Real-time Broadband RFI Excision for the Upgraded GMRT: Shared risk release

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GTAC User Document Version 4.0

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1 Summary and Recommended Settings

In this document a summary of the shared risk release of the real-time (online) broadband (BB) Radio Frequency Interference (RFI) filter for the Upgraded GMRT(uGMRT) users is provided. **Users should note that when the real time RFI filtering is chosen for GTAC observations, the unfiltered data cannot be recorded and thus the filtering once done is irreversible.**

The currently recommended settings for the RFI filtering are 4σ threshold with digital noise replacement for continuum observations and 3σ threshold with digital noise replacement for pulsar observations. Also, the power equalization should be between 80-90 counts.

Please contact us at onlinerfi@ncra.tifr.res.in well in advance for using the filter in GTAC observations or related queries.

Table 1: Broadband (BB) RFI filtering [1] for shared risk usage in GTAC observations. The first sector is for interferometric mode observations and the second sector for pulsar mode observations. "DNR" stands for Digital Noise Replacement.

Band	Filter settings	Typical Fil. Frac.	Reference
5	3σ cutoff, DNR	$< 0.5\%$	Sec. 3
4	3σ cutoff, DNR	$0.5 - 1.5\%$	Sec. 3
3	3σ cutoff, DNR	$1 - 2\%$	Sec. 3
2	3σ cutoff, DNR	$4 - 5\%$	Sec. 5
3 (Pulsar mode)	3σ cutoff, DNR		Sec. 4

2 Broadband RFI Mitigation for the uGMRT: Method

The Median Absolute Deviation (MAD) is computed on Nyquist-sampled digitized time series for each polarization of each antenna using 16k samples. Further, a median of 16k such MAD values (median of MAD, MoM) is calculated. To meet the real-time requirements, these calculations are carried out on every fourth input sample arriving at 1.25 ns sampling interval. Thus, (16384 samples $\times$ 16384 MAD values $\times$ 1.25×10^{-9}seconds) $\times 4 = 1.34$ seconds worth of data goes into the real time statistics for the RFI filtering and is applied to the subsequent data. Values outside the threshold, median$\pm n \times 1.4826\times$ MoM are treated as RFI and can be replaced either by a constant value or digital noise ($n = 3$, $\sigma = 1.4826\times$ MoM,

Table 1). The typical percentage of samples that are affected by the filtering are also provided for hte interferometric mode observations at bands 2, 3, 4 and 5.

An RFI counter can be enabled through the command file during the observation to keep a record of the number of detected RFI samples per antenna per polarization. The ratio of these counts with the total number of points provides the fraction of flagged samples over user-defined time intervals (minimum duration of 5 minutes as per current configuration) during the observation. The observation settings generator [1] can be used by choosing the option of Online RFI filtering to get the command file with additional commands for the counter. The RFI counter cannot be activated for scans shorter than 5 minutes. A Python utility [2] has been developed to provide plots for percentage flagging (average and per antenna) using the file with counter values generated at the end of the observing session.

3 Interferometric observations: Bands 3, 4 and 5

We have tested the online RFI filter with 3σ threshold and digital noise replacement (DNR) for bands 3, 4 and 5. The Indian polar mode and default continuum settings were used. The unfiltered signal from half the array was copied into the remaining half to obtain a simultaneous recording of filtered and unfiltered data (1:2 digital copy mode). At bands 3, 4 and 5 we found that any change in the recovery of calibrator flux densities was $< 3\%$. The flagging percentage is lower by $10 - 40\%$ for central square antennas as compared to that in unfiltered data (see Fig. 1 for an example of a short baseline).

We carried out standard steps of flagging, calibration and imaging of target source on simultaneous data with and without filtering using the CAPTURE pipeline[3]. The resulting images from filtered data have lower rms and better fidelity (Fig. 2).

