MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY

WESTFORD, MASSACHUSETTS 01886

January 12, 2015

To: Broadband Development Group

From: A.E. Niell

Subject: Calibration of switched noise diode and measurement of antenna efficiency

1. Introduction

This short note describes calibration of the noise diode temperature and calculation of the antenna efficiency when using the outputs of the switched noise diode.

2. Noise diode calibration

As used in this memo, counts is the sum of the squared 2-bit sample values in either a 32 MHz channel or in the sum of all channels in the IF and is thus proportional to the power in that channel or IF, or, equivalently, to the effective temperature. The noise diode is on for half of the cycle.

$$counts = c = \sum V^2 = g(t) * T \tag{2.1}$$

$$\frac{c_{NDon}}{c_{NDoff}} = \frac{g(t) * (T + T_{ND})}{g(t) * T} \tag{2.2}$$

$$T = T_{ND} * \left(\frac{c_{NDoff}}{c_{NDon} - c_{NDoff}} \right) \tag{2.3}$$

Define k:

$$\mathrm{k} = \left(\frac{c_{NDoff}}{c_{NDon} - c_{NDoff}} \right) \tag{2.4}$$

Obtain counts on the sky and with absorber over the feed. Tatm represents all of the contributions not seen by the receiver when the feed is covered with the absorber, e.g. atmosphere, spillover, 3K cosmic background, etc.

$$
\begin{aligned}
c_{NDon}^{sky} &= \mathrm{g}(\mathrm{t}_1)*\left(\mathrm{T}_{rx}+\mathrm{T}_{atm}+\mathrm{T}_{ND}\right)\\
c_{NDoff}^{sky} &= \mathrm{g}(\mathrm{t}_1)*\left(\mathrm{T}_{rx}+\mathrm{T}_{atm}\right)\\
\mathrm{k}_{sky} &= \left(\frac{c_{NDoff}^{sky}}{c_{NDon}^{sky}-c_{NDoff}^{sky}}\right)\\
c_{NDon}^{abs} &= \mathrm{g}(\mathrm{t}_2)*\left(\mathrm{T}_{rx}+\mathrm{T}_{atm}+(\mathrm{T}_{abs}-\mathrm{T}_{atm})+\mathrm{T}_{ND}\right)\\
c_{NDoff}^{abs} &= \mathrm{g}(\mathrm{t}_2)*\left(\mathrm{T}_{rx}+\mathrm{T}_{atm}+(\mathrm{T}_{abs}-\mathrm{T}_{atm})\right)\\
\mathrm{k}_{abs} &= \left(\frac{c_{NDoff}^{abs}}{c_{NDon}^{abs}-c_{NDoff}^{abs}}\right)
\end{aligned}
\tag{2.5}
$$

Calculate the noise diode effective temperature from measurements of counts with the absorber on, kabs, and absorber off, ksky.

$$
\begin{aligned}
\mathrm{T}_{sky} &= \mathrm{T}_{rx}+\mathrm{T}_{atm} = \mathrm{k}_{sky}*\mathrm{T}_{ND}\\
\left(\mathrm{T}_{rx}+\mathrm{T}_{atm}\right)+\left(\mathrm{T}_{abs}-\mathrm{T}_{atm}\right) &= \mathrm{k}_{abs}*\mathrm{T}_{ND}
\end{aligned}
\tag{2.6}
$$

Then

$$
\mathrm{T}_{ND} = \frac{\left(\mathrm{T}_{abs}-\mathrm{T}_{atm}\right)}{\left(\mathrm{k}_{abs}-\mathrm{k}_{sky}\right)}
\tag{2.7}
$$

In terms of the ‘k’ factor, the receiver temperature is given by:

$$
\mathrm{T}_{rx} = \mathrm{k}_{sky}*\mathrm{T}_{ND}-\mathrm{T}_{atm}
\tag{2.8}
$$

Brian Corey pointed out that if gain variations between the time of the absorber and sky temperature measurements are ‘small enough’ or can be reduced by averaging, the receiver temperature may be more precisely determined by using only either the diode on or the diode off counts values. Then, for example,

$$
\mathrm{T}_{rx} = \frac{\left(\mathrm{T}_{abs}-\mathrm{T}_{atm}\right)}{\left(\dfrac{c_{NDoff}^{abs}}{c_{NDoff}^{sky}}-1\right)}
\tag{2.9}
$$

To simplify the use of the k-factor, it is calculated from the counts and output for one 32MHz channel for both polarizations from the RDBE-G in personality 3.0.

3. Antenna efficiency measurement

Knowing the temperature of the noise diode, T_{ND}, the efficiency of the antenna at the elevation (and azimuth) of the calibration source can be obtained from measurements of ‘k’ both on and off a source of known flux density, S. (‘k’ is not to be confused with the Boltzmann constant, k_B.)

$$
\begin{aligned}
T_{sky} &= T_{rx} + T_{atm} = k_{sky} * T_{ND} \\
T_{on\_srce} &= T_{sky} + T_{srce} = k_{on\_srce} * T_{ND} \\
T_{srce} &= (k_{on\_srce} - k_{sky}) * T_{ND}
\end{aligned}
\tag{3.1}
$$

If the source is extended compared to the beam size, a source size correction factor, SSCF, must be applied.

The observed system equivalent flux density and the antenna efficiency can be derived from the following relation:

$$
S = 2k_B \frac{T * SSCF}{\eta * A_g} \tag{3.2}
$$

Correcting for the reduction of signal from the radio source by atmosphere absorption, AbsFactor (a factor less than 1.0), the antenna efficiency outside the atmosphere is given by:

$$
\eta = 2k_B \frac{T_{srce} * SSCF}{A_g * S * AbsFactor} \tag{3.3}
$$

From observations of calibration sources at many azimuths and elevations, the efficiency as a function of antenna position, assumed to be only elevation for the following, can be built up. The atmosphere absorption factor, if significant, must be calculated for each observation from the meteorological conditions at the time.

Then from a measurement of sky temperature at an arbitrary elevation, ε, the SEFD is found as:

$$
SEFD(\varepsilon) = 2k_B \frac{T_{sky}}{\eta(\varepsilon) * AbsFactor(\varepsilon) * A_g} \tag{3.4}
$$

4. Acknowledgement

I thank Brian Corey for his suggestions and for proofing of the text.