# Real-time RFI Mitigation for the GMRT Wideband Digital Backend

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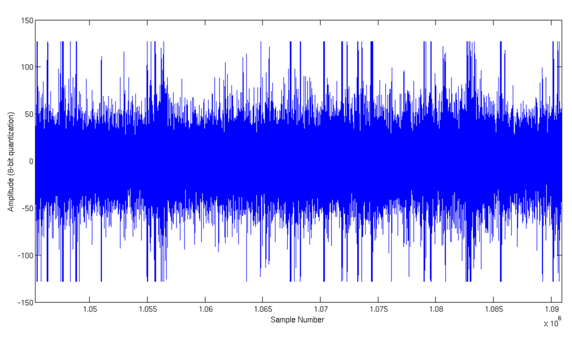
## Abstract

The Giant Metrewave Radio Telescope (GMRT) is one of the most sensitive instruments for observing astrophysical phenomena at metre wavelengths. Currently, the GMRT is undergoing a major technological upgrade which is aimed at achieving almost seamless frequency coverage from 50 to 1500 MHz, with a maximum instantaneous bandwidth of 400 MHz, which will lead to a significant increase in the sensitivity and capabilities of the radio telescope. While the increase in receiver bandwidth would result in better signal-to-noise ratio, it also likely to encounter higher levels of man-made radio frequency interference (RFI).In order to achieve the expected sensitivity and dynamic range, it is necessary to mitigate the effects of RFI from the astronomical signal. A real-time filtering technique for excision of broadband RFI from the Nyquist-sampled (800 MHz) digital time series of the received signal has been described. This non-linear filter uses robust statistical estimation through Median Absolute Deviation which is followed by filtering of samples that are detected outside the robust threshold. This RFI filter is optimized for operation in real-time on the Field Programmable Gate Array (FPGA) board used for receiving the digitized signal. It is currently being tested with the new GMRT wideband backend (GWB). Initial test results show successful removal of broadband RFI and subsequent improvements in the signal-to-noise ratio. The broad plan for future development of real-time RFI filtering techniques for the upgraded GMRT is also outlined.


## Introduction : RFI and its effects

**Impulsive(Broadband)RFI in digitized time series**



**Some Sources of Broadband RFI**

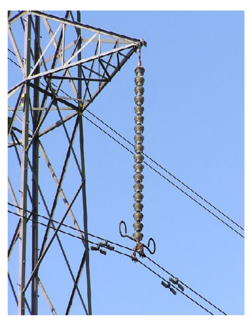
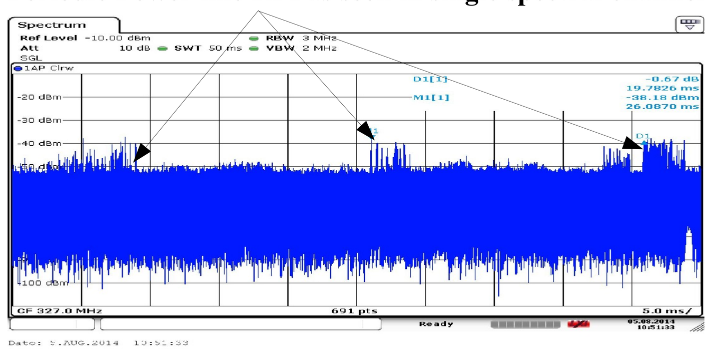


Image Courtesy :Wikipedia

**Periodic Power line RFI as seen in single spectral channel**



- The ITU-R RA.769-2 report [1] defines the level of RFI as detrimental when its presence introduces more than a 10% RMS error in the flux measurement.
- RFI is classified into two types based on the effects that it produces in the spectrum of the received signal.
  - Broadband RFI is a noise-like signal that causes an increase in the power level of the entire spectrum, and is usually generated by temporally impulsive events such as sparking and corona discharges in high power transmission lines, automobile ignitions and switching of inductive loads.
  - Narrowband RFI is the occurrence of an unwanted discrete frequency or a band of frequencies affecting only a narrow part of the receiver spectrum. Narrowband RFI is often produced by communication broadcast transmitters for TV, commercial and short distance radio services, aircraft and satellites.
- In the time-domain, a signal with RFI as observed by a radio telescope can be given as [2]