4 Pulsar observations

We carried out pulsar observation for PSR B0329+54 in the incoherent array (IA) mode at band-3 (200 MHz bandwidth) to check the effect of RFI filtering on strong single pulses and on averaged folded profiles. The observation was carried out with 14 antennas in the 1:2 digital copy mode and with RFI filtering at 3σ threshold and replacement by digital noise. The setup used 4096 spectral channels and a time-resolution of 327.68 μs.

The de-dispersed time-series from a strong pulsar B0329+54 shows an improvement of signa-to-noise ratio (SNR) by a factor of 4 over the unfiltered version (Figs. 4 and 3). The SNR of unfiltered is 60 which increases to 240 after filtering. The strong single pulse from PSR B0329+54 are not clipped during filtering (Figs. 5 and 6).

5 Interferometric observations: Band 2

At band 2 the data in the frequency range 0.19 - 0.24 GHz were analysed to avoid the regions in the spectrum that were affected by the notch filter and dominant narrow band RFI. The calibrated data towards the primary calibrator are shown in Fig. 7. The trend of reduced standard deviation in the data at short baselines is seen at band 2. However, there are long baselines that show an increase in the standard deviation after filtering. This issue is being investigated.

[1] http://www.ncra.tifr.res.in:8081/~secr-ops/cmd3/cmd.html
[2] http://www.gmrt.ncra.tifr.res.in/~kdbuch/counter_page/counter_flagging.html
[3] CASA Pipeline-cum-Toolkit for uGMRT Data Reduction,https://github.com/ruta-k/uGMRT-pipeline

