Technical Note: Investigating the front end terminated receiver system thermal noise character for the UGMRT using phased array Beam mode output.

Prepared by Dipanjan Mitra

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Abstract

We analyse how theoretical Mean/RMS compare with the observed Mean/RMS for UGMRT 200 MHz system, for various cases of time and frequency average of filterbank data obtained from the phased array total power output with front end terminated (at the common box). We mention two cases where we find that (1) keeping raw time resolution of 327.67 μ sec and collapsing the data for 175 MHz about 15% decrease is seen in the Mean/RMS from the expected value: (2) keeping 10 MHz bandwidth and averaging the signal in time domain the Mean/RMS decreases to 50% at 0.1 sec time resolution and the increase in Mean/RMS almost saturates for coarser resolutions.

1 Statement of the Problem

In a radio telescope it is interesting to measure how closely the front end terminated system follow the radiometer equation, i.e. thermal noise character. Currently UGMRT has wide band receivers, and our aim here is to perform an experiment in the phased array mode of operation to estimate thermal noise for various cases by averaging data in time and frequency. The experiment thus analyses the a good approximation for the receiver chain behaviour from front end terminated location upto the beam output of the correlator.

When the front end is terminated, the system power is due to the receiver systems and the corresponding temperature is $\mathbf{T_r}$ which, let us assume to be constant across the wide band. At the output of the correlator the total power data is recorded with time resolution τ is recorded as filter-bank format, where the total observing bands is divided into several channels of $\delta\nu$ bandwidth. One can then use the filter-bank data to check for the effect of averaging the signal both in time and frequency. After every averaging we can calculate the quantity $\mathbf{M} = (signalmean)/(signalrms)$, and check how closely this agree with the expected value of $\sqrt{\mathbf{2n_t n_{ch}}\delta\nu\tau}$, where $\mathbf{n_t}$ and $\mathbf{n_{ch}}$ is the number of time samples and channels averaged and the factor of 2 is for two polarization channels.

The Experiment

The experiment performed is as follows. A set of central square antennas were chosen to produce a phased array at Band 3, in the frequency range 300-500 MHz. The front end was then terminated (before common box) and phased array beam output data was acquired for 300 sec at time resolution of $\tau = 327.68\mu$ sec and 2048 channels across 200 MHz, thus $\delta\nu = 0.09765625$ MHz. The average bandshape for the data is shown in the left plot of Fig. 1. Note the two large and small oscillatory patterns seen in the bandshape, which corresponds to a period of roughly 40 MHz and 5 MHz respectively. In the left plot estimated $\mathbf{M}$ for 100 channel average (9.76 MHz) is shown which is very close to the theoretical value of 80.03, except the initial 100 channels.

- **Time Frequency Behaviour of the Data:** We use the filterbank data to produce the time frequency plot as shown in left panel of Fig 2. The plot is made by first averaging a desired number of channels and then taking a fourier transform of a certain time range (window) and repeating the process for the full channel collapsed time series by sliding the time-window. To calculate $\mathbf{M}$ in the data we use this sliding time-window. The contour plot shows the frequency as x-axis and time as y-axis, where the bottom and side panel shows the collapsed values. These kinds of plots are a powerful way to identify any oscillatory temporal features in data.

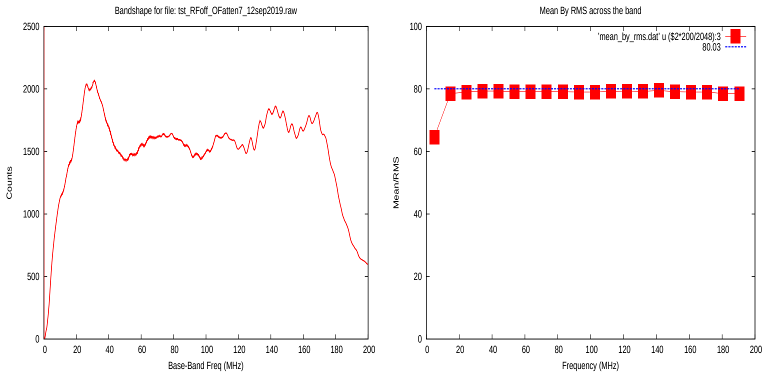

Figure 1: The left plot shows the total power beam output bandshape across the 200 MHz band. The red points in the right plot shows the measured (mean/rms) **M** across the band by averaging 100 channels (9.76 MHz), while the blue line is the expected value.