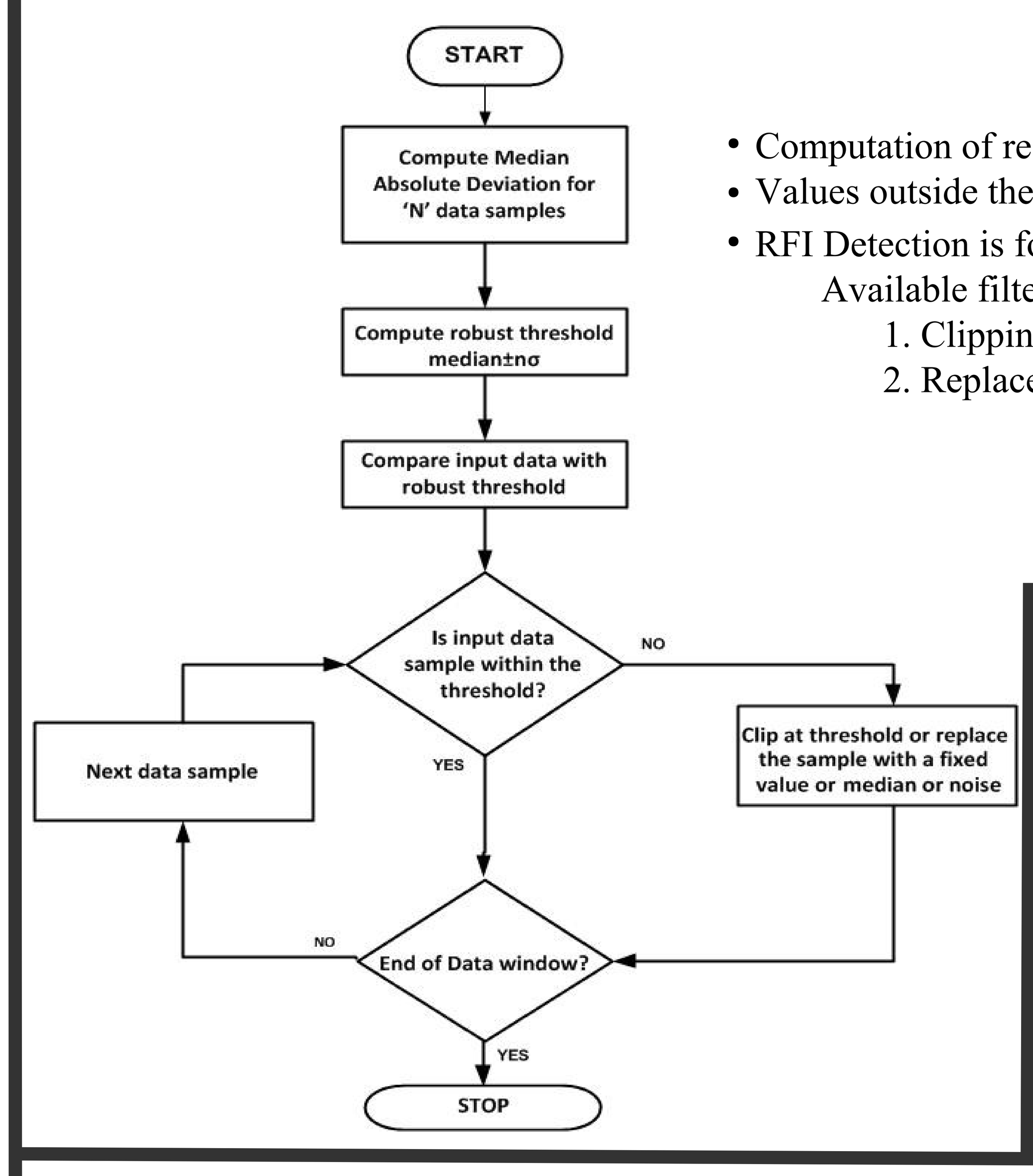
$$x(t) = x_{src}(t) + x_{sys}(t) + x_{RFI}(t)$$

- In the above equation, $x_{src}(t)$ is contribution due to astronomical source (desired signal), $x_{sys}(t)$ is the system noise (undesired signal) and $x_{RFI}(t)$ is the RFI signal (undesired signal). System noise is a combination of sky background noise and receiver noise. Both astronomical signal and system noise are zero mean random signals possessing Gaussian distribution. RFI usually possesses non-Gaussian distribution [2].
- Additional power introduced by RFI can be seen as increase in noise temperature of the receiver.
- Due to its non-random nature, the fluctuations in the received power do not reduce at the theoretical rate given by the radiometer equation as $(B*T)^{0.5}$ where B is the receiver bandwidth and T is the integration time
- Strong RFI drives the receiver into its non-linear region and results in contamination of the resultant power spectrum, which results in undesirable effects in the radio images.

