Characterising the performance of new GWB system

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April 14, 2014

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1 Overview

Several observations of the calibrator sources using GSB (GMRT software backend, currently in use) and new GMRT Wideband Backend (GWB) were performed for a faithful comparison between the two backends. These results showed by and large consistent results at several frequencies. We use cross-correlation coefficient, ccf, for a baseline at a given frequency from a point source with flux density, $S\nu$ is defined as

$$\text{ccf} = \frac{G \times S_\nu}{T_{\text{sys}}},$$

where G and T_{sys} are Gain (in K Jy^{-1}) and system temperature (in K) of a GMRT antenna, respectively, as a measure of performance of the backend. Initial Tests showed that the GWB appears to match the GSB for some baselines or antennas, but not for all, and that there appears to be inconsistencies in the relative values of ccf for different baselines involving the same antenna. Further, several tests done at 610 MHz, *e.g.* tests performed on 5 and 9 February showed even more consistent behavior between GSB and GWB. Finally, results from 250–500 MHz band showed most of the baselines from the GWB to give results to be either comparable or superior than the GSB. In short, lower frequencies, namely 610 MHz and 250–500 MHz bands showed apparently consistent results between GSB and GWB, which match well with the expected theoretical predictions of ccfs. Motivated from this, we performed another set of tests, where optical-fiber (OF) attenuations were put in at various levels and data recorded (Section2 explains methodology of these new tests) in order to observe nature of ccfs and its dependence on OF attenuation.

This report is organized as follows. Section 2 contains our choice of various GMRT test data from several series of tests performed using GWB and GAB listed at
`http://www.gmrt.ncra.tifr.res.in/∼sachin/.`
A summary of results of the analysis are presented in subsequent sections, namely, Section 2.1, 2.2, and 2.3 show results obtained at 1280 and 1390 MHz, 610 MHz, and 250-500 MHz frequency bands, respectively. We summarise our findings in Section 3, make some final concluding remarks, and list some of our future plans in Section 4.

2 Data

GMRT data using new GWB, which is acquired using the new GMRT analog baseband (GAB) chain at several frequencies was acquired in order to understand the performance of it and its comparison with the GSB. The observing log for the test data presented in this report is shown in Table 1.

Table 1: GMRT test data presented in this report.

Frequency	Obs. Date	Target	Expected ccf
1280 MHz	2014-02-12	3C 286	0.055 (@1280 MHz)
1390 MHz	2014-02-13	3C 286	0.055 (@1280 MHz)
610 MHz	2014-02-22	3C 147	0.127
250–500 MHz	2014-03-04/05	3C 147	0.186

Since, these are an upgrade related tests of GMRT to understand varying ccf scales from GWB on various baselines with respect to the GSB, both, broadband system and related antennas are a must and data from GWB and GSB needs to be recorded simultaneously. All observations were typically made in the following manner:

