# A software based automatic level control (ALC) for uGMRT

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*24 Sept. 2020*

## 1 Introduction

Galactic plane observations with a radio telescope at low radio frequencies poses a special challenge. This is due to high brightness temperature of the Galactic plane which varies significantly depending on the Galactic longitude and latitude being observed. High brightness temperature of extended emission causes corresponding rise in system temperature and it could be ≳10  higher than observing the typical sky >10° away from the Galactic plane. Therefore, suitable arrangements are necessary to prevent any non-linearity in the telescope observing chain.

For a radio telescope to work in the linear range of operation, the output power must lie within certain range. Quite often, an automatic level control (ALC) is employed to provide negative feedback to the amplifier gains when output power increases. However, the new analogue backend system of the uGMRT has no hardware based ALC (to achieve higher dynamic range). Therefore, when observations are done in parts of the sky where the sky temperature is a significant fraction of the total system temperature ($T_{sys}$), variation of sky temperatures cause a source position dependent change in total power. This could not only cause a calibration problem due to change in correlation efficiency of the digital correlator, but as mentioned above, put certain system parameters beyond the linear regime of operation. Therefore, it is important that users get proper control on the total output power from the antennas through some other means.

In interferometry, the amplitude of unnormalised cross correlation measured by the correlator is related to visibility amplitude through a scaling factor called '**gain**'. In general, the gain is a function of antenna (could vary with temperature) and is independent of system temperature ($T_{sys}$). Therefore, if the gains do not change during observations, the flux densities of sources can be established with observations of a single flux density calibrator along with phase calibrator and target sources. The above is often used at GMRT for interferometric observations. However, as mentioned above, it encounters serious problem for observations near the Galactic plane at lower frequency bands (below 600 MHz), where the source is on the Galactic plane, but calibrators are typically >10° away from the Galactic plane.

In the past, this problem has been 'partially' addressed by keeping the ALC off which keeps the gain unchanged, and adjust the system gain at the start of the observations such that the source with maximum sky temperature produce the highest tolerable total power (Roy 2006). However, this causes the input operating point of the correlator to change as source changes and this changes the correlation efficiency of the correlator resulting in amplitude calibration error that could be ~10% for a reduction in total power by ~5 from its standard operating point. However, the flux density scale at low radio frequencies is now believed to be accurate to ~2% (e.g., consistency of primary calibrator flux densities among Perley & Butler (2017) vs. Scaife & Heald (2012) vs. Baars et al. (1977). One would like to have similar accuracy in uGMRT flux density measurements, which would drastically reduce the error in spectral indices of sources measured from flux densities obtained from different frequency bands. In this report, I describe a software based ALC that could achieve the above by suitably changing the attenuations of the high dynamic range attenuators connected to the broadband radio frequency (RF) signal chain while one observes different parts of the sky.

The upgraded electronic system of the uGMRT features a variable attenuator (HMC472LP4) which supports 0−31.5 dB variable attenuation in steps of 0.5 dB (accuracy 0.25 dB ±3% of attn. setting max.) in the RF chain of the antennas (see 'http://www.gmrt.ncra.tifr.res.in/local/ugmrt/GAB_blockdiag.pdf' for its location in the uGMRT backend). To keep the input power to correlator constant, one changes the attenuation values of the above following the procedures below. The variable attenuators have been tested quite extensively in the Lab and their attenuations do remain within ~15-20% to what is expected from the ones being set in the lower frequency bands (below 500 MHz) and attenuation values within 20dB. As the error in gains for the attenuators connected to different antennas is expected to be random, the overall error from changes made in attenuation values would therefore be $(15/\sqrt{N})\%$, where $N$ is the no. of antennas. Therefore, absolute gain error of the system could go down to ~3-4% by assuming the error on the attenuation values of the variable attenuators attached to different antennas are random in nature. Accuracy of the attenuations being used above could be improved by a factor of two or more than the above by using a look-up table to incorporate the lab-measurements vis-a-vis the attenuation values selected for the attenuators connected to different antennas.

The second mode of user controlled ALC is to monitor the total power from all the antennas continuously and can detect significant change in total power due to unexpected change in gain or T_sys for an antenna immediately.

The third mode of operation is not just monitoring but changing the attenuation for the antennas to compensate (correcting) for the change. In this mode, the required change in attenuation for that antenna is computed to bring its total power back to the standard operating point and the change in attenuation is implemented by sending necessary commands to attenuator of that antenna.

## 2 Study of bandshape of the system with change in the variable attenuations

Change in attenuation could introduce extra phase to the signal path of antennas (unexpected for a passive attenuator). To check this, we carried out observations of calibrators with change in attenuation to identify any change in bandshape and phase of a calibrator.

We observed a calibrator 3C468.1 in band-4 of uGMRT on 08th Aug 2015 with 200 MHz bandwidth. At this time, the uGMRT wideband correlator supported only 16 antennas at a time. As shown in Figures 1−5, power equalisation was done by varying the variable attenuation values to get total power output count in four different scans as follows. Scan-1, 50; scan-2, 250; scan-3 150; scan-4, 80 counts. For analysis, I used only the 1st and 2nd scan as the change in output power was highest between them (factor of 5). We used the 1st scan to determine band shape and applied to whole data. Using the resultant data calibrated by the 1st scan, we redetermined the bandshape from 2nd scan. If change in attenuation do not change the bandshape, we expect the amplitude gain to be unity across the band, and phase to be zero.