## Real-time RFI detection and filtering using MAD

- MAD – robust measure of dispersion of data set (up to 50% outliers)
- Obtained by calculating median of the difference of data from the median of data
- 1.4826 times MAD is the standard deviation (for Gaussian distribution)

**MAD = median (abs ($X_i$ – median(X)))**




- Computation of real-time median using the histogram method
- Values outside the range of [median ± n*$\sigma_{MAD}$ ] are treated as RFI
- RFI Detection is followed by filtering

  Available filtering options:
  1. Clipping
  2. Replacement with a) Constant value and b) Digital noise

ROACH (Reconfigurable Open Architecture Computing Hardware) -FPGA processing board

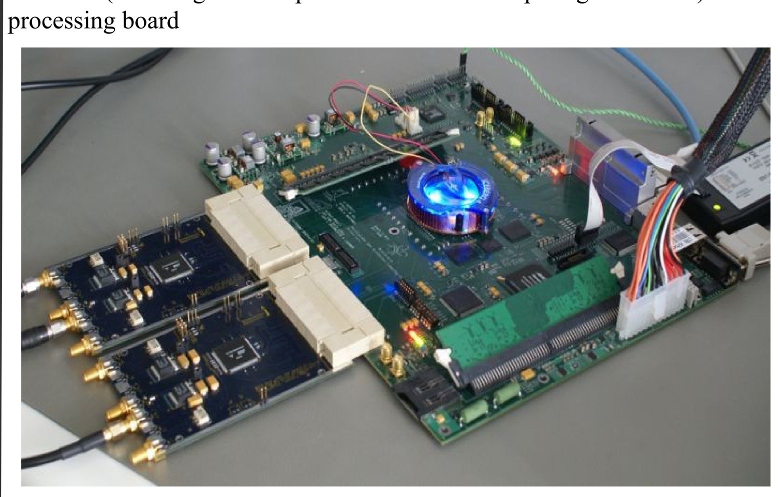
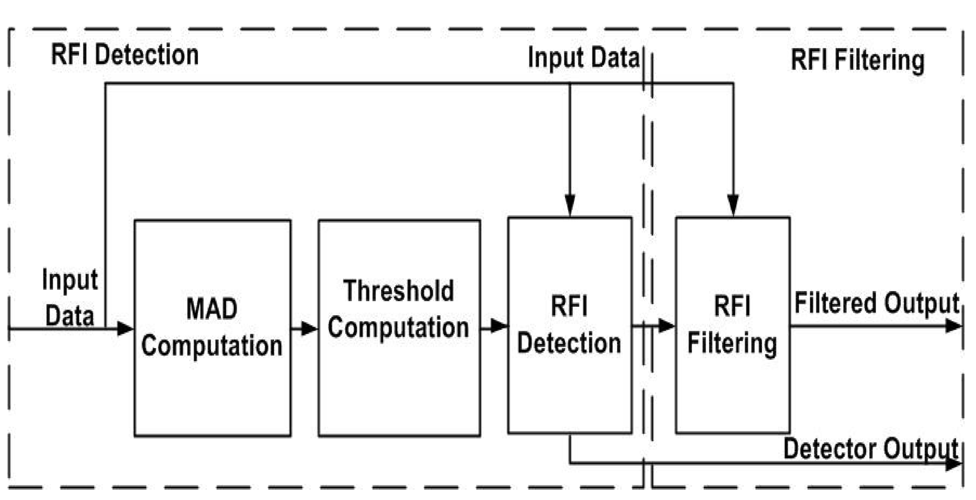