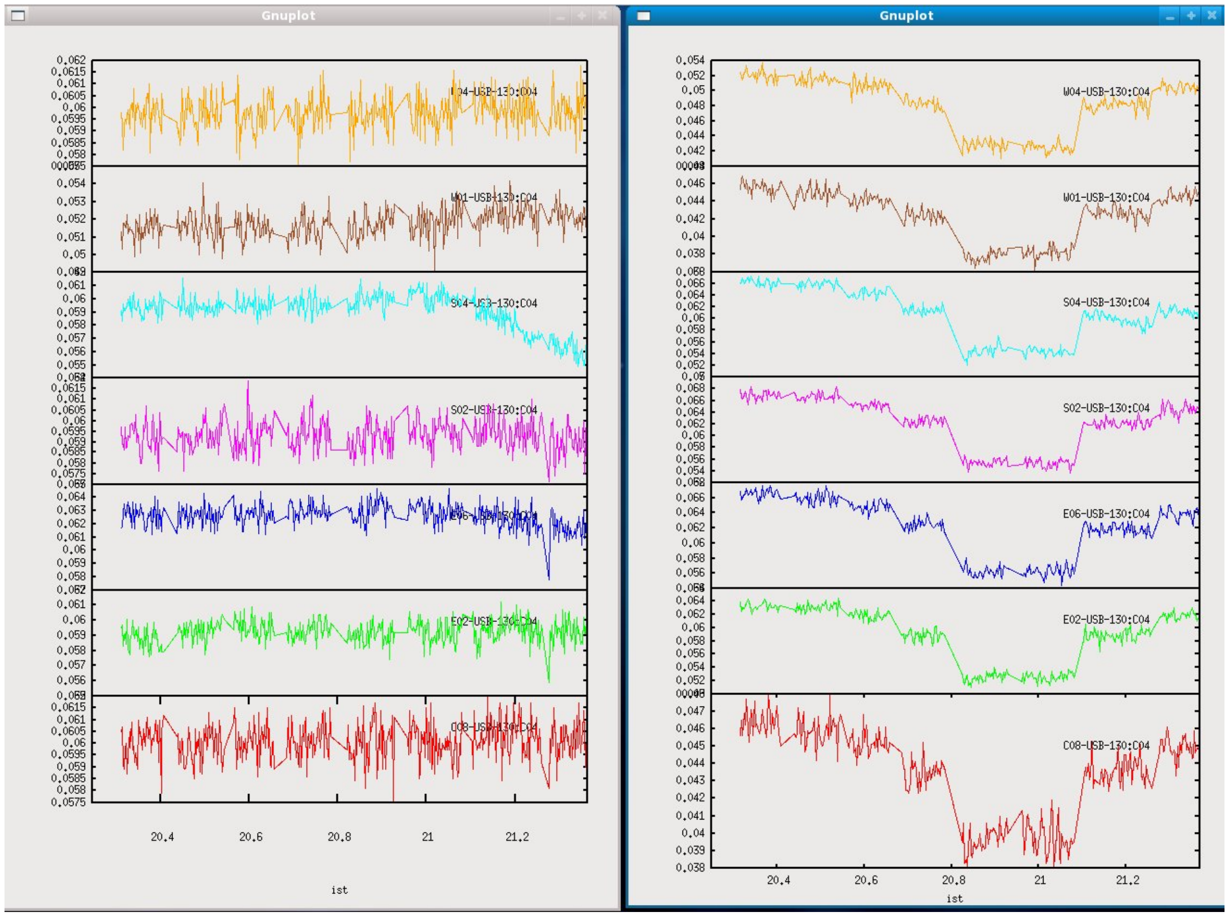

Figure 1: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('1280 MHz') frequency band. Note (i) in both, left (GSB) and right (GWB) panels, channels are chosen such that they correspond to the same frequency, and (ii) no-power equalisation was performed (see Section 2). Scan-0, scan-1, ..., and scan-7 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 5dB–5dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, and 5dB–5dB, respectively.

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
```

This is called as 'no power-equalise' mode of observation and next

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
- OF attn 5dB-5dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
```

is called as 'power-equalise' mode of observation.

