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Signal Conditioning Board in the Receiver Node : Specifications for Version 1.0

Authors: D. Anish Roshi[1], Frank H. Briggs[2]
Affiliation: [1] Raman Research Institute, Bangalore, India, [2] Research School of Astronomy and Astrophysics, Australian National University, Canberra, Australia,

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Abstract

The requirements for the signal conditioning board used in the receiver node of the MWA were determined. Based on these requirements we drew up the specifications for version 1.0 of the conditioning board.

1 Introduction

The signal conditioning board (SigCB) forms the first stage of the receiver node electronics. The function of this board is to amplify the signals coming from each of the 8 tiles to the power levels necessary for the analog to digital converter (ADC). Since each tile has two polarizations, there will be 16 analog channels. In this report, we determine the requirements of the SigCB board.

2 Total Gain needed in SigCB

Fig. 1 shows a typical spectrum obtained from 1T data taken on 28-03-2007. We use this spectrum to estimate the power level at the input of the SigCB. Since there is some uncertainty in the calibration of the existing data we estimate the power as follows. The expected LNA noise temperature at 190 MHz is about 38 K and a typical value for the coupled sky background is 50 K (Corey 2006). Using this value we estimate the power over the spectral resolution of 120 KHz at the input of the LNA as -128 dBm. We choose 190 MHz since the effect of mismatch is relatively low at this frequency. In Fig. 1 the spectrum is scaled such that the power at 190 MHz is -128 dBm. Note that the frequency dependence of the 200 m LMR400 cable attenuation is taken out by characterising it as $0.8 \times \sqrt{f} + 0.002 \times f$ dB, where f is the frequency in MHz. The total power at the input of the LNA over the frequency range 80 to 330 MHz is -94.6 dBm. Here we consider that the above specified frequency range is selected using a filter in the system. Such a selection is essential due to the presence of RFI at frequencies beyond this range. The total gain due to amplification in the tile electronics is expected to be about 35 dB (Corey 2006). With the above mentioned cable characteristics we estimate that the input power to SigCB is -70 dBm. (If we use 200 m RG6 cable instead of LMR400 as considered by Corey (2006), then the power level with be about -76 dBm)

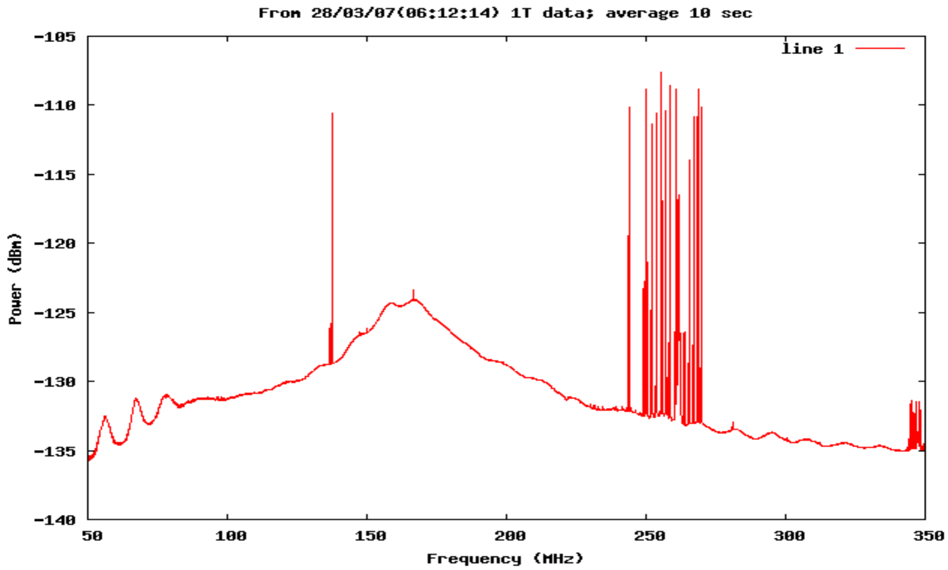

Figure 1: A 10 sec average spectrum obtained from 1T data taken on 28/03/2007. The spectral power is scaled such that the power at 190 MHz is the estimated value (-128 dBm) at the input of the LNA. The frequency dependent attenuation due to the LMR400 cable is also corrected for.