Image courtesy:CASPER

## Implementation on FPGA (ROACH Board)

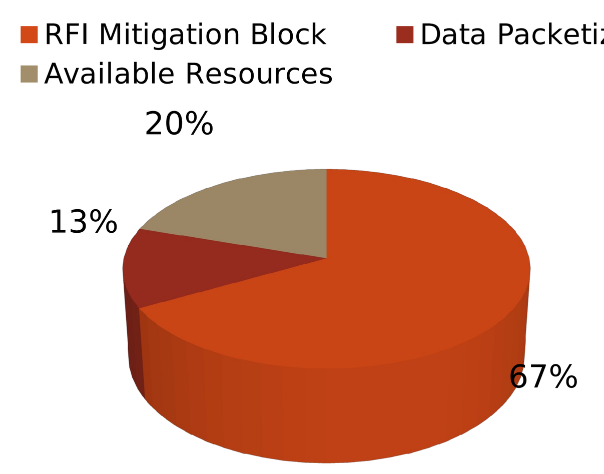
### Block Diagram




RFI mitigation block [3] was designed using MATLAB-Simulink and Xilinx System Generator and implemented on ROACH-1 FPGA board designed by CASPER collaboration (https://casper.berkeley.edu/).

### Resource Utilization

**4K Data window for 8-bit input**




Two RFI mitigation blocks each having 4K window size utilize 67% resources on Xilinx Virtex-5 SX95 FPGA.

## Design Features

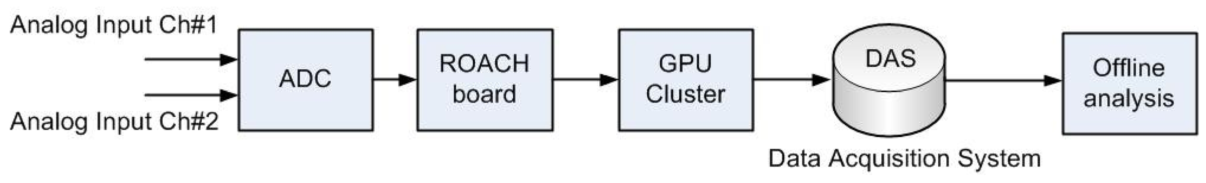
- Parameterized window size – maximum 8192 samples
- Threshold calculation and filtering options can be changed on-the-fly.
- Bypass mode for bypassing filtering
- MAD computation on contiguous windows
- 4-bit, 6-bit and 8-bit versions operating at 400 MHz bandwidth
- Filtering options – Clipping, Replacement (median, constant value, Gaussian noise)

## Testing with GMRT Wideband Backend(GWB):

GWB is a wideband signal processing backend consisting of FPGAs and GPU cluster for real time computation of signals received from the GMRT antenna array. GWB can process maximum bandwidth of 400 MHz.

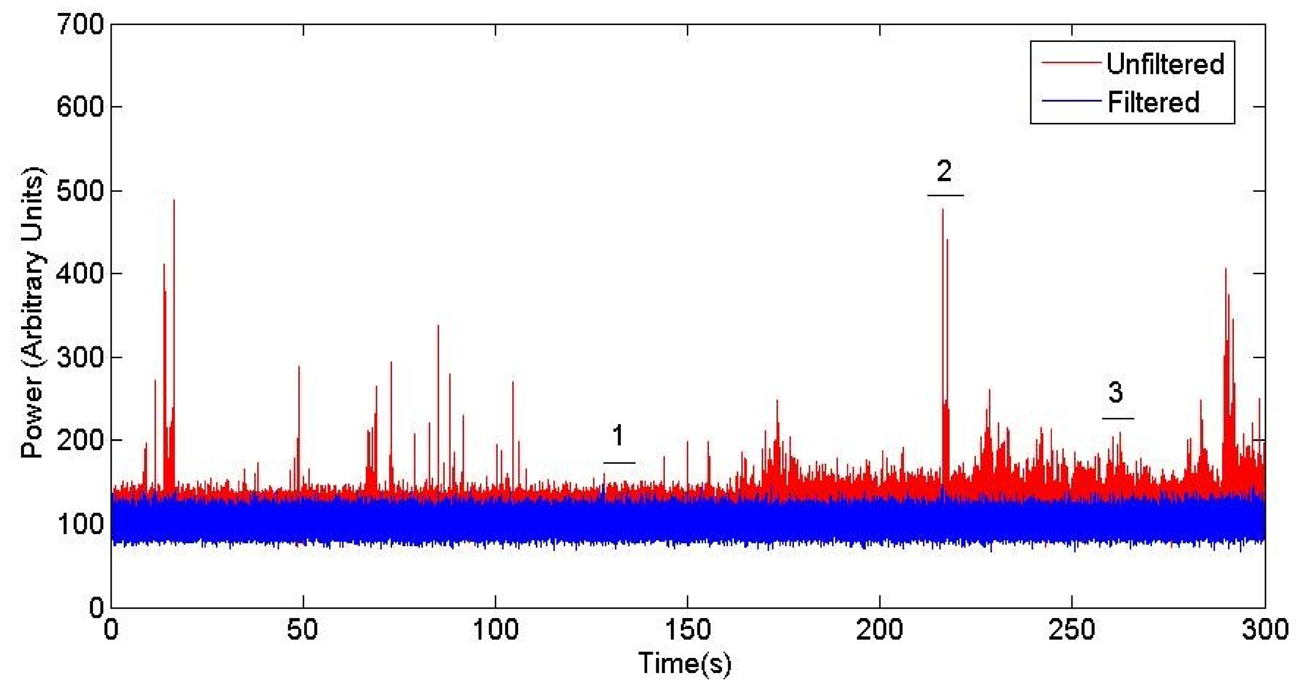
Mean to RMS ratio is used for expressing signal to noise ratio in communication receivers. This is a normalized quantity impervious to system gain fluctuations or other scaling parameters in the RF or analog receiver chain.

