How to Verify the SNR of a Receiver Based on the AD8307 Logarithmic Detector

Christian Monstein, HB9SCT

As a designer of radio astronomical receivers, I am always thinking of ways to prove that the signal-to-noise ratio (SNR) of a receiver fits with theory as introduced by John D. Kraus [Kraus 1986] in his radiometer equation for a total power receiver,

$$\delta T = \frac{T_{sys}}{\sqrt{B\,\tau}} \tag{1}$$

where δT is the system sensitivity, or smallest change in antenna temperature that can be measured, in kelvins, T_{sys} is the system noise temperature also in kelvins, B is bandwidth in hertz and τ is the integration time in seconds. Equation (1) shows that the sensitivity of a radio receiver is proportional to the system temperature T_{sys} and inversely proportional to the square root of the bandwidth B times the integration time τ. We can avoid any calibration in terms of noise temperature by rearranging equation (1), or

$$\frac{T_{sys}}{\delta T} = \sqrt{B\,\tau} \tag{2}$$

The ratio $\frac{T_{sys}}{\delta T}$ is equivalent to the radiometer SNR, therefore,

$$SNR = \frac{T_{sys}}{\delta T} = \frac{I_{hot} - I_{cold}}{\sigma_{hot}} = \sqrt{B\,\tau} \tag{3}$$

The system noise temperature T_{sys} in equation (3) can be found by a simple observation of a cold noise source such as a resistance termination at room temperature to obtain I_{cold} and of a hot source like a semiconductor noise source, hot part of the Milky Way galaxy, the sun or any other hot broadband radio source to obtain I_{hot}. The smallest change in noise temperature δT that we can observe is equivalent to the standard deviation or root-mean-square (rms) value of the noise source noise, σ_{hot}, which we can calculate from the statistics of the I_{hot} data. The last part of equation (3) follows from equation (2). The advantage of this approach is we do not need to know the actual noise temperature or received flux because SNR is dimensionless. In my case, for the Callisto receiver, the radiometric bandwidth is in the order of 300 KHz and the integration time is 1 ms. Therefore, the SNR should be about $\sqrt{300}$ = 17.3. This will be compared to actual measurements shown in figures 1 through 4.

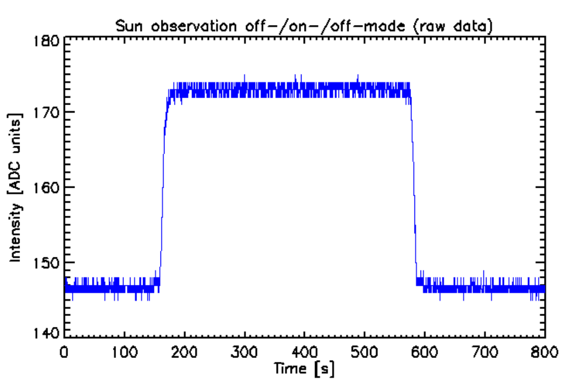

Figure 1 ~ A typical light curve of a telescope movement through the position of the sun with a 5 m parabolic dish at 1152 MHz. The intensity is un-calibrated and expressed in digits read from Callisto's analog-digital converter (ADC).

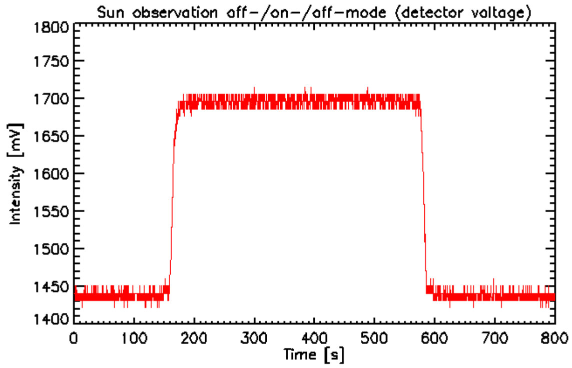

Figure 2 ~ The same data as in figure 1 but now expressed in mV as measured by the ADC, where the ADC's full scale range is 2500 mV

$$I_{mv} = \frac{I_{digits}}{255}\, 2500\ mV \tag{4}$$

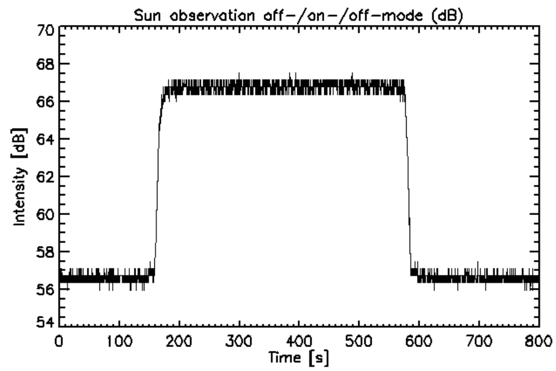

Figure 3 ~ The same data as in figure 2, but now expressed in dB as calculated by the specification for the AD8307 logarithmic detector

$$I_{dB} = \frac{I_{mv}}{25.4\ mV/dB} \tag{5}$$

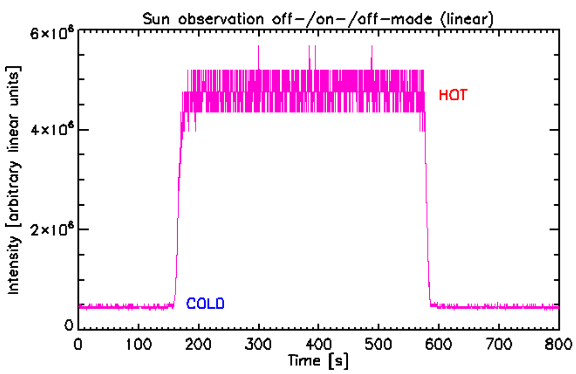

Figure 4 ~ Still the same data but now the plot is converted into a linear scale by

$$I_{linear} = 10^{0.1\, I_{dB}} \tag{6}$$

When we finally get the data in linear form, we can apply statistical functions to it. To get the signal itself, that is, T_{sys}, we need the average of the 'hot' part (I_{hot}) and the average of the 'cold' part (I_{cold}). To get the rms noise of the 'hot' part we calculate the standard deviation of it, leading to σ_{hot}. In my case, based on Callisto observing the sun at 1152 MHz, I get:

$$SNR = \frac{4.82E6 - 4.58E5}{2.72E5} = 16.0 \tag{7}$$

As shown above we expect from theory an SNR of 17.3, which is 7.5% higher than the measured value but acceptable. This error can be explained by non-ideal construction of the time constant τ in the integration circuit as well as imperfect knowledge of the bandpass filter's equivalent noise bandwidth.

Conclusion

With a simple hot and cold measurement, the sensitivity of a nonlinear receiver can be checked with respect to theory. Equations (4) through (6) can be easily combined into one equation and applied to any observation.

Further information and reading:

[Kraus 1986] John D. Kraus, Radio Astronomy, 2nd Ed., Powell, OH, Cygnus-Quasar Books, 1986

More information about the instrument Callisto and the network e-Callisto can be found here:
http://e-callisto.org/