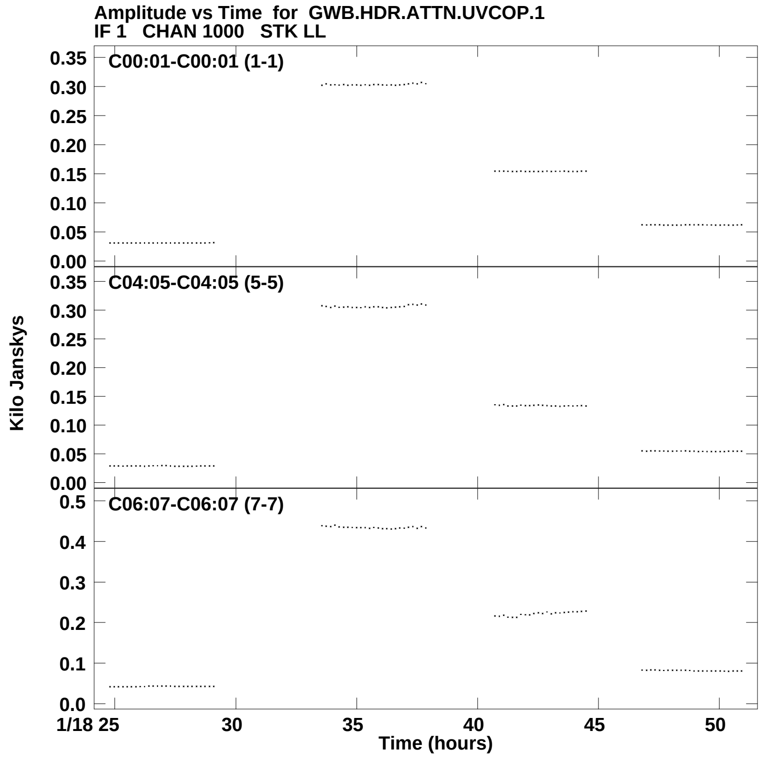


**Figure 1.** Total power output (in counts) from uGMRT correlator for C00, C04 & C06 antennas as a function of time due to change in attenuation values. Note the time gap separating the scans.

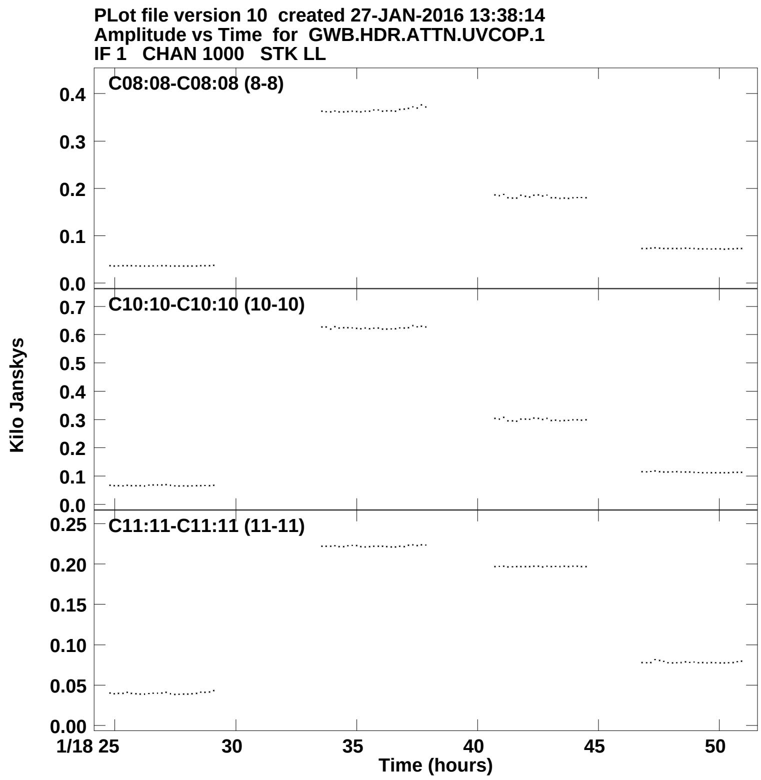


**Figure 2.** Total power output (in counts) from uGMRT correlator for C08, C10, C11 as a function of time due to change in attenuation values.

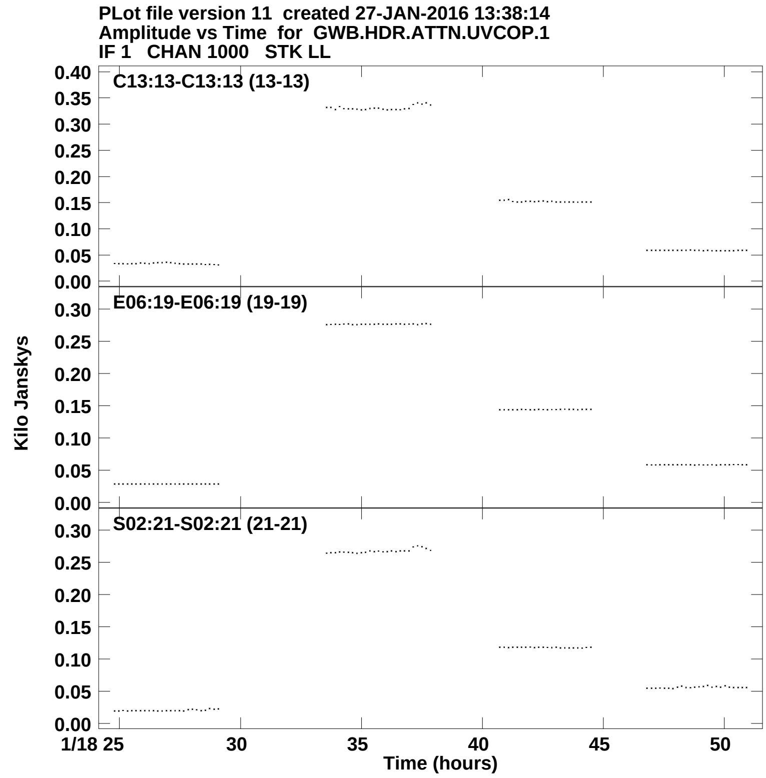


**Figure 3.** Total power output (in counts) from uGMRT correlator for C13, E06 & S02 as a function of time due to change in attenuation values.