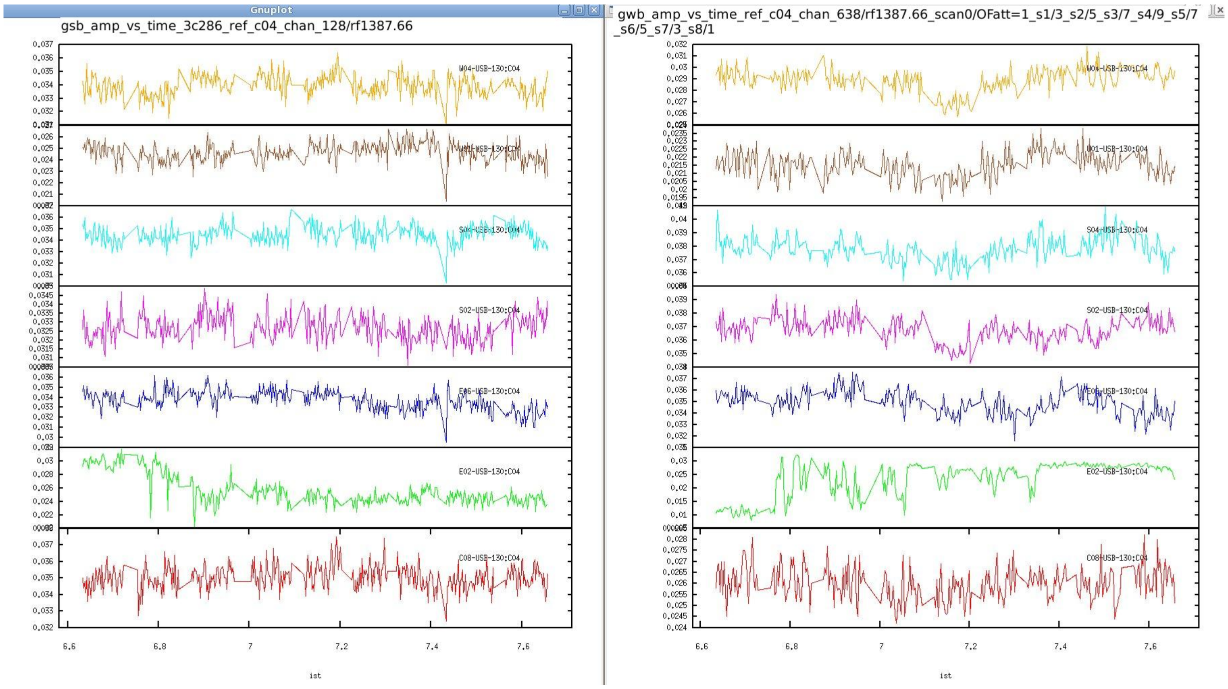

Figure 2: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('1390 MHz') frequency band. Note (i) in both, left (GSB) and right (GWB) panels, channels (channel-128 in the left panel and channel-638 in the right panel) are chosen such that they correspond to the same frequency, and (ii) no-power equalisation was performed (see Section 2). Scan-0, scan-1, ..., and scan-8 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 5dB–5dB, 7dB–7dB, 9dB–9dB, 7dB–7dB, 5dB–5dB, 3dB–3dB, and 1dB–1dB, respectively.

2.1 Tests at 'L' band

Initial tests concentrated on the 'L' band system for reasons that it was the frequency band which had almost all antennas available with upgraded systems. Hence, there were several test observations carried out at the sub-bands of 'L' band. Two set of tests were performed, at 1280 MHz and at 1390 MHz sub-bands.

Figure 1 shows results from 'no power-equalise' mode of observation and individual scans in it are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
```

Again Figure 2 shows results from 'no power-equalise' mode of observation and individual scans in it are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
```

