Stability of noise calibration sources installed on C11, C13 and S02

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Abstract

In this report, we present temperature of various noise-calibrators installed presently on three antennae, C11, C13 and S02 as a function of frequency channel as part of the uGMRT.

1 Introduction

The on-going upgrade of the GMRT have renewed interest in the measured system temperature at each observing frequency. Since efforts are being made to have lowest possible receiver temperature, several noise-sources for calibrations are being installed on GMRT antennas. Presently, they are installed on three antennas, namely C11, C13 and S02 and soon many more antennas will have such noise-source calibrators. These noise deflection is provided with switchable attenuations, *e.g.*, extra-high, high, medium and low calibration noise sources have 0 dB, 6 dB, 10 dB and 16 dB attenuations. Here we present, results, behaviour of noise-calibrators as a function of time and stability for these three antennae.

2 Aims / Expectations

Long-term goals

- To determine first order values of the low, medium, high and extra-high calibrators that are being installed on several antennas.
- To compare these among different polarisation channels of the same antennas and its stability on a long term basis.
- To formulate a methodology and build tools so that it can be done uniformly for all antennas on a regular basis, say as part of the PMQC.

Immediate / short-term goals

- To compare the behaviour of noise-cal temperature as a function of time for two different polarisation channels of the same antenna.
- Since the GWB has no ALC, the ratio of noise-cal ON and noise-cal OFF (scan-averaged!) would provide (i) the health of the antennas, which have the new FE boxes with noise-cal installed and (ii) look for non-linearities, if any that may be happening in the Rx-chain.

3 uGMRT test observations

Observation setup

We used GWB-III ver. of the new GMRT wideband backend to acquire data and perform our first data analyses and reduction. Two observing runs were performed and both were made in the similar manner, *i.e.*, in any experiment, we recorded nine scans with normal, extra-high cal, normal, high cal, normal, medium cal, normal, low cal and normal scans; where the normal scan is the one where no noise-calibrator has been fired and whereas the extra-high or high or medium or low calibrator scans are the ones where the corresponding noise calibration source have been fired. The log of observation is shown below:

```
Observation file name: tst1183_noise-cal-26feb2015.lta
  Date of observation: 2015-Feb-26
    Sequence of scans:
   Obj   RA          Dec         IST      RF  Ch-wid Nrecs
 0 3C286 13:31:50.25 30:25:53.1 01:35:25 500 97.656 55 (normal scan)
 1 3C286 13:31:50.25 30:25:53.1 01:50:17 500 97.656 54 (extra-high noise cal)
 2 3C286 13:31:50.25 30:25:53.1 02:02:56 500 97.656 56 (normal scan)
 3 3C286 13:31:50.25 30:25:53.1 02:17:55 500 97.656 55 (high noise cal)
 4 3C286 13:31:50.25 30:25:53.1 02:30:27 500 97.656 55 (normal scan)
 5 3C286 13:31:50.25 30:25:53.1 02:45:06 500 97.656 55 (medium noise cal)
 6 3C286 13:31:50.25 30:25:53.1 02:57:44 500 97.656 55 (normal scan)
 7 3C286 13:31:50.25 30:25:53.1 03:12:43 500 97.656 56 (low noise cal)
```

```
 8 3C286 13:31:50.25 30:25:53.1 03:25:28 500 97.656 53 (normal scan)

Observation file name: tst1192_ncal_500lo_25mar2015.lta
  Date of observation: 2015-Mar-25
    Sequence of scans:
   Obj  RA          Dec         IST      RF  Ch-wid Nrecs
 0 3C48 1:38:33.65 33:14:12.74 17:31:30 500 97.656 43 (normal scan)
 1 3C48 1:38:33.65 33:14:12.74 17:45:15 500 97.656 44 (extra-high noise cal)
 2 3C48 1:38:33.65 33:14:12.74 17:56:13 500 97.656 43 (normal scan)
 3 3C48 1:38:33.65 33:14:12.74 18:10:39 500 97.656 44 (high noise cal)
 4 3C48 1:38:33.65 33:14:12.74 18:21:23 500 97.656 44 (normal scan)
 5 3C48 1:38:33.65 33:14:12.74 18:35:42 500 97.656 43 (medium noise cal)
 6 3C48 1:38:33.65 33:14:12.74 18:46:40 500 97.656 44 (normal scan)
 7 3C48 1:38:33.65 33:14:12.74 19:00:32 500 97.656 44 (low noise cal)
 8 3C48 1:38:33.65 33:14:12.74 19:11:16 500 97.656 43 (normal scan)
```

Note that RF and channel-width are in MHz and kHz, respectively.