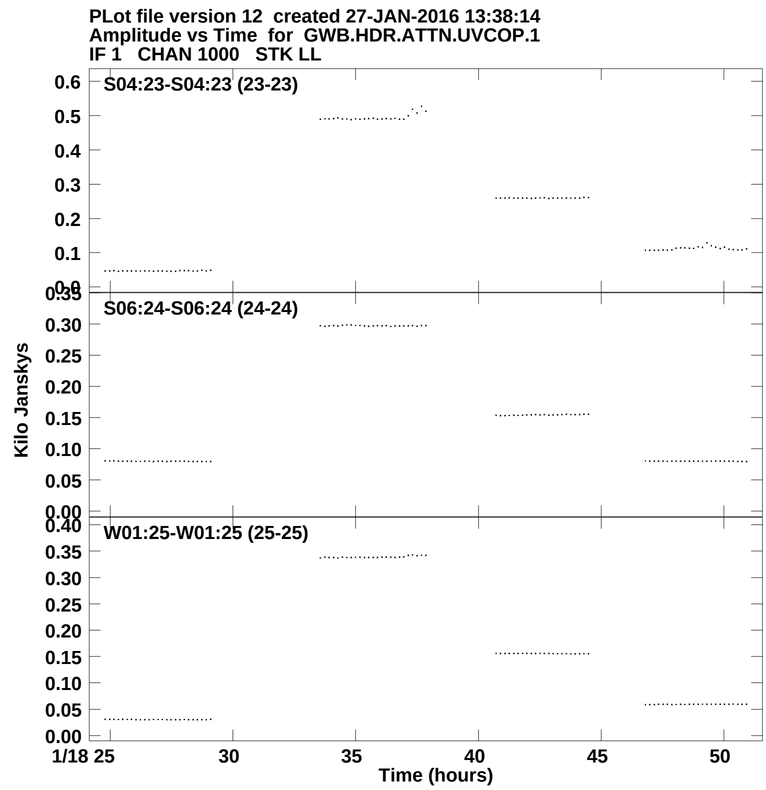


**Figure 4.** Total power output (in counts) from uGMRT correlator for S04, S06 & W01 as a function of time due to change in attenuation values.

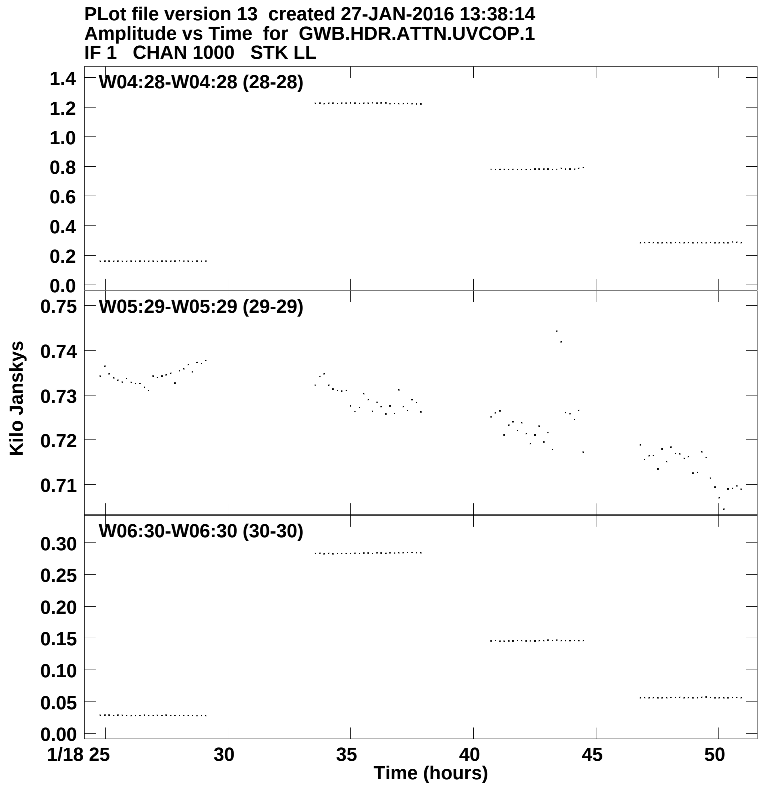


**Figure 5.** Total power output (in counts) from uGMRT correlator for W05, W05 & W06 as a function of time due to change in attenuation values (for W05, attenuation values did not appear to obey Online commands).

As shown in Figs. 6−13, the bandpass amplitude for almost all the antennas remained within ±5% of unity and phase to be within ±5 deg.