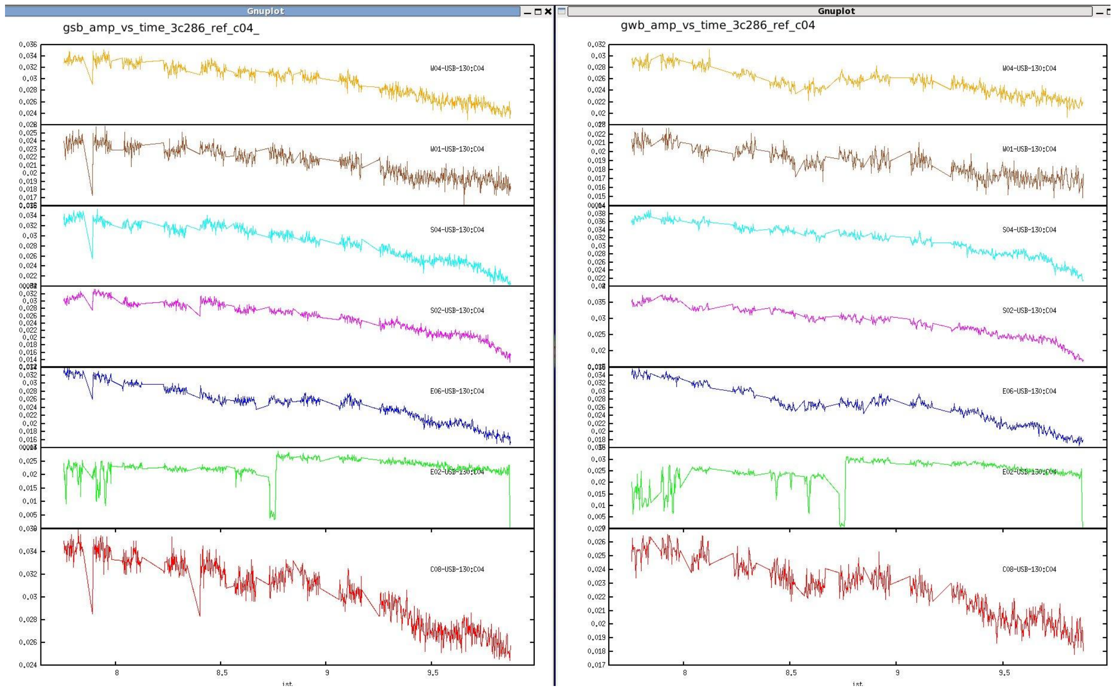

Figure 3: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('1390 MHz') frequency band. Note (i) in both, left (GSB) and right (GWB) panels, channels are chosen such that they correspond to the same frequency, and (ii) power equalisation was performed (see Section 2). Note also the remarkable agreement of falling ccfs as a function of time for several baselines between GSB and GWB. Scan-9, scan-10, ..., and scan-18 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 5dB–5dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, 5dB–5dB, 3dB–3dB, and 1dB–1dB, respectively.

```
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 1dB-1dB, (DO NOT power-eq) and record data for 5min
```

Finally, Figure 3 shows results from 'power-equalise' mode of observation and individual scans in it are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
- OF attn 5dB-5dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 5dB-5dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
```

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
```

We report results and summary from several tests that were performed at the sub-bands of 'L' band feed, namely 1280 and 1390 MHz. Figures 1, 2 and 3 show plot of ccfs (amplitudes) as a function of time for a channel from GSB and GWB. Here, Figures 1 and 2 are from the 'no power-equalise' mode of observation and Figure 3 is from the 'power-equalise' mode of observation performed on 12 Feb and 13 February 2014.

2.1.1 Inferences from tests at 'L' band

(I) Results from scan-0 (OF attenuation 1dB, 1dB and 'power-equalise') show the following:
- There is a systematic difference in the ccfs between GWB and GSB, with GWB being significantly less than GSB for the short baselines and slightly more for the long baselines. The drop in ccfs ranges from ∼20–30% for short baselines to 5–10% for long baselines.
- It seems that this trend, significantly less ccfs in GWB as compared to GSB for the short baselines and slightly more ccfs in GWB as compared to GSB for the long baselines is independent of choice of antennas and choice of reference antenna.
- Some baselines show strikingly similar variation in phase as a function of time between GSB and GWB data; this is more so for long baselines. Of course these are some baselines where we do not see similar variation in phase as a function of time between GSB and GWB data.

(II) Results from rest of the scans (higher levels of OF attenuations and 'no power-equalise') show the following:
- In addition to a systematic difference in the ccfs between GWB and GSB, there is a clear trend for falling ccf with increasing OF attenuation for the 1280 MHz sub-band, and also in the 1390 MHz sub-band to some extent. This is at least true for the two cases of with and without GAB power equalisation.
- The fall in ccf is monotonic with increasing OF attenuation and is maximum for 1280 MHz sub-band, being close to ∼20%, whereas it is ∼10% for 1390 MHz sub-band.

(III) Results from rest of the scans (higher levels of OF attenuations and 'power-equalise') show the following:
- There is a remarkable agreement of falling ccfs as a function of time for several baselines between GSB and GWB.

To summarise, it appears that the GWB seems to match the GSB for some baselines or antennas, but not for all, and that there seems to be some "inconsistency" in the relative ccfs values for different baselines involving the same antennas.