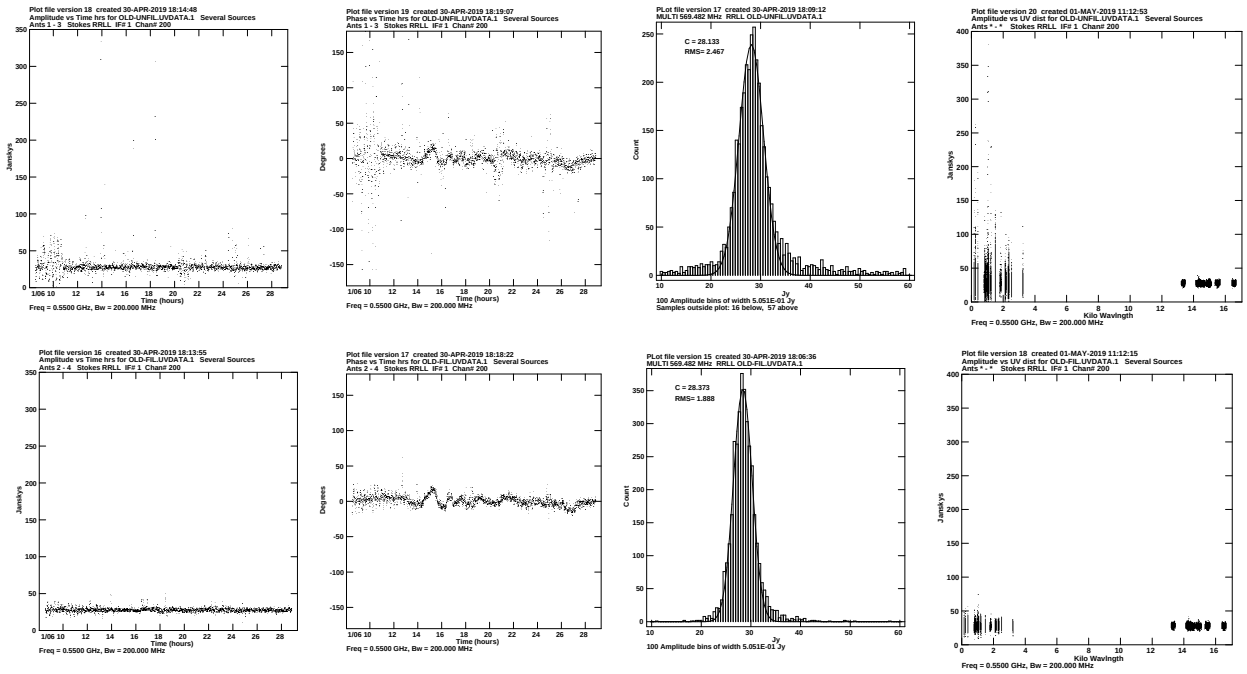

Figure 1: Top panels are for unfiltered data and bottom panels are the corresponding filtered data (Band 4, 14 June 2018). The calibrated data on baseline C00-C02 in unfiltered data (top) and the filtered copy C01-C03 (bottom) for the channel 200 (0.550 GHz). The panels from left to right show Amplitude Vs time, Phase Vs Time, a histrogram of amplitudes and Amplitude Vs uv-distance. The improvement by the online RFI filter is mainly at short baselines.

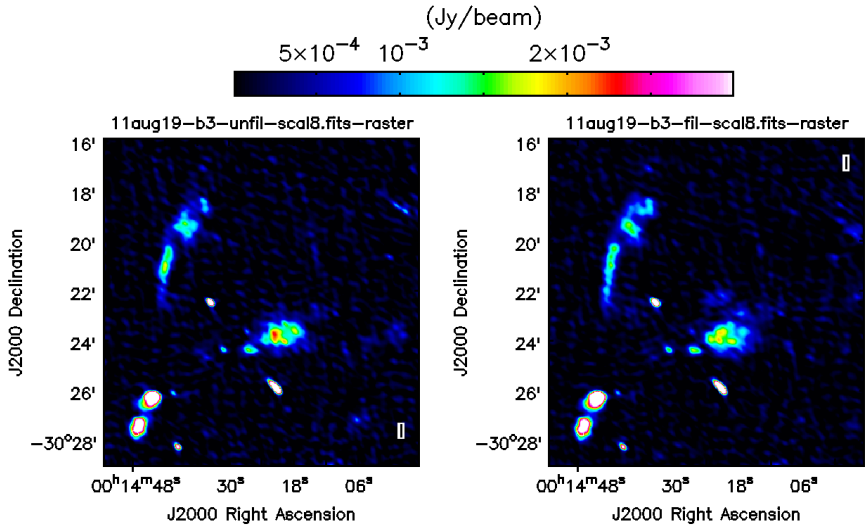

Figure 2: Band 3 images of A2744 field: unfiltered (left) and filtered (right). The rms in the unfiltered image is 115 μJy beam^{-1} and in the filtered image is 107 μJy beam^{-1}. The beam size is $17.9'' \times 10.6''$ with a position angle 53°.

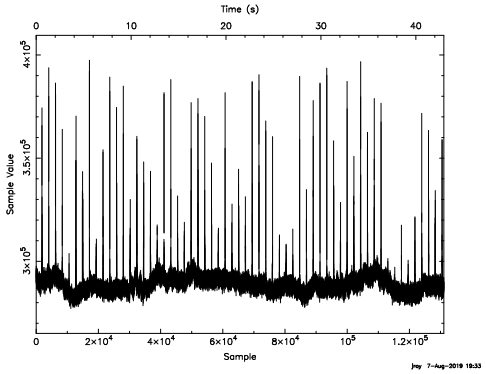

Figure 3: Unfiltered de-dispersed time-series from a strong pulsar B0329+54 : observation carried out in the digital copy (1:2) mode

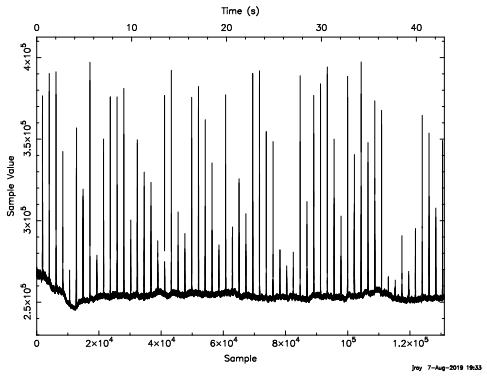

Figure 4: Filtered de-dispersed time-series from a strong pulsar B0329+54 : observation carried out in the digital copy (1:2) mode. SNR improvement by a factor of 4.