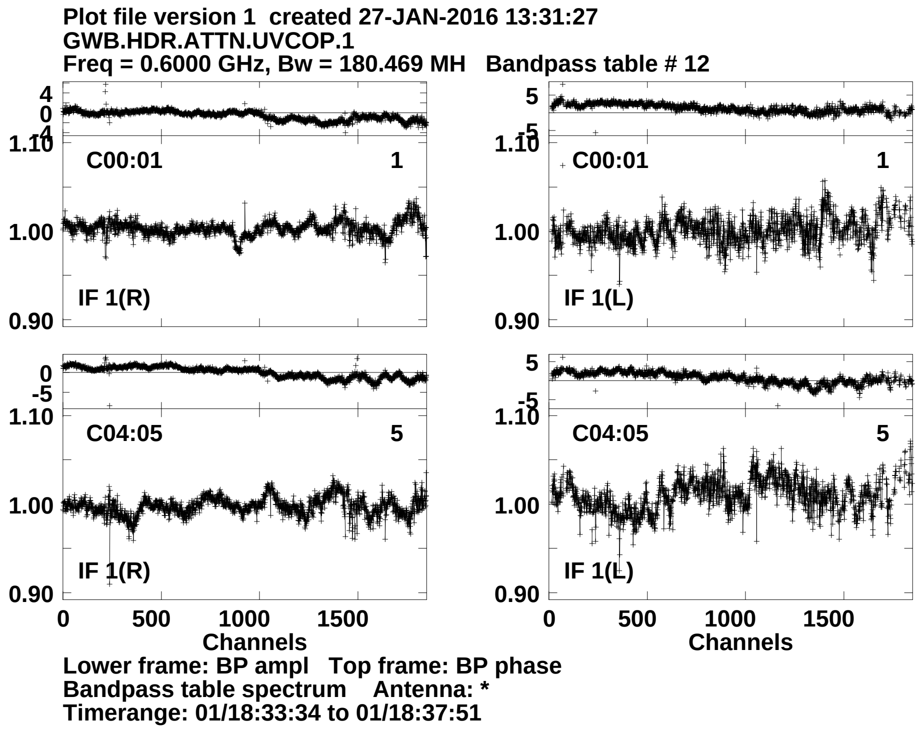


**Figure 6.** Bandpass redetermined from the 2nd scan of antennas C00 & C04 (see Sect. 2 for details)

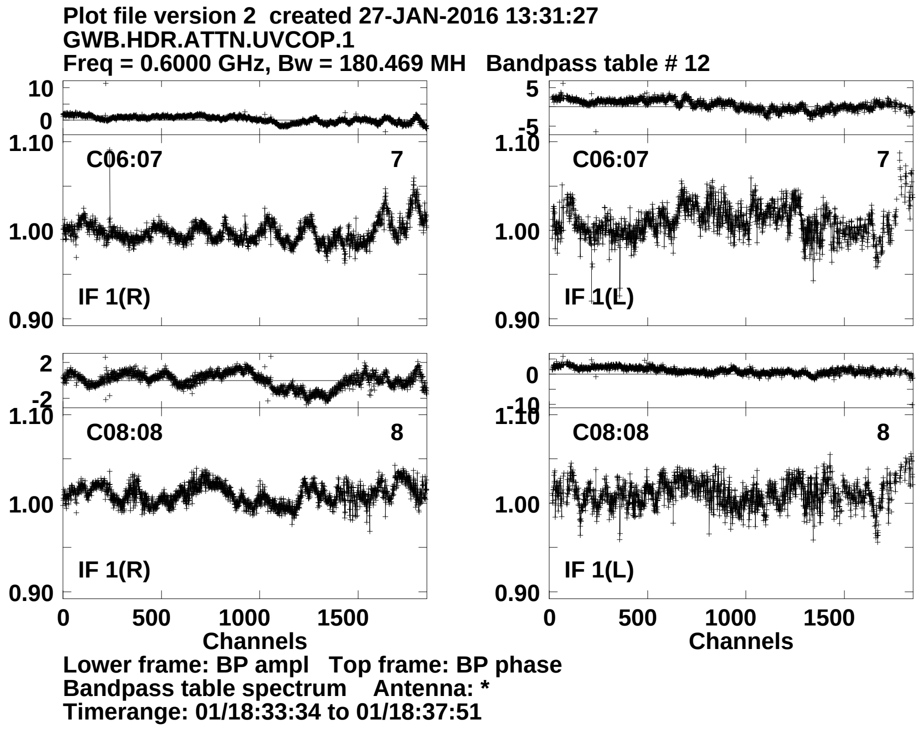


**Figure 7.** Bandpass redetermined from the 2nd scan of antennas C06 & C08 (see Sect. 2 for details)

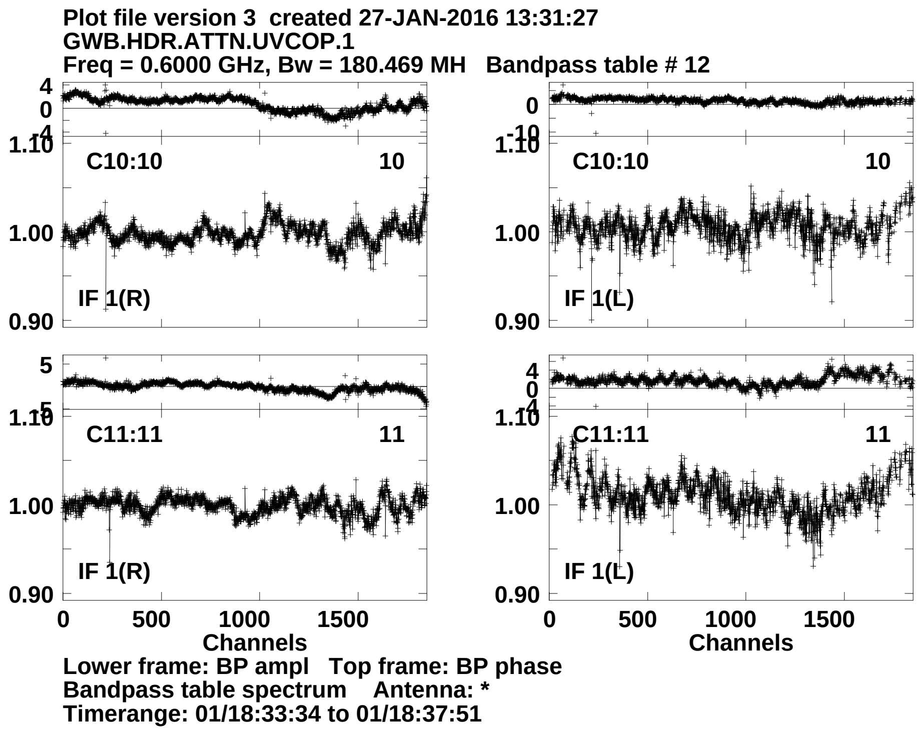


**Figure 8.** Bandpass redetermined from the 2nd scan of antennas C10 & C11 (see Sect. 2 for details)

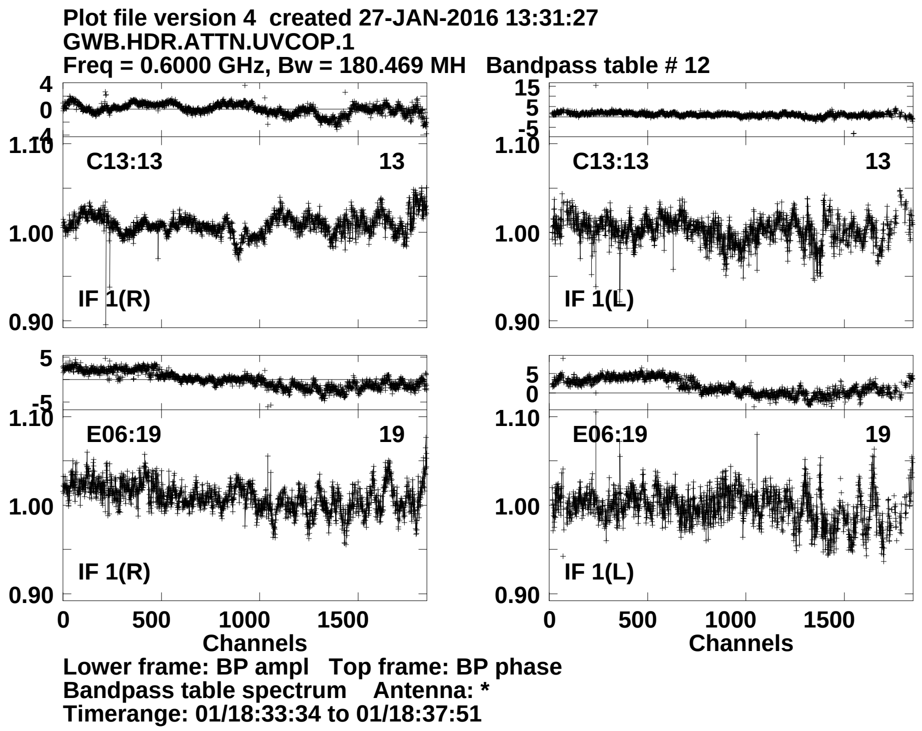


**Figure 9.** Bandpass redetermined from the 2nd scan of antennas C13 & E06 (see Sect. 2 for details)

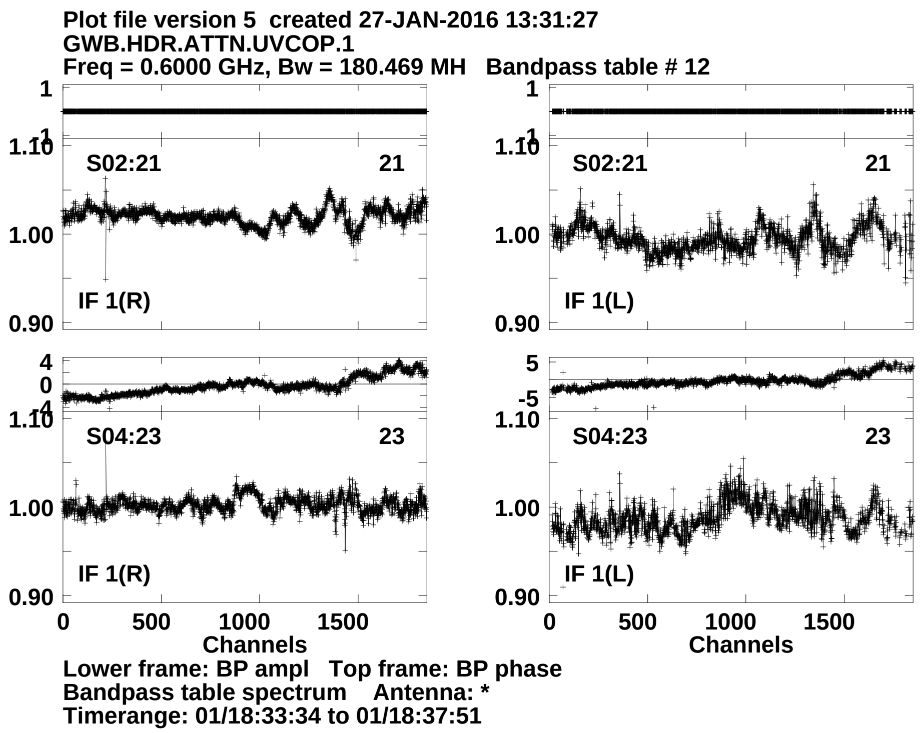


**Figure 10.** Bandpass redetermined from the 2nd scan of antennas S02 & S04 (see Sect. 2 for details)

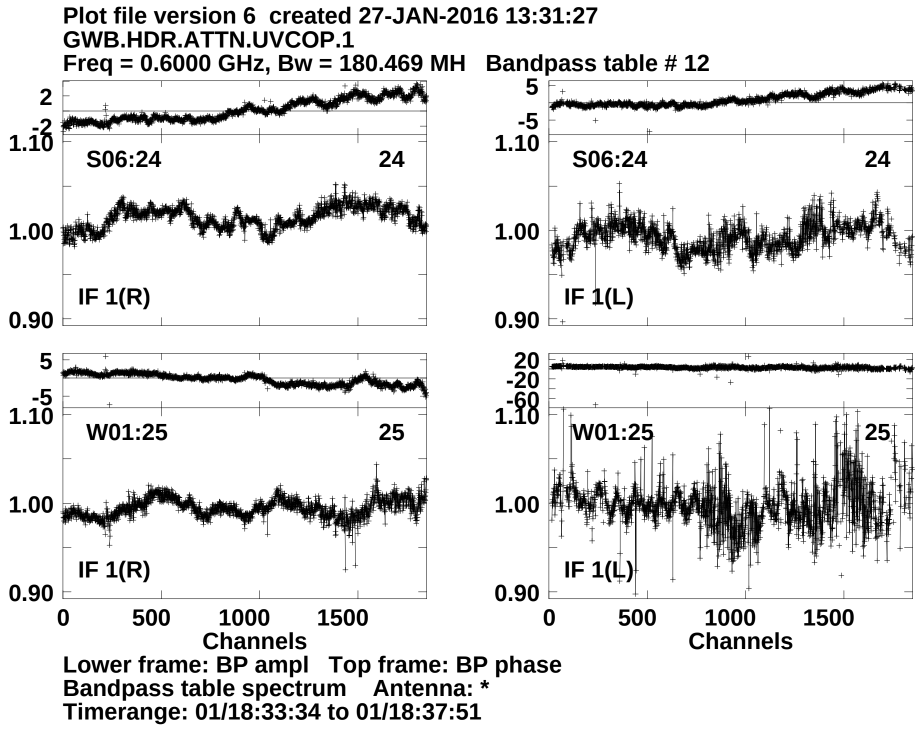


**Figure 11.** Bandpass redetermined from the 2nd scan of antennas S06 & W01 (see Sect. 2 for details)

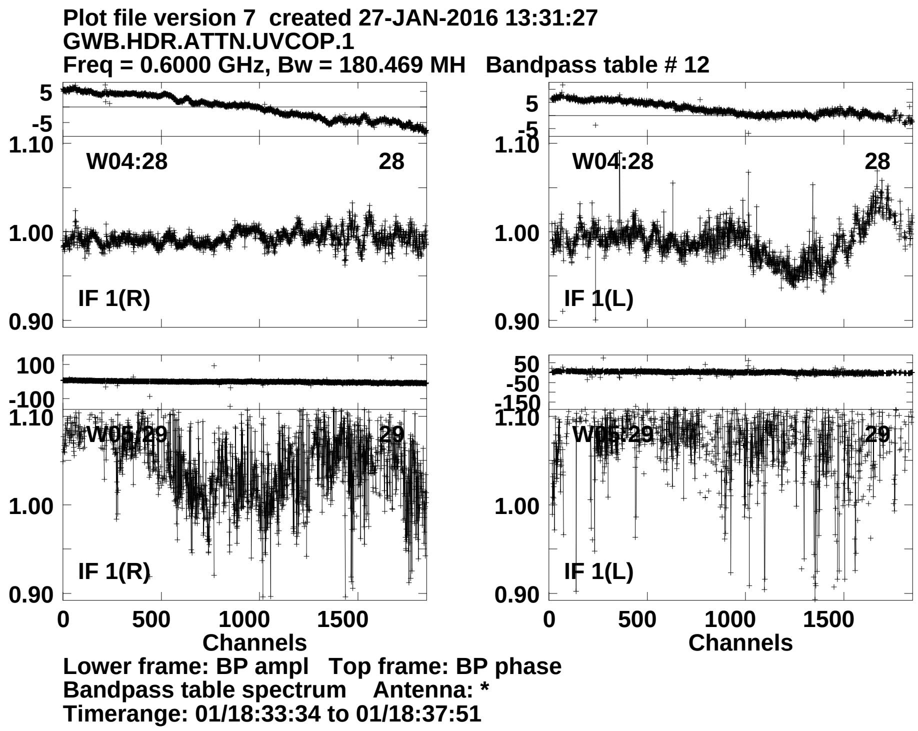


**Figure 12.** Bandpass redetermined from the 2nd scan of antennas W04 & W05 (see Sect. 2 for details)

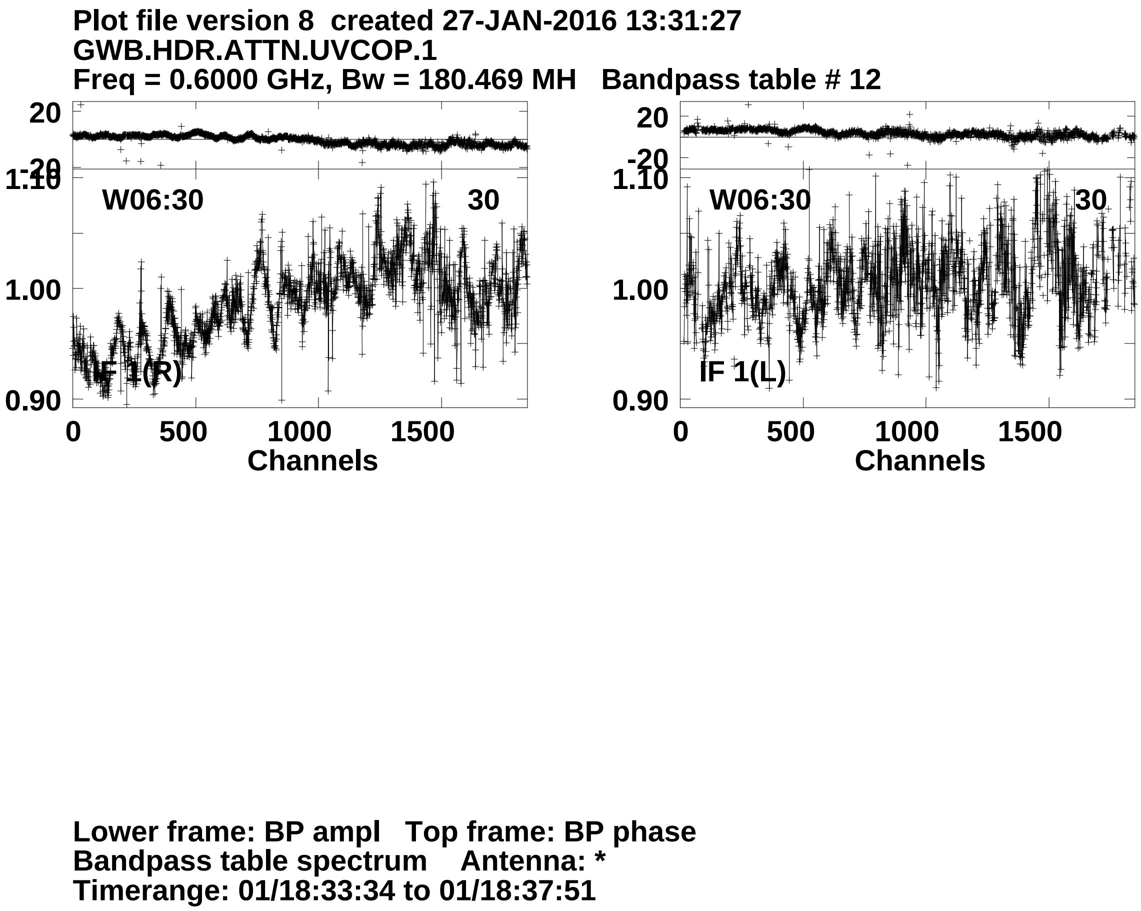