2.2 Tests at '610 MHz' band

Next, we report results and summary from several tests that were performed at the '610 MHz' frequency band. Figures 4 and 5 show plot of ccfs (amplitudes) as a function of time for a channel from GSB and GWB. Here, Figures 4 and 5 uses the same input data obtained from the 'no power-equalise' mode of observation on 22 February 2014, but uses different reference antennas; C04 in the former and W04 in the latter. Here, in Figures 4 and 5 the first half of the scans, 'no power-equalise' mode are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 5dB-5dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
```

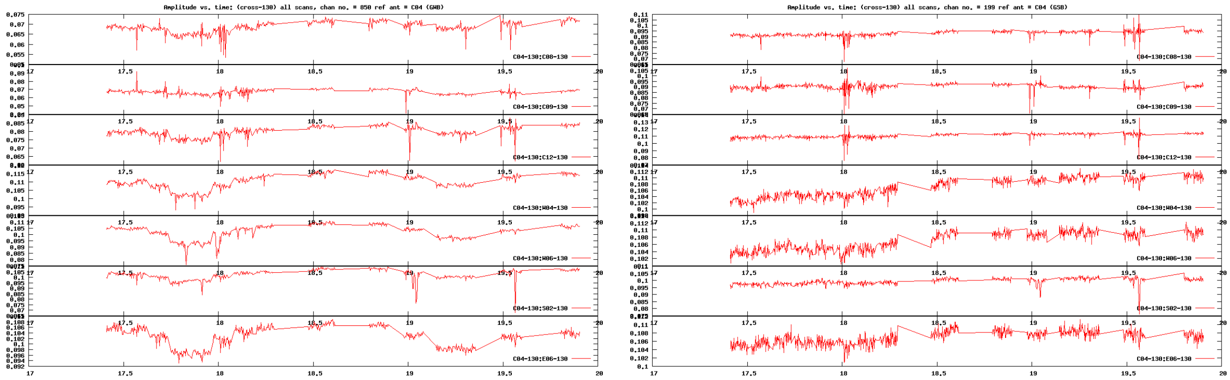

Figure 4: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('610 MHz') frequency band. Note (i) in both, left (GWB) and right (GSB) panels, channels are chosen such that they correspond to the same frequency, and (ii) both, no power equalisation and power equalisation was performed (see Section 2). Scan-0, scan-1, ..., and scan-7 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, 3dB–3dB, and 1dB–1dB, respectively, and correspond to 'no power-equalise' mode. Whereas, scan-8, scan-9, ..., and scan-14 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, and 3dB–3dB, respectively, and correspond to 'power-equalise' mode.

```
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 1dB-1dB, (DO NOT power-eq) and record data for 5min
```

and rest of the scans, 'power-equalise' mode are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
```

2.2.1 Inferences from tests at '610 MHz' band

These tests show a relatively consistent behavior between GSB and GWB as compared to the 'L' band data. Figures 4 and 5 show results from the same data using two different reference antennas.

(I) The results from scan-0 (OF attenuation 1dB, 1dB and 'power-equalise') of the '250–500 MHz' frequency band showed the following:
   - The systematic difference in the ccfs between GWB and GSB, for specific antennas is seen here as well, *e.g.* C08, C09, C12 (and also E06 which had replaced E02) show ccfs from GWB that are lower by 25–30% as compared to the ccfs from GSB.
   - This drop for C08, C09, C12 (and E06) is comparable to that seen in the sub-bands of 'L' band discussed above (section 2.1).