2.1 ADC input peak-to-peak voltage at 6σ level

The ADC used in the ICT board is AT84AD001B. The maximum peak-to-peak input voltage to the ADC is 0.5 V (see e2v data sheet on AT84AD001B). For multi-bit ADC the input peak-to-peak voltage when sampling a Gaussian noise is usually set at 6σ level, implying that the noise power should be -8.5 dBm. Thus the net gain needed in the SigCB is about 62 dB. Allowing for some unaccounted attenuation in the signal path, the required total gain in the SigCB board is 70 dB.

2.2 ADC input peak-to-peak voltage at 15σ level

For MWA application we may want to operate the input peak-to-peak voltage level to the ADC at about 15σ level due to the presence of RFI. In this case, the noise power at the input of the ADC becomes -16.5 dBm and the net gain needed in the SigCB is about 54 dB. We can reduce the gain of the amplifier by about 10 dB (ie net gain is 60 dB), if we choose the operation of the ADC at 15σ level.

3 Attenuator range and step size

The required range of attenuation is estimated by considering Solar observations with the MWA. The flux density of "disturbed" Sun is typically 10^8 Jy near the operating frequency of MWA (from Fig. 8.34; Kraus 1986). Considering a collecting area of 10 m^2, the estimated power at the output of a tile due to Sun is -59 dBm. If we assume only 50% of the power is coupled to the amplifier the total attenuation needed to bring the power level to the cold sky level (ie -95 dBm, see Section 2) is about 33 dB. Based on these considerations, the range of attenuation needed is about 40 dB. For solar observations the power level at the input of the ADC can be brought down by observing using a single dipole. The power will drop by a factor of 16 (12 dB) in this observing mode, since

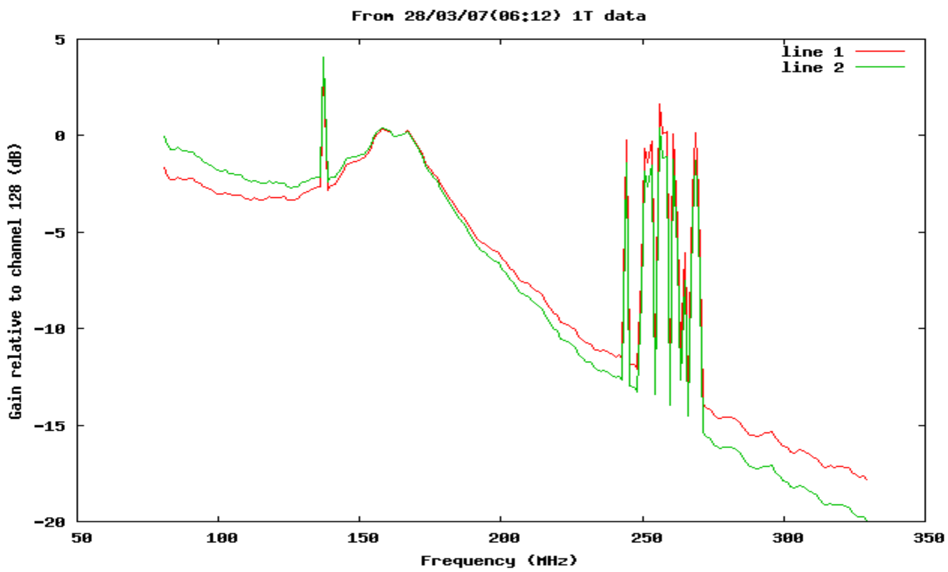

Figure 2: Expected gain variation across the 256 channel polyphase filter bank when using 250 m RG6 (green) and LMR400 (red) cables to connect the tile output to the Receiver Node. The gain plot is obtained from the 1T average power spectrum shown in Fig.1 by converting the spectral resolution to 1.29 MHz and normalizing the spectral power with respect to that in channel 128.

Sun is roughly a “point” source for the tile beam. If we plan to use the MWA in this observing mode then the attenuation range needed will be about 30 dB.

A 1 dB step in attenuation will be adequate for adjusting the power level at the input of the ADC. Any further adjustment of the gain can be done in the ADC to an accuracy of 0.01 dB.

4 Is a slope quantization filter required ?

In the receiver node, a polyphase filter bank (PFB) follows the digitization of analog signal. The spectral noise power (excluding RFI) changes by about 18 dB in the frequency range between 80 and 350 MHz (see Fig. 1). Normally, a spectral slope equalization filter would be needed if this variation in power across the frequency range were not adequately measurable in the PFB. However, we argue below that realizable PFBs have enough dynamic range and that such a filter is not necessary. We considered RG6 and LMR400 cables with a worst case length of 250 m for the analysis. The attenuation of RG6 is characterized by $0.6\sqrt{f} - 0.0005f + 0.4$ dB/100m, where f is the frequency in MHz between 50 and 500 MHz.

