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

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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,

$$\delta T = \frac{T_{sys}}{\sqrt{B \tau}}$$  \hspace{1cm} (1)

where $\delta T$ 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 $\tau$ 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 $\tau$. We can avoid any calibration in terms of noise temperature by rearranging equation (1), or

$$\frac{T_{sys}}{\delta T} = \sqrt{B \tau}$$  \hspace{1cm} (2)

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

$$SNR = \frac{T_{sys}}{\delta T} = \frac{l_{hot} - l_{cold}}{\sigma_{hot}} = \sqrt{B \tau}$$  \hspace{1cm} (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 $l_{cold}$ 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 $l_{hot}$. The smallest change in noise temperature $\delta T$ that we can observe is equivalent to the standard deviation or root-mean-square (rms) value of the noise source noise, $\sigma_{hot}$, which we can calculate from the statistics of the $l_{hot}$ 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](image1.png)  
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).
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 $\sigma_{hot}$. In my case, based on Callisto observing the sun at 1152 MHz, I get:

$$SNR = \frac{4.82 \times 10^{-6} - 4.58 \times 10^{-5}}{2.72 \times 10^{-5}} = 16.0$$  \hspace{1cm} (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 $\tau$ 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:

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