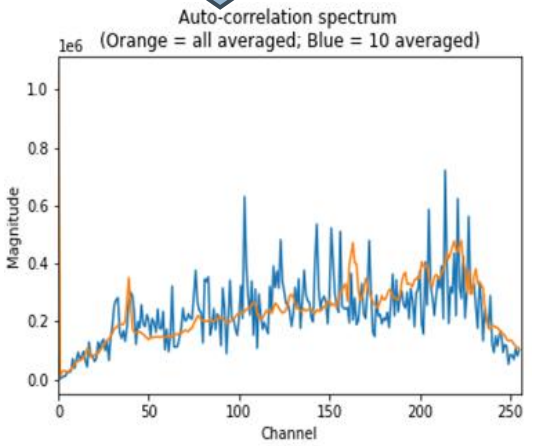
Auto-correlation Power Spectrum

Averaging





Autocorrelation spectrum



Time-Averaged Autocorrelation spectrum

Autocorrelation – Dynamic Spectrum

Raw Voltage Data
C11 or C12

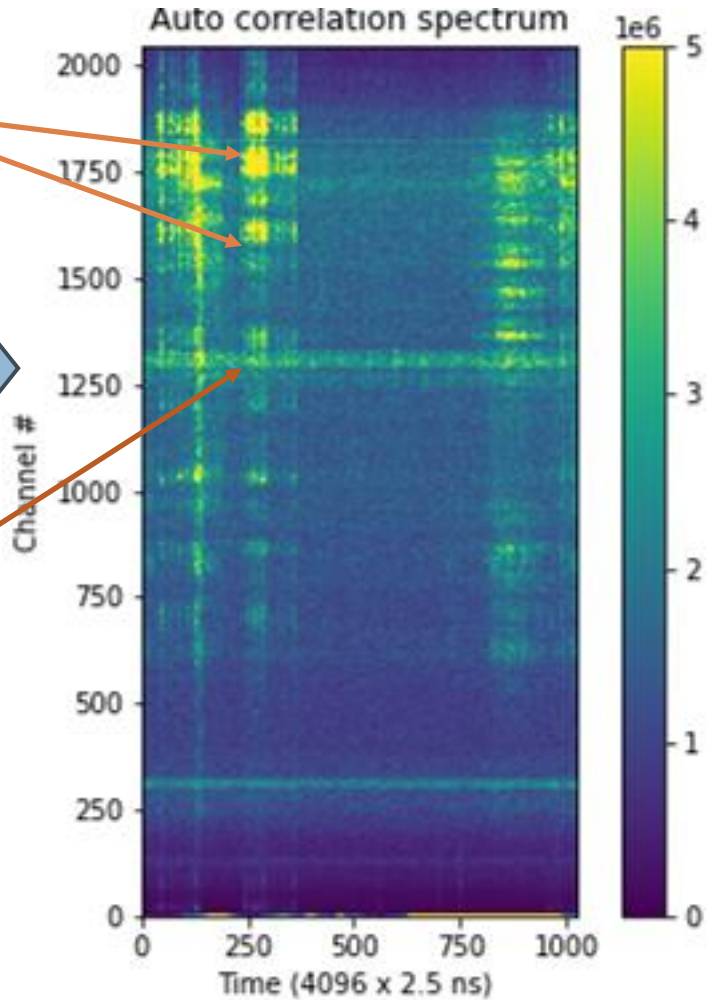
FFT

Auto-correlation Power Spectrum

Averaging

Broadband RFI

Narrowband RFI



Time – Frequency data plot