Real-time RFI filtering was tested with GWB through two types of tests-
1. Antenna Test
2. Test using RFI emulator




## Antenna Test

Single spectral channel plot over time from one of the GMRT central square antennas processed through GWB at 1.3 ms time resolution.



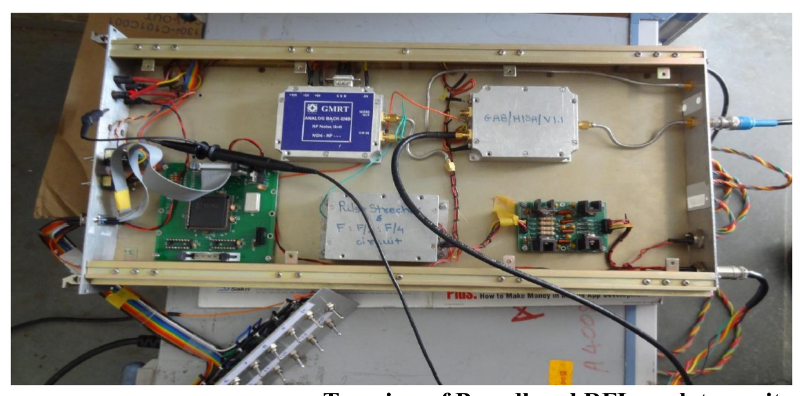

- **RF: 650 MHz (centre)**
- **BW: 100 MHz**
- **Processing BW: 200 MHz**
- **Source: 3C 147**
- **Filtering threshold: 3σ**

| Parameter | Filtered | | | Unfiltered | | |
|---|---|---|---|---|---|---|
| | 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 |

