# Test Report of the Noise Diode on the 19-Beam Receiver

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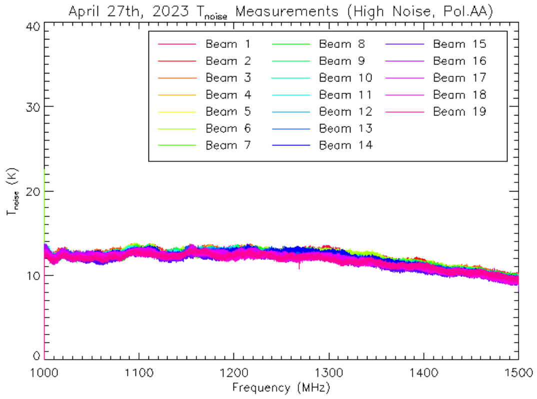
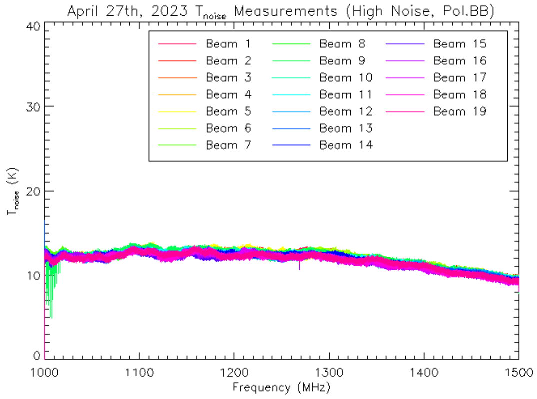
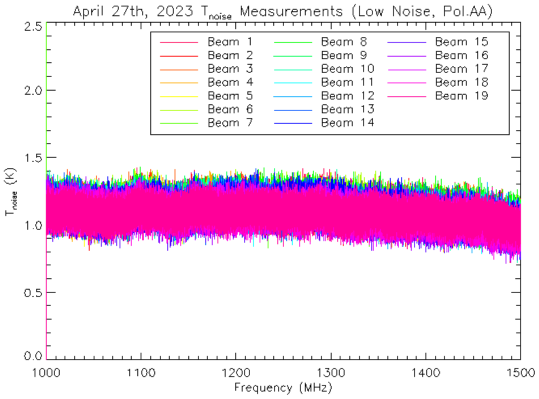
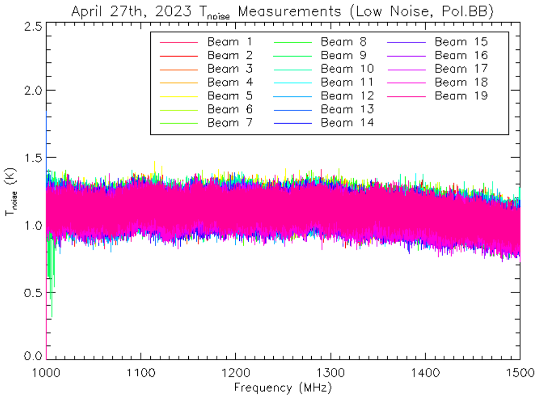
We performed a noise temperature test on the noise diode of the FAST 19-beam receiver between 12:30-17:40, April 27, 2022 (BJT), in order to provide a reference for calibrating observed data. The injected noise spectra were measured as shown below, with high noise on the top, low noise on the bottom, Polarization A on the left, and Polarization B on the right.