Cross-correlation

Raw Voltage Data C11

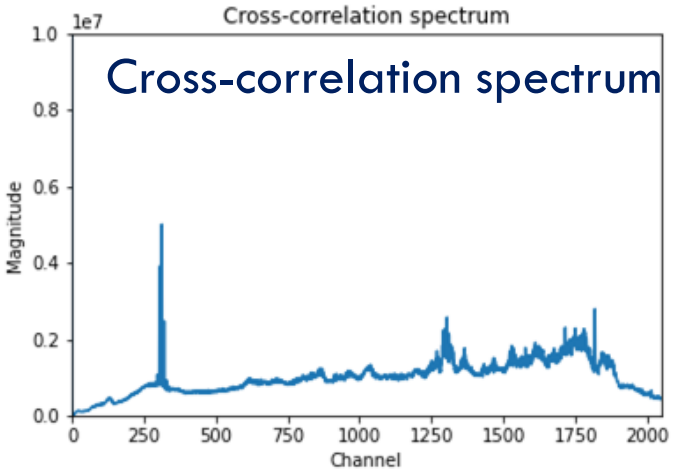
FFT

Raw Voltage Data C12

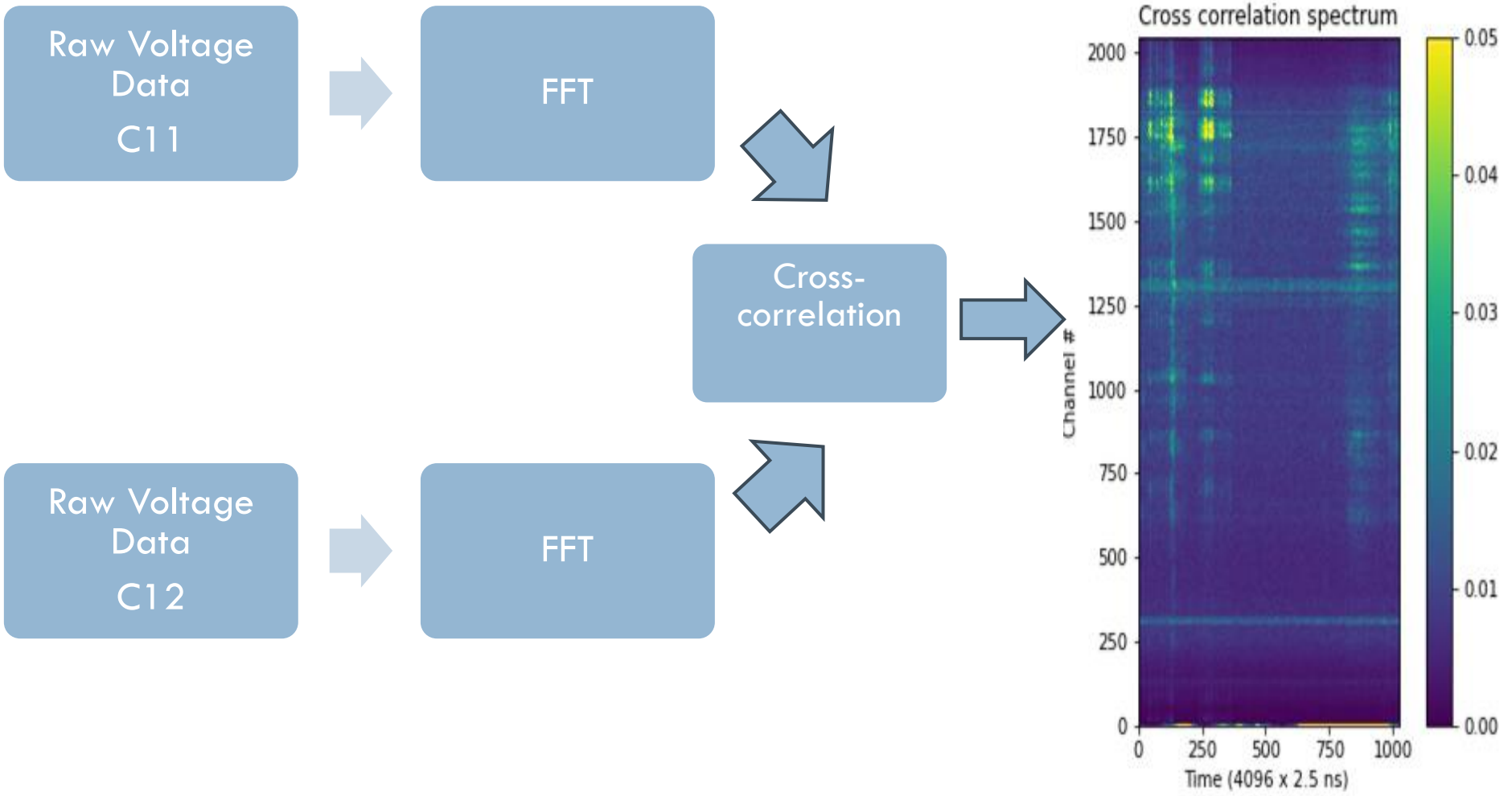
FFT

Cross-correlation

Averaging

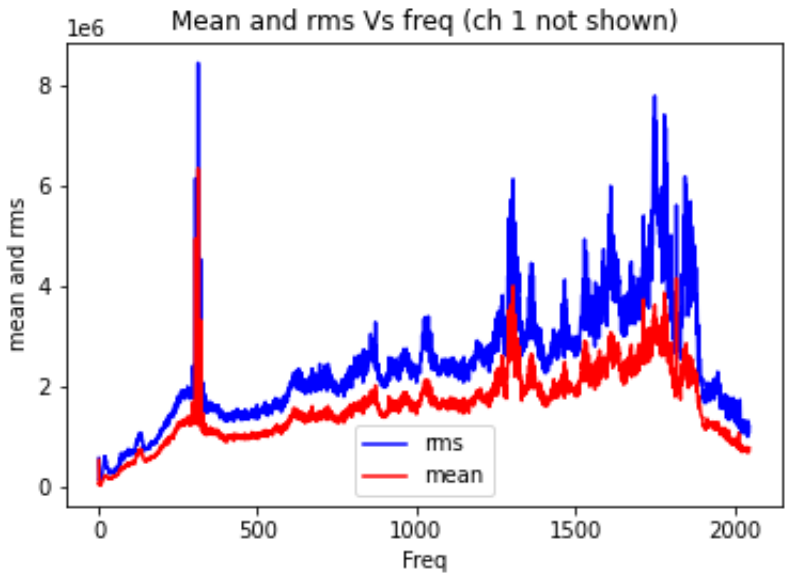


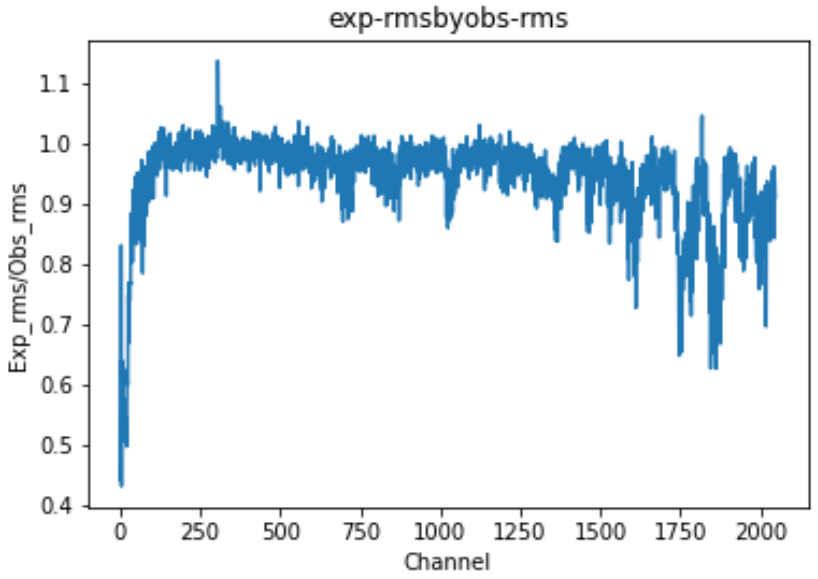
Cross-correlation



Dynamic spectrum (Time-Frequency plot)

Analysis of Statistics for RFI





Mean-to-RMS ratio across the spectrum helps indicate frequency channels affected by RFI

Resource Material

Source Data and Files

- http://www.gmrt.ncra.tifr.res.in/~kdbuch/Otherstuff/raw_voltage_expt/raw_voltage_RFI_expt.html

Instruction manual

- http://www.gmrt.ncra.tifr.res.in/~kdbuch/Otherstuff/raw_voltage_expt/RAWS_GMRT_Experiment_manual.pdf