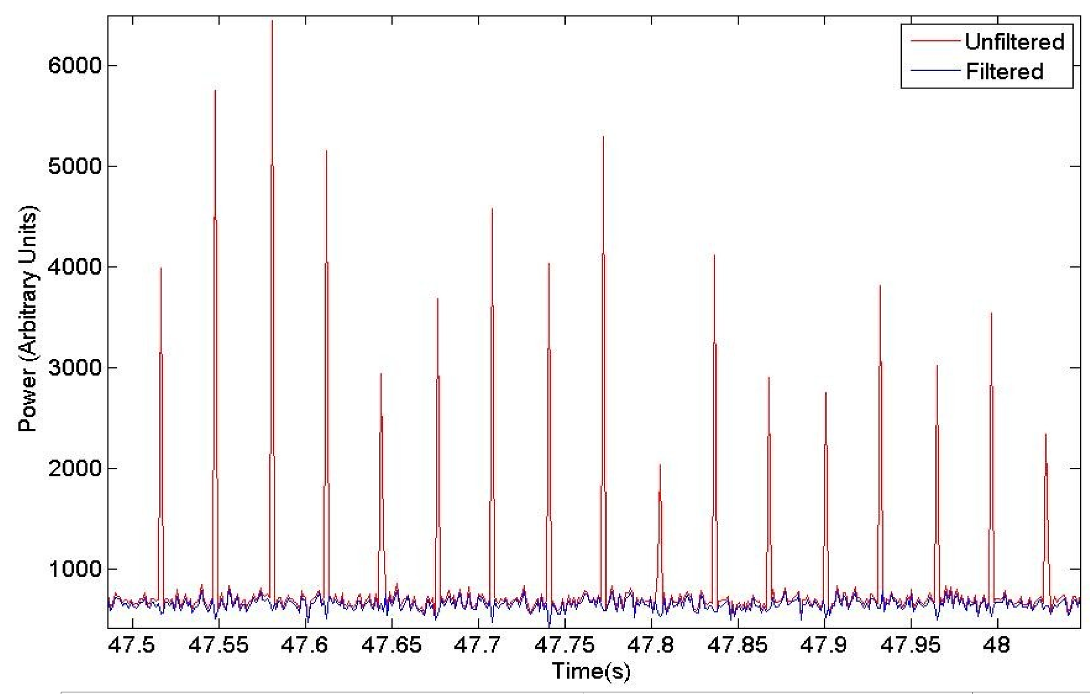
## Test using RFI emulator

In order to test the block using controlled inputs, a programmable,versatile broadband RFI emulator was developed.This emulator can generate pulsed noise of desired duty cycle at RF or baseband frequencies.

Radiation test using Broadband RFI emulator unit



Top view of Broadband RFI emulator unit

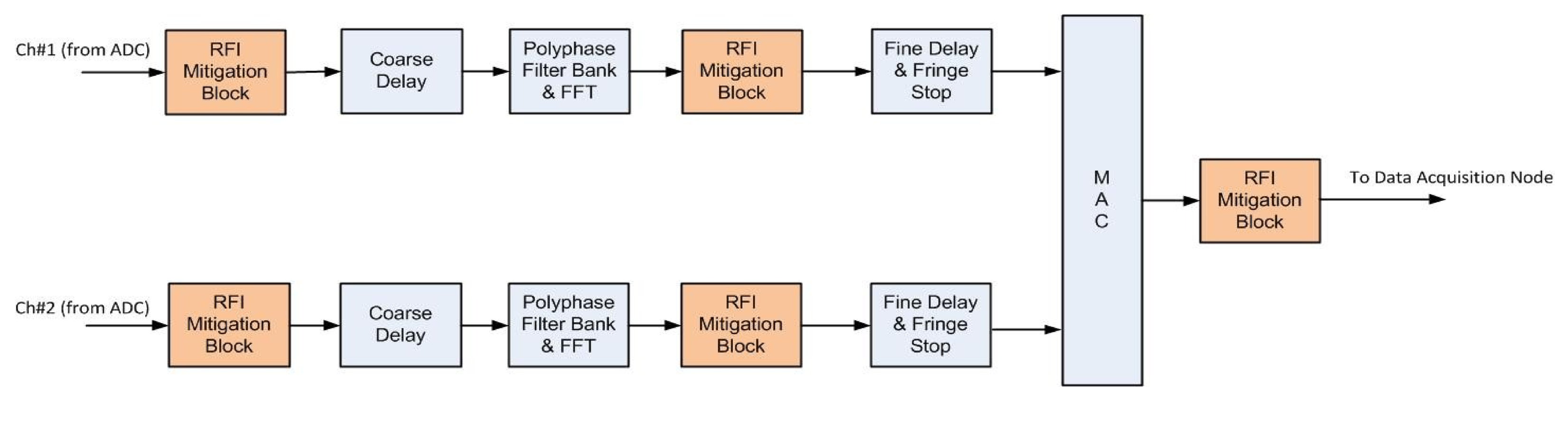



- **Input : Pulsed noise(On time-256 us Off time-32 ms)**
- **BW: 100 MHz**
- **Processing BW: 200 MHz**
- **Filtering threshold: 3σ**

| Parameter | Filtered | Unfiltered |
|---|---|---|
| Mean / RMS ratio | 10.4104 | 1.2398 |

## Future plans

- Implementation of record of detected / filtered samples (flag)
- Test the broadband RFI mitigation design with different modes of GWB and optimize the parameters of the design
- Implement real-time narrowband RFI filtering using MAD




In order to remove diverse types of RFI , RFI Mitigation is proposed to be carried out in pre-correlation and post-correlation domains in the digital subsystem of the GWB.


### References

[1] ITU-R RA.769-2, "Protection Criteria for Radio Astronomical Measurements", 2003.
[2] P.A. Fridman and W.A. Baan, "RFI mitigation methods in radio astronomy", Astronomy & Astrophysics, 378, 2001, pp. 327-344.
[3] Impulsive RFI Excision – CASPER Library Block; https://casper.berkeley.edu/wiki/Impulsive_RFI_Excision:_CASPER_Library_Block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