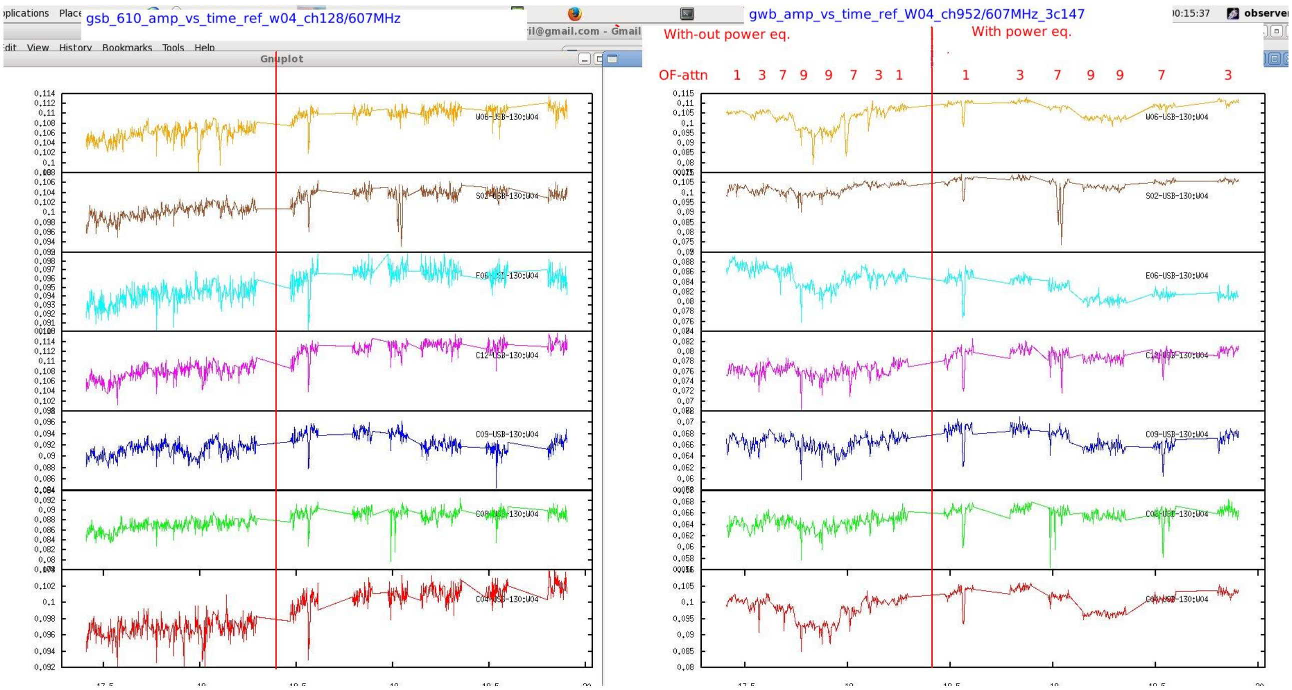

Figure 5: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('610 MHz') frequency band. Here, as compared to the previous plot, Figure 4, W04 is chosen as the reference antenna. Note (i) in both, left (GSB) and right (GWB) panels, channels are chosen such that they correspond to the same frequency, and (ii) both, no power equalisation and power equalisation was performed (see Section 2). Scan-0, scan-1, ..., and scan-7 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, 3dB–3dB, and 1dB–1dB, respectively, and correspond to 'no power-equalise' mode. whereas, scan-8, scan-9, ..., and scan-14 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, 9dB–9dB, 9dB–9dB, 7dB–7dB, and 3dB–3dB, respectively, and correspond to 'power-equalise' mode.

  - And for the other antennas the values of ccfs between GSB and GWB compare very well and there is no noticeable increase, as seen at 'L' band.
  - Finally, here again, some of the baselines show very similar phase variation as a function of time for GSB and GWB.

(II) Results from rest of the scans (higher levels of OF attenuations and 'no power-equalise') show the following:

  - It appears that the ccfs obtained on large number of baselines from GWB match well with the ccfs from GSB, except for 2–3 baselines, where ccfs from GWB are below the GSB values.
  - The trend for falling ccf with increasing OF attenuation is seen for 610 band too; however, it typically less than 10%, and it appears to be negligible for the antennas that show low ccfs wrt GSB (C08, C09, C12 and also E06).

Briefly, as compared to the sub-bands of the 'L' band, the tests done at 610 MHz show relatively more consistent behavior between GSB and GWB in both amplitudes and phases on almost all baselines. Presently, there are $<10\%$ baselines, which should inconsistent behavior.

