Test Report of Noise Diode on the 19-Beam Receiver

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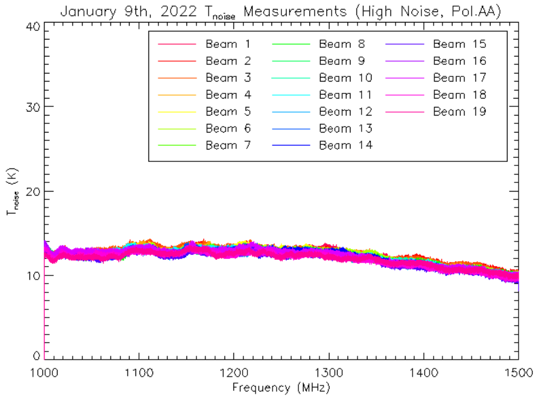
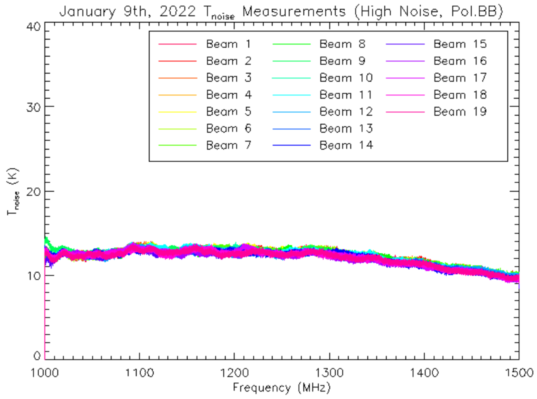
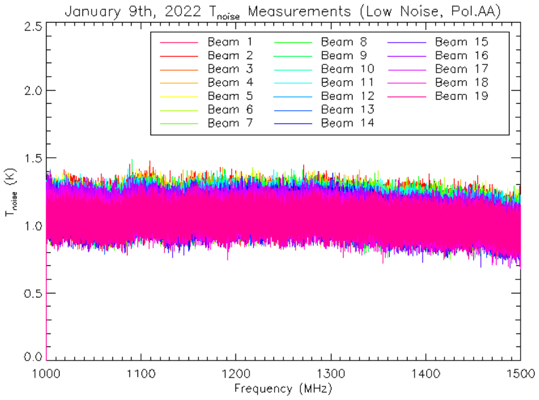
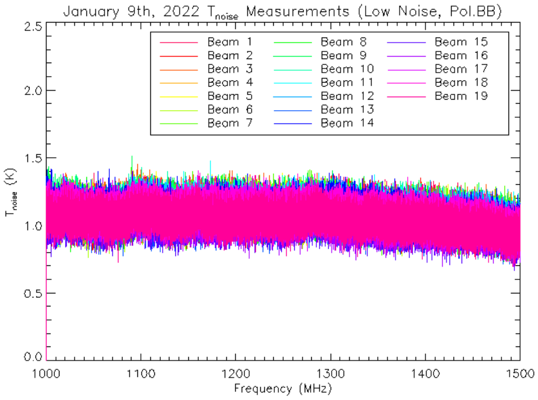
February 21, 2022

We performed a noise temperature test on the noise diode of the FAST 19-beam receiver between 10:00-15:10, January 9, 2022 (BJT), in order to provide a reference for flux calibration. The injected noise spectra were measured as shown below, with high noise on the top, low noise on the bottom, Polarization A on the left, and Polarization B on the right.









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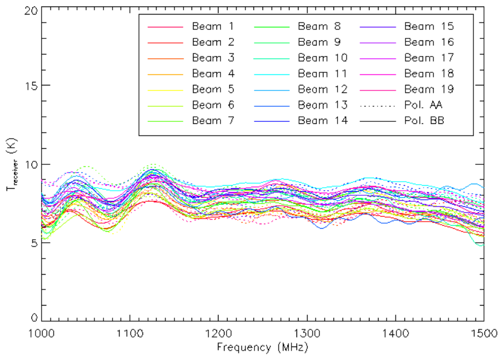
It can be seen that the characteristic noise temperatures are ~ 12.5 K and ~ 1.1 K, for high and low noise, respectively. The exact temperature reading, which is higher at $\sim 1100-1300$ MHz, and becomes lower at ~ 1300 MHz, shows dependency on frequency. The noise data can be extracted from high.tar.gz (high noise) and low.tar.gz (low noise), with frequency channels listed in freq.dat, and noise spectra in files "T_noise_W_high/low_XXa/b.dat". Here, "high" denotes data for high noise, "low" for low noise, with "XX" showing the beam number, and "a/b" for Polarization A or B.