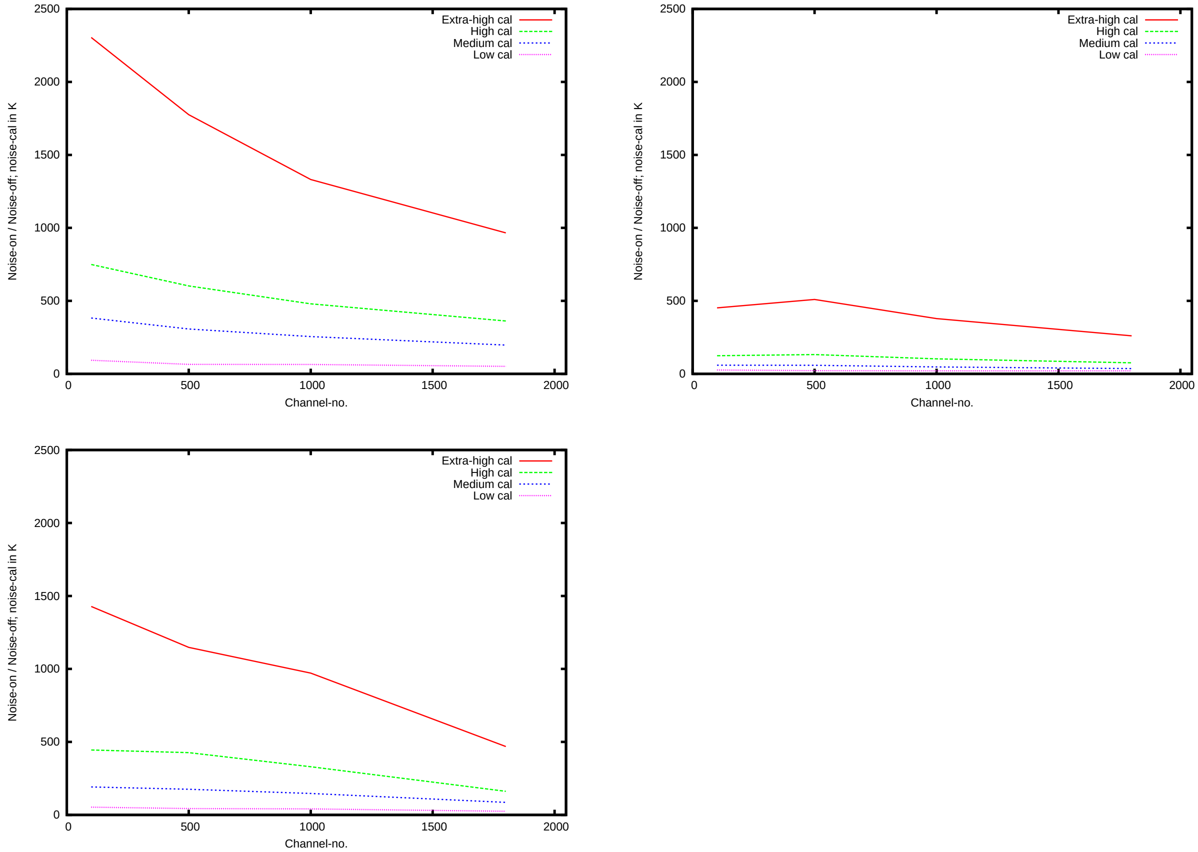

Figure 1: Plot showing temperature of the noise-calibration source as a function of channel/frequency for the channel-1 polarisation data acquired on 2015 Feb 26. Top-left plot is for C11, top-right is for C13 and bottom-left is for S02 antennae. We determine the temperature for extra-high, high, medium and low calibration noise sources at four frequency channels, *i.e.* channels 100, 500, 1000, and 1800 in order to understand the behaviour of temperature across the 200 MHz frequency band for the 250-500 MHz feed.