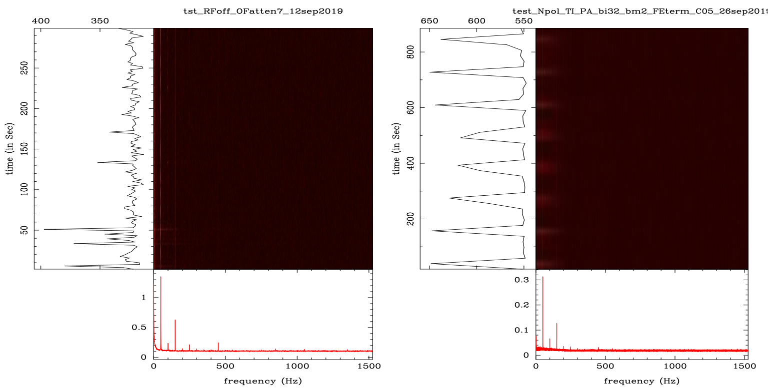

Figure 2: The left and right plot correspond to time frequency analysis of the filterbank files. The left plot is the data that is being used for estimating (mean/rms) **M** analysis by collapsing channel 100 to 1900. The right plot is an example plot (obtained from a different experiment) to show how the 60 to 1 system affects the beam data. See text for details.

For example in the current data frequencies like 50Hz and harmonics are clearly seen. This technique, as shown in the right plot of Fig. 2 was also used to identify a 110 second signal that was leaking in the system due to the 60 to 1 subsystem.

The data that we are anlysing does not have the 110 sec signal, however there are some temporal variation seen in the initial 60 seconds (see left plot y-axis left panel).

- **Collapsing across the band**

  Since **M** is constant across the band, we can now collapse channel to check the data for $\sqrt{\mathbf{2n_t n_{ch}}\delta\nu\tau}$ effect. To do this we reject the first hundred channels and collapse the data from 100 to 1900 channels in steps, but keeping $n_t = 1$. In Fig. 3 the estimated (mean/rms) **M** is plotted as a function of averaged frequency as red point (and line). The expected **M** is plotted as a blue line.

  A 15% reduction in the value of **M** from the expected value is seen after collapsing about 175 MHz band. It is possible that this effect arises due to a frequency dependent change in the receiver temperature, which is not taken into account while calculating the expected **M**. The other causes that can result in the reduction is the presence of line frequency in data which can results in correlated signals while collapsing channels.

- **Collapsing across time**

  In this case we fix the collapsed channel and find **M** by averaging the data in time. For the case shown in Fig. 4 we take $\mathbf{n_{ch} = 5}$ or 0.48 MHz. In the figure the estimated **M** versus time averaging in plotted in red and we find that there is about 10% reduction of **M** from the expected value (shown as blue curve) after about 0.2 sec time sample average. In Fig. 5 we

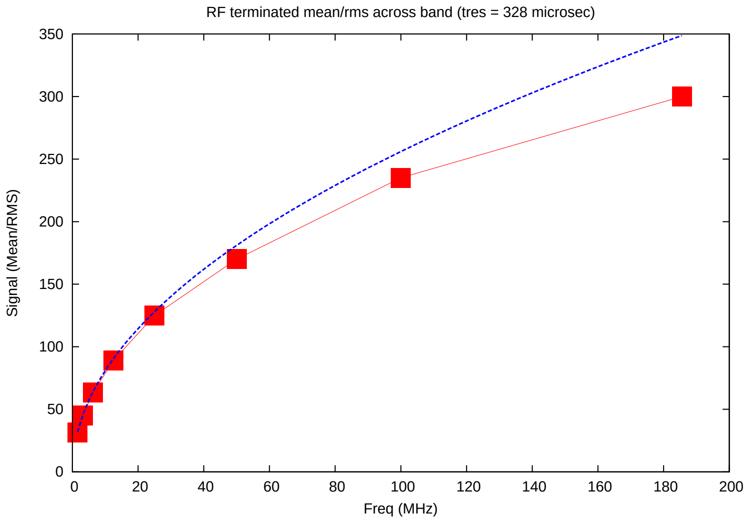

Figure 3: The red line and point in the plot shows the measured (mean/rms) **M** as a function of collapsed bandwidth. The blue curve is the expected **M** (for constant $\tau = 327.68\mu$ sec

show the case for $\mathbf{n_{ch}} = \mathbf{100}$ or 9.76 MHz and find that around 0.1 sec the value of **M** reduces by 50% and the growth curve of **M** almost remains flat for coarser time sample resoltuions.

In the time collapse averaging scheme, $\mathbf{T_r}$ does not change, so possible reason for reduction of **M** from the expected can be due to the presence of fluctuating 50 MHz signal and its harmonics or some other source of temporal correlated signal. This aspect is shown in the bottom plot of Fig. 5, where for coarser resolution the time signal deviates significantly from gaussian noise. Thus while calculating **M** the mean of the signal is remaining constant but the RMS after a certain temporal averaging does not reduce as expected.

2 Inference

The experiment done here deals with the total power property of the receiver signal chain. We have systematically studied the (mean/RMS) **M** behaviour for the front end terminated wide-band, i.e. 200 MHz, receiver system. We find that time frequency averaging causes **M** to reduce below the expected value. The reason for this reduction is currently not clear, however presence of correlated signal like power line modulation can be a likely source.