**Figure 13.** Bandpass redetermined from the 2nd scan of antenna W06 (see Sect. 2 for details)

Two antennas showed change in bandshape more than the above mentioned limits. Between them, power level of W05 antenna did not change despite online commands (Fig. 5), and its bandshape variation could not be due to change in attenuation values. For W06, bandshape variation was significant. However, this is an isolated problem, which should go away after replacing the affected hardware. The overall result is consistent with the tests done in lab. on the variable attenuators.

# 3 Implementation of software ALC

The following procedure uses the legacy Online system to control the total power of the antennas.

**Mode-I**: Change of attenuation with change in source (antenna temperature change) to keep total power constant is implemented by writing a set of scripts.While observing a source for the first time in an observing run, a script 'power_eq.new.run' is to be executed from the user's Command file in the Online computer with the Source name, Start channel (default value 300), End channel (default value 1700) and Power level (default value 150) as its arguments. The script uses 'power_eq' (Raskar et al. 2014) to derives the median value of total power across the frequency channels as observed at time 't' within the beginning and end channels, and using the existing attenuation, computes the new attenuation needed to bring the output power to the optimum Power level (in counts). The estimated new attenuations are then set using another command 'stgablev('src_name')' from the user's command file. When the same source is observed afterwards, only loading the last attenuation table for the given source is carried out by executing another script 'run Asrc_name' . The procedure to load the attenuation is typically repeated once more from the user's Command file to make sure the command gets executed at the corresponding antenna. A schematic block diagram of the procedure is shown below (Fig. 14).

In the above case, the attenuation will increase when $T_{sky}$ increases and vice-versa in a way such that the output power will remain the same despite change in $T_{sky}$. The attenuation values are recorded for all the antennas for each source. The attenuation files for sources are stored in '/home/gpuuser/GWB/PowerEq/' area in the GWB computer (gwbh6). The naming convention of the files are 'gab_attn.src_name' (where 'src_name' indicates the sources for which the script was run). After the observing run, the operator needs to copy the files produced during the observing run and mail to the user. User can find the attenuation differences between calibrator and target source for the antennas by using a shell script 'attenuation.difference.gwb'. This allows one to correct the data during analysis for different antenna based gains for different sources by modifying the antenna gains while observing each sources (e.g., by using AIPS Task SNCOR).

The above procedure for observations towards the Galactic plane at frequencies <1 GHz could be incorporated into the Command file generated by the Astronomers either by themselves or by the on duty operator on request well before the observation. This mode has used during multiple observations towards the Galactic plane, and it did work satisfactorily.

A program to plot median value of total power across the frequency channels as a function of time for all the antennas has been written (plot.total.power). It needs 'gwbmp' (written by the 2nd author) programme also to run in the same machine described above (gwbh6). It can show significant change in total power due to an unexpected change in gain or Tsys of an antenna immediately during observations.