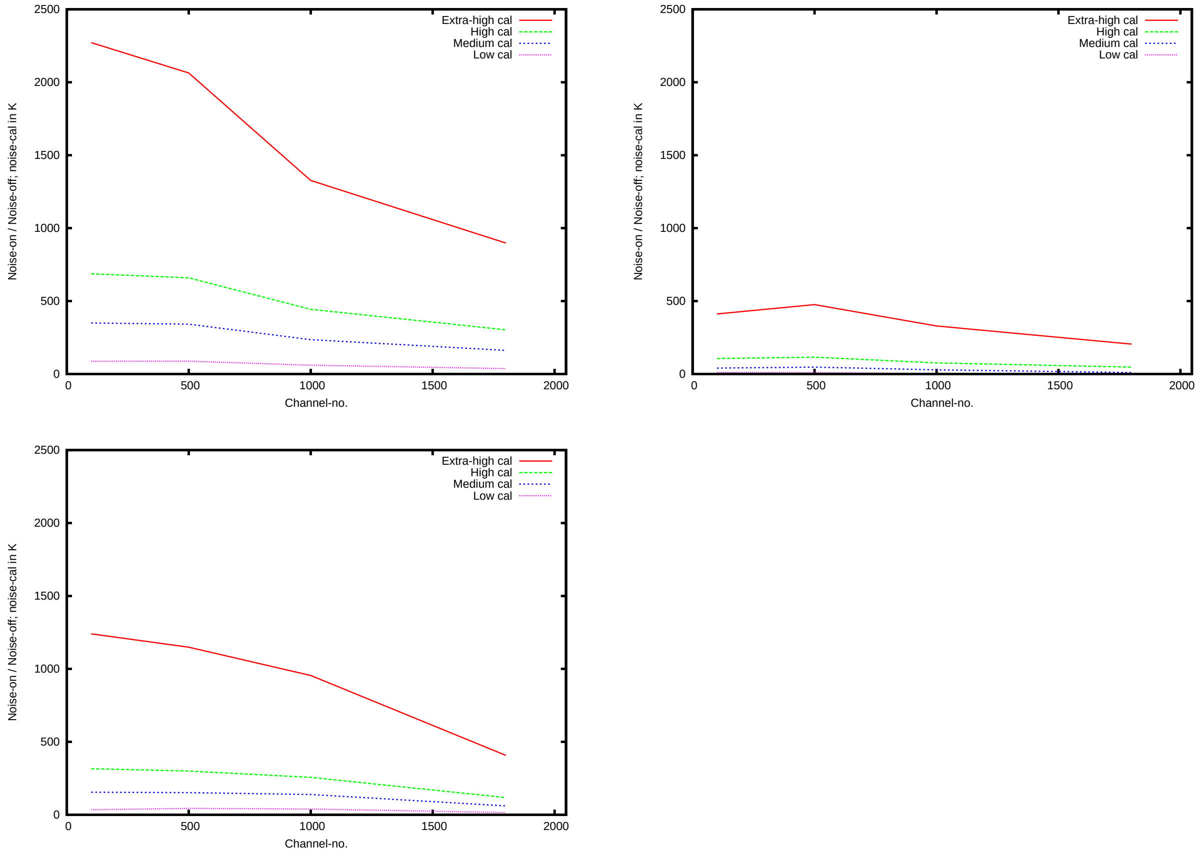

Figure 2: Plot showing temperature of the noise-calibration source as a function of channel/frequency for the channel-1 polarisation data acquired on 2015 Mar 25. Top-left plot is for C11, top-right is for C13 and bottom-left is for S02 antennae. We determine the temperature for extra-high, high, medium and low calibration noise sources at four frequency channels, *i.e.* channels 100, 500, 1000, and 1800 in order to understand the behaviour of temperature across the 200 MHz frequency band for the 250-500 MHz feed.