Data used for this analysis: tst_RFoff_OFatten7_12sep2019.raw

Acknowledgement

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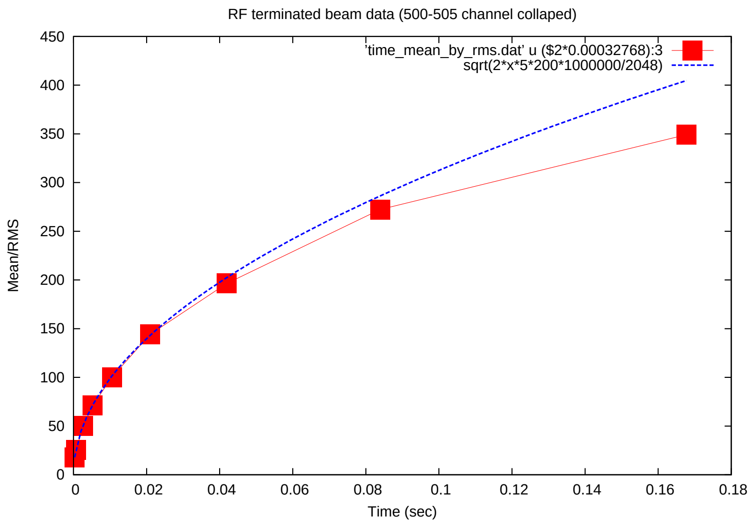

Figure 4: The red line and point in the top plot shows the measured (mean/rms) **M** as a function of time averages (where the time series has been produced by collapsing 100 channels). The blue curve is the expected **M**.

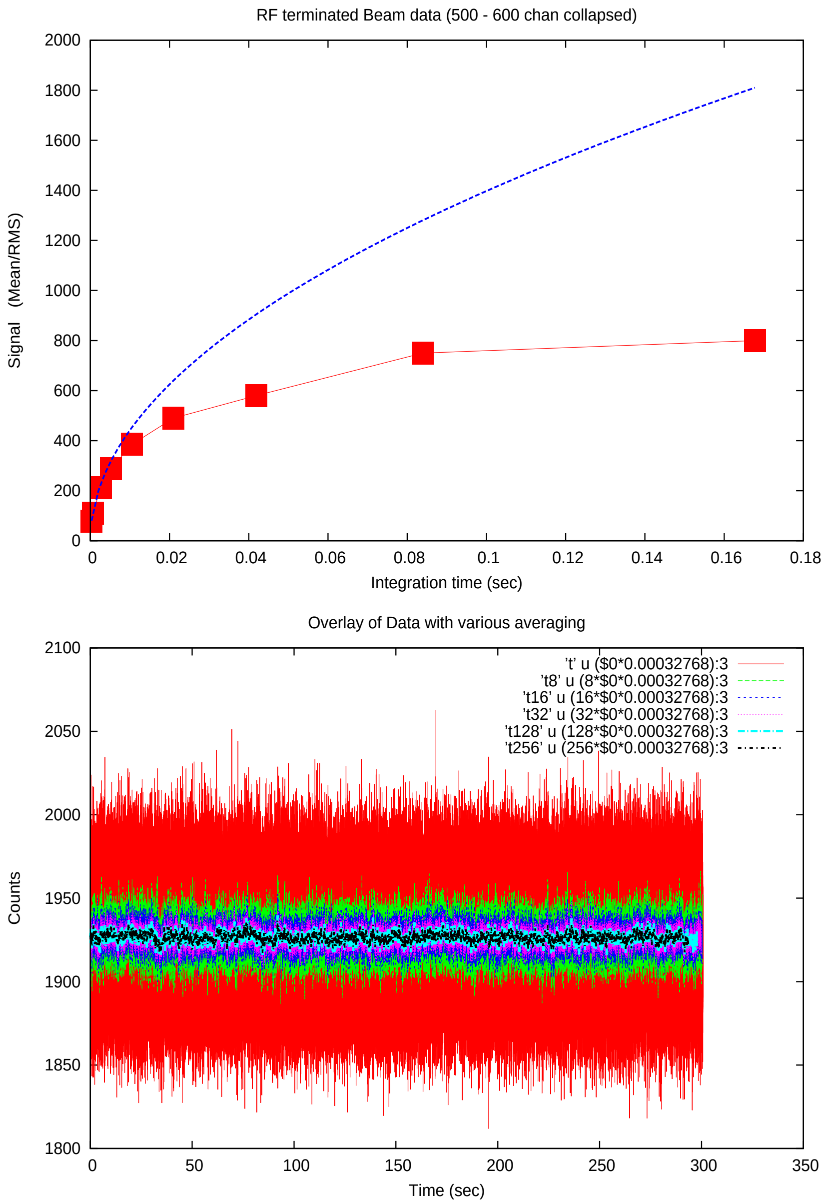

Figure 5: The red line and point in the top plot shows the measured (mean/rms) **M** as a function of time averages (where the time series has been produced by collapsing 100 channels). The blue curve is the expected **M**. The time series for various averages are shown in the bottom plot.