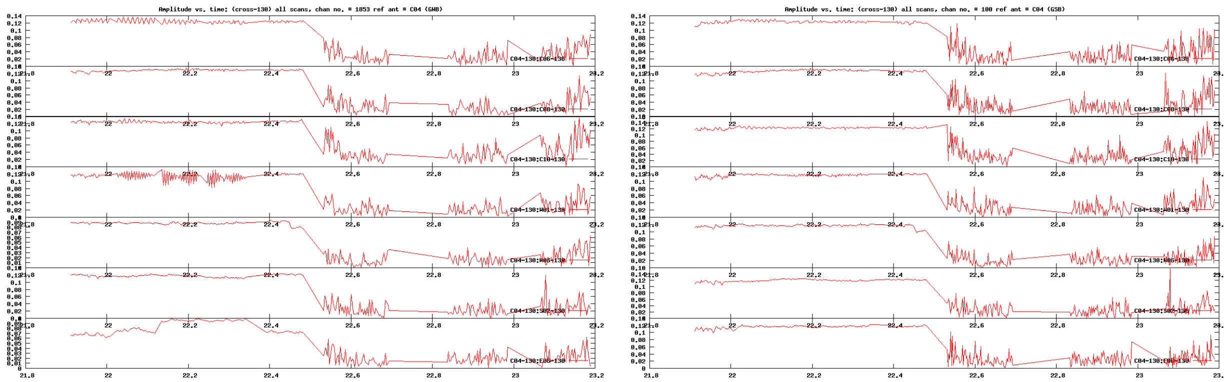

Figure 6: Plot showing ccfs (amplitudes) as a function of time for a channel at the centre of the ('250–500 MHz') frequency band. Note (i) in both, left (GWB) and right (GSB) panels, channels are chosen such that they correspond to the same frequency, and (ii) both, no power equalisation was performed and power equalisation was performed (see Section 2). Scan-0, scan-1, ..., and scan-3 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, and 9dB–9dB, respectively, and correspond to 'no power-equalise' mode. Whereas, scan-4, scan-5, ..., and scan-7 correspond to OF attenuations of 1dB–1dB, 3dB–3dB, 7dB–7dB, and 9dB–9dB, respectively, and correspond to 'power-equalise' mode. Important: ignore last three scans, which are scintillations affected.

2.3 Tests at '250–500 MHz' band

Finally, we report results and summary from several tests that were performed at the '250–500 MHz' frequency band. Figure 6 shows plot of ccfs (amplitudes) as a function of time for a channel from GSB and GWB. the data was acquired from both'no power-equalise' and 'power-equalise' modes of observation on 04–05 March 2014. Here, in Figure 6, the first half of the scans, 'no power-equalise' mode are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, (DO NOT power-eq) and record data for 5min
- OF attn 7dB-7dB, (DO NOT power-eq) and record data for 5min
- OF attn 9dB-9dB, (DO NOT power-eq) and record data for 5min
```

and rest of the scans, 'power-equalise' mode are as follows:

```
- OF attn 1dB-1dB, perform power-eq and record data for 5min
- OF attn 3dB-3dB, perform power-eq and record data for 5min
- OF attn 7dB-7dB, perform power-eq and record data for 5min
- OF attn 9dB-9dB, perform power-eq and record data for 5min
```

2.3.1 Inferences from tests at '250–500 MHz' band

(I) The results from scan-0 (OF attenuation 1dB, 1dB and 'power-equalise') of the '250–500 MHz' frequency band showed the following:
   - In contrast to results from 'L' band and from 610 MHz, the results for 250–500 MHz band, show most of the GWB baselines to give results to be same or better than GSB. To a large degree the ccfs are often always consistent with each other on a maximum of a few percent levels.

- Changing the reference antenna and looking at the data more closely suggests the same, *i.e.* there are no baselines baselines from the GWB that are worse than the corresponding baselines from the GSB. Such stability was also observed in earlier routine observation of a calibrator for long observing run lasting for 2–3 hrs.
- Similarly, the phases also show stability on these timescales.

(II) Results from rest of the scans (higher levels of OF attenuations and 'no power-equalise') show the following:

- Tests pertaining to changing the OF attenuations suggest that the clear trend for falling ccfs with increasing OF attenuation seems to be diminishing with decreasing observing frequency. The fall in ccf being higher for 'L' band and this fall decreases as we move to 610 MHz and further to 250–500 MHz frequency band.

3 Summary

We have presented results from a series of tests performed at several frequency bands of the GMRT. Our conclusions from these new observations can be summarized as follows.

- 'L' band
  - i There is a clear trend for falling ccf with increasing OF attenuation for the 1280 sub-band, and also in the 1390 sub-band to some extent, this is true for both cases, with and without GAB power equalisation.
  - ii The fall in ccf is monotonic with increasing OF attenuation and is maximum for 1280 MHz sub-band, $\sim$20%, whereas it is $\sim$10% for 1390 sub-band.
  - iii In addition, there is a systematic difference in the ccf between GWB and GSB, with GWB being significantly less than GSB for the short baselines and slightly more for the long baselines. The drop at short baselines ranges from $\sim$20% at 1390 MHz to $\sim$30% at 1280 MHz; the increase at long baselines ranges from 5–10% at 1390 MHz to $\sim$5% at 1280 MHz.
  - iv Some baselines show strikingly similar variation in phase as a function of time between GSB and GWB data; this is typically seen for long baselines at several frequency bands. Of course these are some baselines where we do not see similar variation in phase as a function of time between GSB and GWB data.
- 610 MHz band
  - i Specific antennas show systematic difference in the ccfs between GWB and GSB. This was seen earlier as well (see report by S.S. Sherkar and D.V. Lal, "Analysis of L-band data from the new GWB, in order to test long term amplitude and phase stability"), *e.g.* C08, C09, C12 (and also E06) show ccfs from GWB that are lower by 25–30% as compared to the ccfs from GSB.
  - ii This drop for C08, C09, C12 (and E06) is comparable to that seen in the sub-bands of 'L' band discussed above (section 2.1 and report by S.S. Sherkar and D.V. Lal).
  - iii And for the other antennas the values of ccfs between GSB and GWB compare very well and there is no noticeable change, as seen at 'L' band.
  - iv Finally, here again, some of the baselines show very similar phase variation as a function of time for GSB and GWB.
- 250–500 MHz band
  - i In contrast to results from 'L' band and from 610 MHz, the results for 250–500 MHz band, show most of the GWB baselines to give results to be same or better than GSB. To a large degree the ccfs are often always consistent with each other on a maximum of a few percent levels.
  - ii Changing the reference antenna and looking at the data more closely suggests the same, *i.e.* there are no baselines baselines from the GWB that are worse than the corresponding baselines from the GSB. Such stability was also observed in earlier routine observation of a calibrator for

long observing run lasting for 2–3 hrs.

iii Similarly, the phases also show stability on these timescales.

4 Future directions

The clear trend (i) for falling ccf with increasing OF attenuation for several sub-bands of the L-band, and (ii) for lower ccf in GWB as compared to the GWB are issues and it needs immediate attention. The appropriate team members have been informed, who would take it up and following it we would test the system once again. Below, we also list many other issues that we plan to test in future:

- At the '610 MHz' frequency band (see Section 2.2) we found the trend for falling ccf with increasing OF attenuation is seen. However, it typically is less than 10%, and it appears to be negligible for the antennas that show low ccfs wrt GSB, *e.g.* C08, C09, C12 and also E06.
- This result at 610 MHz needs to be compared with ∼5-10% lower ccfs seen in GWB wrt GSB for the long baselines and ∼20% lower ccfs seen for the short baselines. These differences are in addition to differences seen in data from the three sub-bands of L-band. These inferences have been shared with the back-end team, hopefully it would be resolved.
- The 1280 MHz data with default settings has some unexplained RFI in ∼16 MHz bandwidth which can be seen in first 100 channels of GSB and corresponding 800–900 channel range of GWB. This needs to be followed and tracked.
- This report focusses on issues pertaining to ccfs (amplitudes) as a function of time; there are possibly issues pertaining to phases as a function of time as well, which would also need to be addressed.

Acknowledgments

DVL thanks all the members of the GMRT backend and OF teams, operators for the support and help, and for making these observations. We thank the staff of the GMRT that made these observations possible. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.