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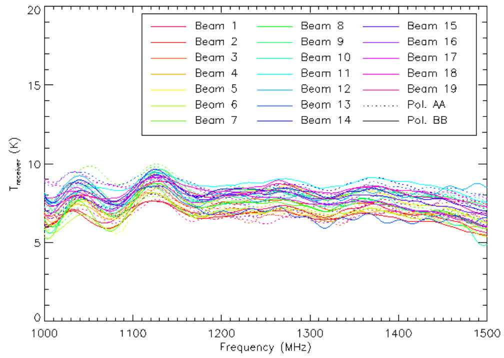
It can be seen that the characteristic noise temperatures are ∼ 12.3 K and ∼ 1.10 K, for high and low noise, respectively. The exact temperature reading, which is higher at ∼ 1100−1300 MHz, and becomes lower at ∼ 1300 MHz, shows dependency on frequency. The noise data can be extracted from high_202304.tar.gz (high noise) and low_202304.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 April 27th test, the receiver was operated Xiang-Wei Shi, with Yu-Tao Zhao acted as observer at the control room. And data reduction was performed by Dr. Bo Zhang. We adopted the hot load measurement method, with the feed cabin lowered down to the bottom of the reflector, and the receiver fully covered by a piece of microwave absorber (i.e., hot load) with a quasi-blackbody temperature $T_{BB} \sim$ environmental temperature. Thus, the signals recorded by the receiver include the instrument background $T_{receiver}$, the noise diode emission $T_{noise}$, along with the quasi-blackbody radiation from the absorber. In order to determine 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 temperature can be calculated according to Rayleigh-Jeans Law as

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

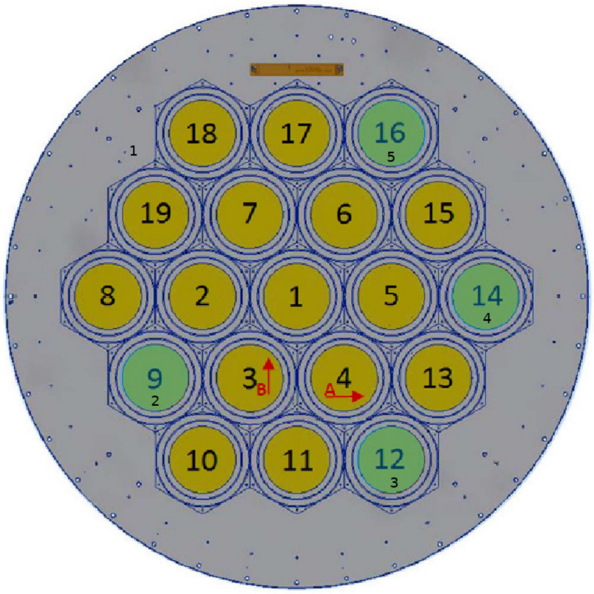
Here, the background temperature measured with cold/hot loads in laboratories of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) during the receiver's construction phase has been adopted as $T_{receiver}$, with a correction of ∼ 0.6 K added to compensate the changes of the receiver's Dewar temperature. The original $T_{receiver}$ data, which are provided by Alex Dunning from CSIRO, who was a member of the development team of the 19-beam receiver, are shown in the figure below.



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 = 8, and dgain = 400. The high noise test was performed at 12:30-13:30, while the low noise test covering 13:40-17:40, with a 10-minute interval in between for set-up switching.

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



The $T_{BB}$ value varied between $\sim 295.9$ and $\sim 299.3$ K during the whole test. Each set of 5 temperature readings took at the same time show typical fluctuations less than $\sim 0.5$ K. Since such a variation can only bring an uncertainty less than $\sim 1/600$ 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, $n_{\text{on}}$ and $n_{\text{off}}$ 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 $\sim 30$ mins, with a typical

$T_{BB}$ variation less than $\sim 0.5$ K. The noise temperature for each interval was calculated using Eq. (2), and the final result of $T_{noise}$ was taken as the weighted average of all intervals. The $T_{BB}$ value for each interval was computed as the 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 of treating $T_{BB}$ can only bring an uncertainty of as large as $\sim 1/600$ K. And data reduction for high level noise done with Eqs (2) and (3) can lead to a difference less than $\sim 0.05$ K in $T_{noise}$. And the low noise data shows a difference of $\sim 0.29$ K between the results deduced by the two methods, which equals to $\sim 26\%$ change in the noise level.

And we set the noise delay as 0 during the April 27th test. A signal delay lasting several dozens of $\mu$s does exist between the control room and the receiver, which can lead to a noise spill over in the off data. Yet, such a delay is at the order of $10^{-4}$ of the noise injection period, thus can be largely neglected.