Method of Test and Data Reduction

During the January 9th test, the receiver was operated Xiang-Wei Shi and Ming-Lei Guo , with Jin-You Song served as observer at the control room. Data reduction was performed by Dr. Bo Zhang. We adopted the hot load measurement, with the feed cabin lowered down to the bottom of the reflector, and the receiver covered by a piece of microwave absorber (served as hot load) with a quasi-blackbody temperature $T_{BB} \sim$ environmental temperature. Thus, the signals recorded by the receiver include system background $T_{receiver}$, noise diode emission T_{noise}, along with blackbody radiation from the absorber. In order to measure the noise level, we injected noise periodically. Let on be the receiver's instrumental reading with the noise diode turned on, off be the reading without noise, the noise level can be calculated with Rayleigh-Jeans Law as

$$T_{noise} = \frac{\text{on} - \text{off}}{\text{off}} \times T_{off} = \frac{\text{on} - \text{off}}{\text{off}} \times (T_{BB} + T_{receiver}) \tag{1}$$

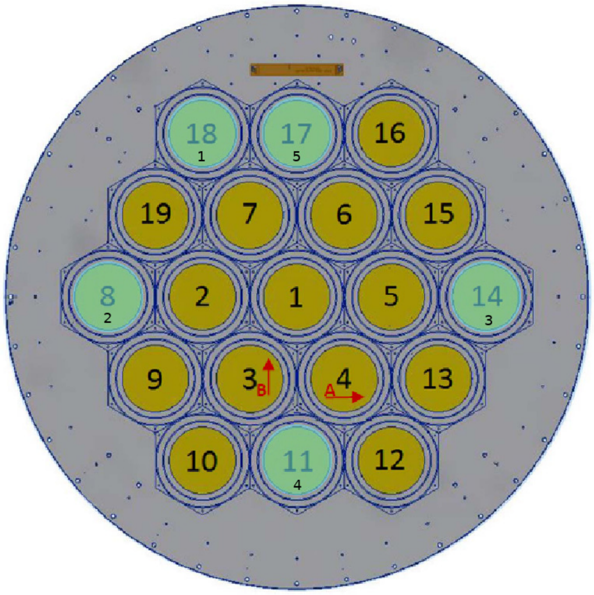
Here, the background temperature measured with cold/hot loads in CSIRO laboratories during the receiver's construction phase has been adopted as $T_{receiver}$. The data, which are provided by Alex Dunning from CSIRO, are shown as follows. It can be seen that the characteristic temperature level sits at $6-9$ K range, and shows dependencies on frequency and polarization.



Original Data: Alex Dunning

The noise injection period adopted was 1.00663296×2 s, with noise on and off each lasting for 1.00663296 s, which equals to sampling time of the spectral line backend. The system gain was set as RFgain = 400, and dgain = 8. The high noise test was performed at 10:00-11:00, while the low noise test covering 11:10-15:10, with a 10-minute interval in between for set-up switching. Data recorded during 12:06-12:24, as well as 15:00-15:06 have been omitted in reduction, due to appearance of instantaneous RFI.

The absorber temperature T_{BB} was measured on-site with a thermometer every 5 minutes. We took measurements at selected positions near the 5 outer beams denoted by cyan in the figure below.



The T_{BB} value fluctuated between ~ 281.5 and 283 K during the whole test. Each set of 5 temperature readings took at the same time show typical fluctuations less than ~ 0.5 K, while the most significant difference can be as large as ~ 1 K. Since such a fluctuation can only bring an uncertainty less than $\sim 1/300$ K to T_{BB}, we took the averaged value of each set as T_{BB} at the corresponding time.

Also, it is worth noting that 2 different methods exist to calculate the noise spectra. The first one is to calculate averaged values for all on and off samples, and substitute the corresponding items in Eq. (1) with the average values

$$T_{noise,1} = \frac{\sum_{i=1}^{n_{\text{on}}} \text{on}_i/n_{\text{on}} - \sum_{i=1}^{n_{\text{off}}} \text{off}_i/n_{\text{off}}}{\sum_{i=1}^{n_{\text{off}}} \text{off}_i/n_{\text{off}}} \times (T_{BB} + T_{receiver}) \tag{2}$$

Here, n_{on} and n_{off} are numbers of on and off samples, respectively.

Another method is to calculate T_{noise} with each single on and off reading, and take an average of the resulting T_{noise} values

$$T_{noise,2} = \frac{1}{n} \sum_{i=1}^{n} \frac{\text{on}_n - \text{off}_n}{\text{off}_n} \times (T_{BB} + T_{receiver}) \tag{3}$$

Here, n means the total number of on/off pairs. It can be proved that $T_{noise,1} \leqslant T_{noise,2}$. Eq. (3) applies only if the background fluctuation can be described by white noise, and could not be suitable for cases with lower system noise and higher spectral/temporal resolution. Thus, we perform the data reduction work with Eq. (2). The whole testing session was divided into several intervals, each lasting ~ 30 mins. The noise temperature for each interval was calculated using Eq. (2), with weighted average of all intervals served as final result of T_{noise}. The T_{BB} value for each interval was computed as average of several temperature measurement sets within.

Error Analysis

The possible sources of error for our test results includes the method to deal with T_{BB} measurement data, as well as the discrepancy between Eqs. (2) and (3). However, calculations show that different ways can only bring an T_{BB} uncertainty of $\sim 1/300$, while data reduction done with Eqs (2) and (3) can lead to a ~ 0.3 K difference in high level T_{noise}.

And we set the noise delay as 0 during the January 9 test. A signal delay lasting several dozens of μs does exist between the control room and the receiver, which can lead to a noise spill over on the off data. Yet, such a delay is at the order of 10^{-4} of the noise injection period, thus can be largely neglected.