Basic formulation

We use the ratio of noise-cal ON and noise-cal OFF as a measure of characteristic temperature of the noise-cal and we determine this quantity at several frequency channels. Briefly,

$$\left(\frac{\mathrm{self-counts}_{[\mathrm{noise-cal+cold-sky+flux-cal}]}}{\mathrm{self-counts}_{[\mathrm{cold-sky+flux-cal}]}}\right) = \frac{\mathrm{noise-cal}_{\mathrm{ON}}}{\mathrm{noise-cal}_{\mathrm{OFF}}},$$

where,

$$\frac{\mathrm{noise-cal}_{\mathrm{ON}}}{\mathrm{noise-cal}_{\mathrm{OFF}}} = \frac{\mathrm{T}_{\mathrm{noise-cal}} + \mathrm{T}_{\mathrm{cold-sky}} + \mathrm{T}_{\mathrm{flux-cal}}}{\mathrm{T}_{\mathrm{cold-sky}} + \mathrm{T}_{\mathrm{flux-cal}}},$$

or

$$\mathrm{T}_{\mathrm{noise-cal}} = \left[\left(\frac{\mathrm{self-counts}_{[\mathrm{noise-cal+cold-sky+flux-cal}]}}{\mathrm{self-counts}_{[\mathrm{cold-sky+flux-cal}]}}\right) \times (\mathrm{T}_{\mathrm{cold-sky}} + \mathrm{T}_{\mathrm{flux-cal}})\right] - (\mathrm{T}_{\mathrm{cold-sky}} + \mathrm{T}_{\mathrm{flux-cal}}).$$

Following this formulation, we made plots for both polarisation channels, ch-1 and ch-2 data. (Note as per the old convention, these two channels are also called as 130 MHz and 175 MHz channels.)

The plot shown below essentially uses the ratio of self-count obtained when noise-cal was ON and when noise-cal was OFF. And this ratio is translated to temperature in units of Kelvin for these noise-calibration sources at several frequencies in the 200 MHz frequency band. The 200 MHz frequency band corresponds to 2048 channels and we determine temperature of these noise-calibration sources at 100, 500, 1000 and 1800 channels. Typical temperature of cold-sky, $T_{\rm cold-sky}$ is 110 K and the temperatures contributed by flux calibrators, $T_{\rm flux-cal}$ *e.g.* 3C48 is 15 K, 3C147 is 17.5 K and 3C286 is 9 K at this observing frequency band, 250–500 MHz.

Attached plots, namely,

Figure 1: 2015 Feb 26 (ch-1) data,
Figure 2: 2015 Mar 25 (ch-1) data,
Figure 3: 2015 Feb 26 (ch-2) data,
Figure 4: 2015 Mar 25 (ch-2) data,

show temperature of the noise-calibration sources (in K) determined from this noise-cal ON and noise-cal OFF ratio for C11, C13 and S02 antennas. We scan-averaged the data to increase signal-to-noise ratio and determine these for four frequency-channels, namely 100, 500, 1000 and 1800 channels.