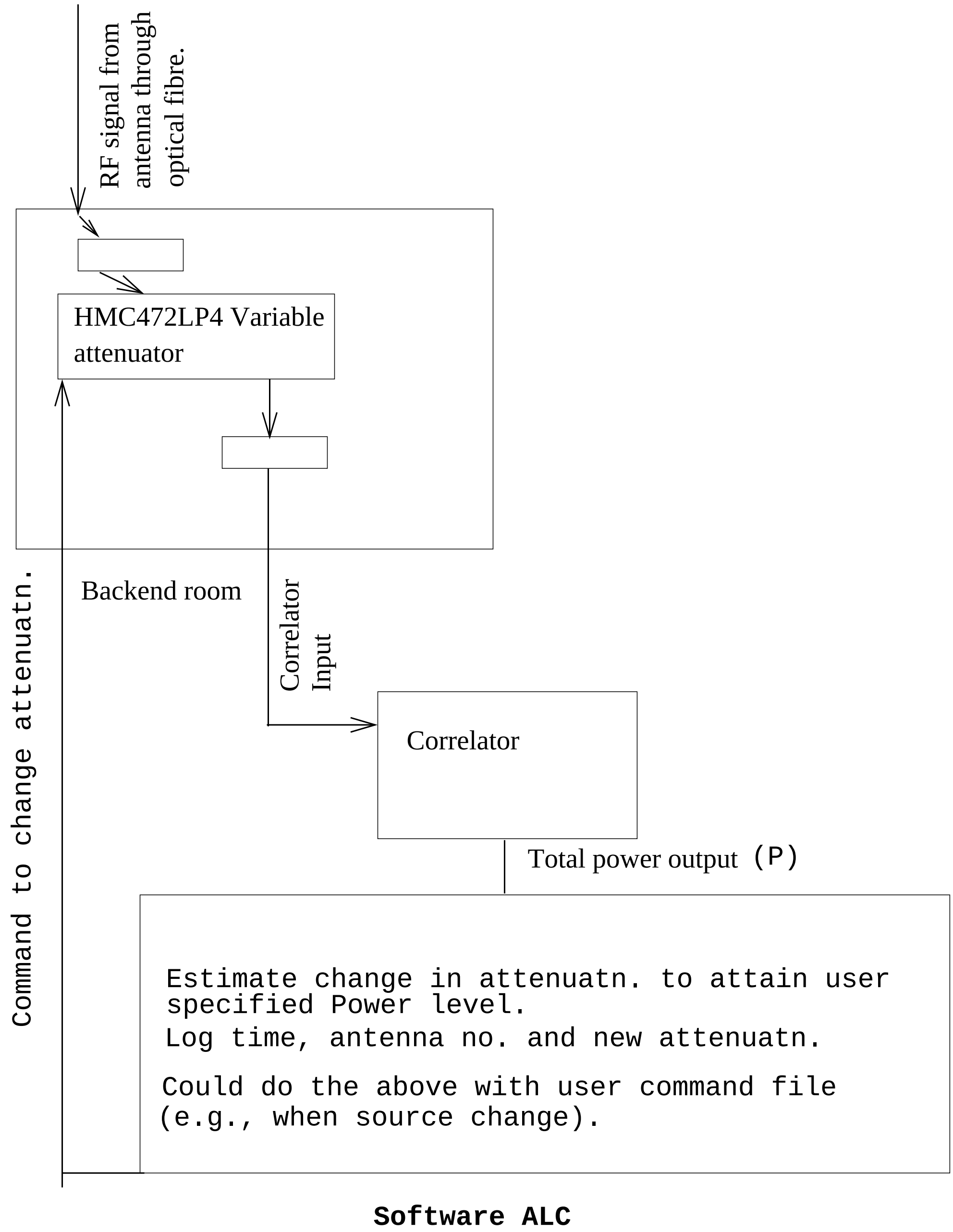


**Figure 14.** Flowchart of an user controlled ALC to keep the input power to the correlator constant during observations with sources seen through high sky temperature.

**Mode-II**: Monitoring the power level has been implemented with a script 'analyse.self_monitor'. The script need 'gwbmp' to run in parallel (which writes median values of total power from all the frequency channels as a function of time for every antennas every 5 seconds to a file). The script reads the file produced by 'gwbmp' and finds from last 11 data points the median (latest_median) and rms (latest_rms) and compares it to the mean and rms of user defined much longer stretch of data. The longer stretch must be >3 times of the last 11 data points (i.e., >33 averaging time). We note that the 'longer stretch of data' should not be too long, as any slow systematic change would affect the long term mean and rms, and suggest 10 minutes to be a sensible period to check for long term mean and rms.

If the latest_median differs from the mean value of the longer stretch by a user defined threshold (default 20%) and is also >5×latest_rms, then the antenna name, polarisation and time is written to a specific file defined by the on duty operator. This programme also checks for self values above (powermax) and below (powermin) certain thresholds, which are beyond the linear range of operations. It has been tested on real data, and was found to work satisfactorily.

Based on the above, an offline programme (offline_analyse.self) has also been written that could be used to check archival data (it uses total power as a function of time from one user extracted representative frequency channel) for sudden significant jumps in total power or for counts beyond the linear range of operation of the system.

**Mode-III**: A script 'correct_total_power' has been written to actively change antenna based attenuations when the total power from an antenna suddenly goes below or above certain user defined thresholds. For it to work, it needs (i) 'gwbmp' to run in the same computer where this script is running, (ii) legacy online needs to run in multi sub-array mode, so that it can take command from a shell, and (iii) GAB needs to be communicating with online (achieved by issuing 'initgab' command from online). It analyses and detects jumps and power variation as in mode-II. However, if the variation is beyond certain user defined thresholds, based on the existing attenuation for the affected antenna, it generates new attenuation values to bring the power back to the expected level. The modified attenuation for the corresponding antenna is written to a file which is sent to the computer running Online, which instructs the antenna to reload the new attenuation value. It has to be noted that no testing of this mode has been made yet.

# 4 Future direction

As the legacy online is going to be replaced by Tango based monitor control system (TGC) at GMRT, the above scripts shall have to be adapted for the same.

# 5 References:

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