6 Current Usage Statistics for Real-time RFI Filtering

Real-time RFI filtering usage in the recent observing cycle (GTAC-40) is summarized in Table 2.

Table 2: Real-time RFI filtering usage during GTAC observations in Cycle 40 (April-October 2021) for uGMRT Band-2 (120-240 MHz) and Band-3 (250-500 MHz). The table shows total approved GTAC duration and RFI filtering usage (in hours and in percentage of total duration) along with type of observation.

Band	Duration (Hrs.)	Filtering (Hrs.)(%)	Obs. Type
2	30	24 (80%)	Continuum (100%)
3	418	203 (49%)	Continuum (55%), Pulsar(45%)

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References

[1] K. D. Buch, K. Naik, S. Nalawade, S. Bhatporia, Y. Gupta, and B. Ajithkumar, "Real-time implementation of MAD-based RFI Excision on FPGA," *Journal of Astronomical Instrumentation*, vol. 8, 2019.

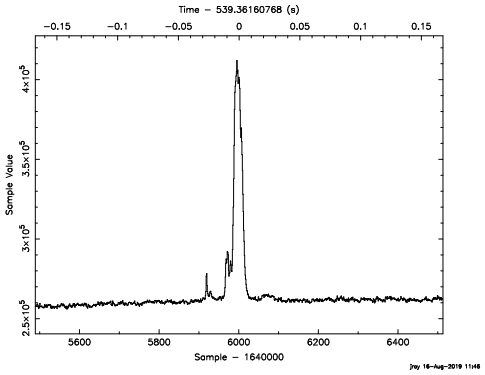

Figure 5: Single pulse (unfiltered) from a strong pulsar B0329+54

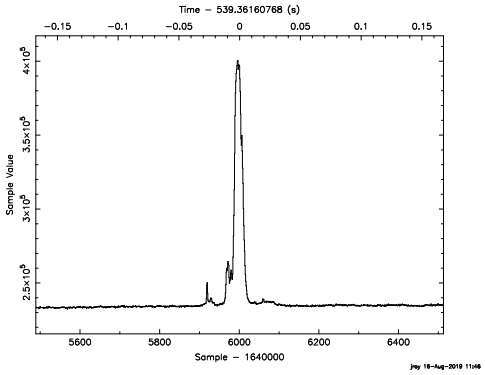

Figure 6: Single pulse (filtered) from a strong pulsar B0329+54

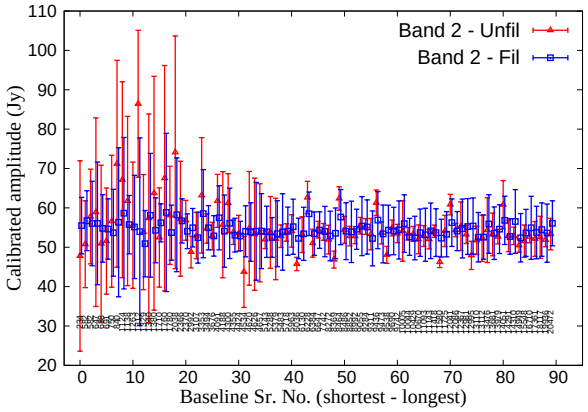

Figure 7: The band 2 calibrated flux density of a primary calibrator source for a single channel is plotted as a function of baseline numbers sorted according to their lengths. The integers in the plot indicates the length of the baseline in metres (234 - 20472 m). The unfiltered (red) and filtered (blue) points are offset on the x-axis for comparison.