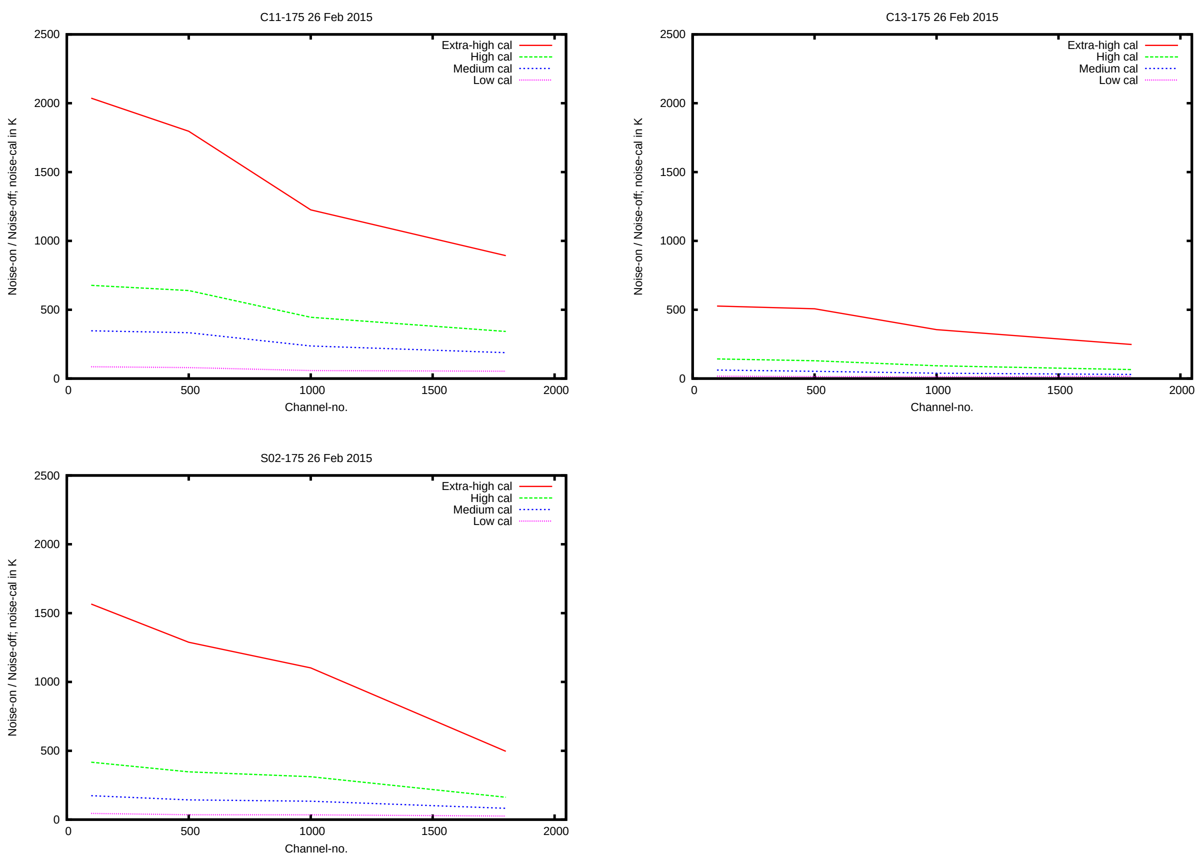

Figure 3: Plot showing temperature of the noise-calibration source as a function of channel/frequency for the channel-2 polarisation data acquired on 2015 Feb 26. Top-left plot is for C11, top-right is for C13 and bottom-left is for S02 antennae. We determine the temperature for extra-high, high, medium and low calibration noise sources at four frequency channels, *i.e.* channels 100, 500, 1000, and 1800 in order to understand the behaviour of temperature across the 200 MHz frequency band for the 250-500 MHz feed.