4.1 ADC input peak-to-peak voltage at 6σ level

We consider a 256 channel PFB with 9 bit input and 16 bit real and imaginary outputs. Since our intention is to get the relative number of bits needed to represent the RMS value (see below) at the PFB outputs, the details of truncation and/or rounding off are not important (Simulation using Grant’s PFB code, which will include the effect of quantization and rounding will be presented elsewhere). The selected ADC has 8 bit resolution. The input power P_{in} to the ADC is related to a 256 channel ideal filter bank output by

$$P_{in} = \sum_{i=1,256} P_i = P_{128} \sum_{i=1,256} W_i, \tag{1}$$

where P_i is the power at the i^{th} channel and W_i is the gain of channels relative to that of 128. Fig. 2 shows the plot of W_i estimated from the 1T data for 250m of RG6 and LMR400 cables. $\sum_{i=1,256} W_i$ estimated from this data for the two type of cables are 99 and 88 respectively. Assuming that the signal at the ADC input is Gaussian random noise we get

$$\sigma_{128} = \sigma_{in} / \sqrt{\sum_{i=1,256} W_i}. \tag{2}$$

Here σ_{128} is the RMS value of the signal at channel 128 and σ_{in} is the RMS at the input. We first consider the case $\sigma_{in} = 256/6$. The PFB uses 512 point FFT and the output is not normalized. Therefore $\sigma_{128}^{PFB} = \sigma_{128} \times 512/\sqrt{2}$ for real or imaginary output. This means that the RMS value can be represented with 11 bits for both type of cables. The channels near 330 MHz have power levels $\sim$ 20 dB below that of channel 128 when using RG6 cable, which means that the number of bits needed to represent the RMS value is 8. Even for power levels of about 30 dB below that of channel 128 near 330 MHz the RMS value needs to be represented by more than 5 bits. This means that the power level is spread over more than 5 bits in all channels. Thus all PFB outputs can be re-quantized to 5 bits in the subsequent stages. We conclude that there is no need for slope equalization filter.

4.2 ADC input peak-to-peak voltage at 15σ level

We re-evaluate the number of bits needed to represent the RMS value across the PFB bands when the ADC input peak-to-peak voltage is 15σ. The number of bits needed to represent the RMS at 128 channel is now 10 and that needed to represent the RMS value for the 350 MHz channel is about 6 for both type of cables. Thus all PFB outputs can be re-quantized to 5 bits in the subsequent stages. We conclude that there is no need for slope equalization filter for the 15σ level case as well.

5 Is an anti-aliasing filter required ?

The SigCB has about 70 dB gain and most commercial amplifiers have bandwidth $>$ 330 MHz. The receiver node has digital systems which operate at frequencies above 330 MHz. Any coupled noise from the digital part of the receiver node at frequencies $>$ 330 MHz will get amplified and be present at the input of the ADC. Therefore it is better to have an anti-aliasing filter just at the input of the ADC. One way to avoid multiple filters in the SigCB would be to provide the low-pass filter required for the band selection in the SigCB to be placed at the output of the last amplifier.

6 Summary of the specification for version 1.0

- Total Gain: at least 60 dB, desirable 70 dB
- Attenuator range: at least 30 dB, desirable 40 dB
- Attenuator step size 1 dB

- Needed a band selection filter of bandwidth 80 to 330 MHz.
- Anti-aliasing filter needed. If possible the low-pass section of the band selection filter can be placed at the output of the last amplifier to form the anti-aliasing filter.

Reference

Corey, B. E, 2006, System performance, MWA knowledge tree
Kraus, J. D., 1986, Radio Astronomy, Cygnus-Quasar Books, Ohio.

Revision history

V1.0 – April 22, 2007
V1.1 – July 13, 2007
(a) re-evaluated 1T spectrum with 200 m LMR400 cable; RG6 was assumed in v1.0
(b) Included the case when the ADC is operated at 15σ level
(c) Included the case when 1 dipole is used for Solar observations
(d) Included the computation of the number of bits needed across the PFB for 250 m RG6 and LMR400 cables.