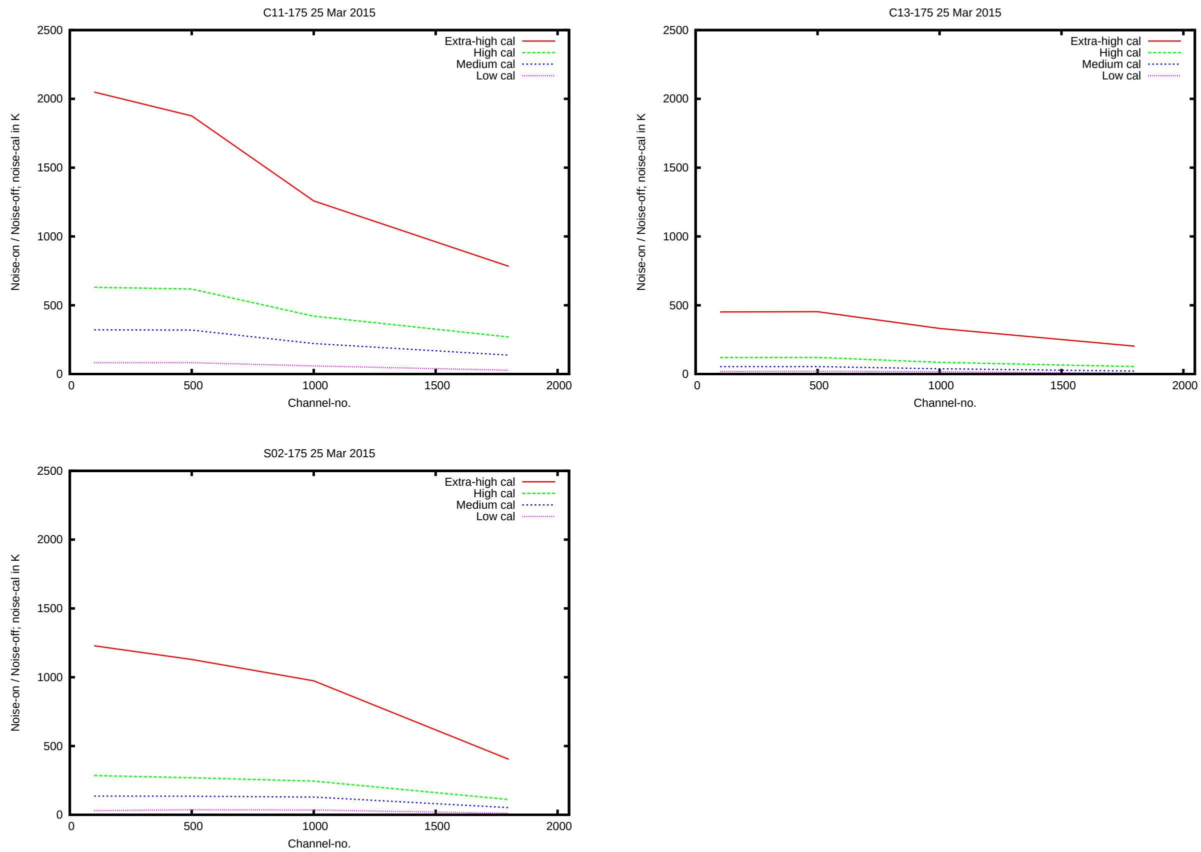

Figure 4: Plot showing temperature of the noise-calibration source as a function of channel/frequency for the channel-2 polarisation data acquired on 2015 Mar 25. Top-left plot is for C11, top-right is for C13 and bottom-left is for S02 antennae. We determine the temperature for extra-high, high, medium and low calibration noise sources at four frequency channels, *i.e.* channels 100, 500, 1000, and 1800 in order to understand the behaviour of temperature across the 200 MHz frequency band for the 250-500 MHz feed.

4 Key inferences

The data analysis and reduction presents following quick conclusions:

- In all three cases, we see some slope in the temperature of the noise-calibration source as a function of frequency/channel.
- Additionally, the absolute temperature scale (or normalisation) of the noise-calibration is different across antennas.
- This temperature slope across the frequency-band seen in all three cases is probably a limitation of design of the directional coupler, which has a slope of 6 dB. The slope is $-$ve; note that here in the plots, channel-0 corresponds to 500 MHz and channel-2047 corresponds to 300 MHz.
- The noise-calibration temperatures of S02 is almost twice that of C11 antennas; this could be due to control bits being swapped at the time of wiring (latter is due to private communication, Mr. Suresh Kumar). Alternatively, it is also possible that the directional coupler port is swapped, which then could show low deflection (private communication, Mr. V.B. Bhalerao) If the above issue is resolved, the noise source power output for C11 and S02 are expected to same since the design is identical for both FE-boxes.
- Since the FE-box design of C13 antenna is old and noise-calibration sources too are different, hence one sees different behaviour of this, C13 antenna as compared to C11 and S02 antennae.

Finally, the FE-team expects that (i) the noise source power is constant and (ii) it is maintained with constant current and voltage circuits. Hence no variation is expected from one unit to another unit (as per the current design, *e.g.* units that are installed on C11 and S02 antennae). Additionally, the noise-calibration sources were tested over wide operating temperature range (10 - 60 deg. C) and are expected to give constant power output.

5 Immediate future plans

- We would like to know what are the theoretical values of the noise-calibration sources from the front-end team so that they can be faithfully compared with our subsequent efforts. More importantly, if identical copies of noise-calibration sources are being put as part of the FE-box on each new antennas, above results are clearly in contradiction. We know C13 and S02 have identical FE-boxes.
- We would also compare with the noise deflection tests performed by the control room and other teams and look for (in)consistencies, if any for a faithful comparisons.
- Finally, we would like to build tools so that this exercise can be performed in a routine manner on a regular basis, say as a part of PMQC. This would provide us aid us in long term stability tests of the uGMRT system.