NATIONAL RADIO ASTRONOMY OBSERVATORY MEMORANDUM

DATE: August 7, 2002
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SUBJECT: GBT Tipper and Aips++ data reduction

The following discusses an alternative model we might want Aips++ to fit to the data from the GBT water vapor tipper. In this memo I'll be using the following notation:

A = Air Mass at which sky measurements are made (= *csc(elevation)* for $A < 10$ or elevation angles > 6°).
T_{rcvr} = Receiver noise temperature in K.
T_{amb} = Ambient (air) temperature.
T_{ecco} = Temperature of eccosorb which lines the inside of the tipper's enclosure.
T_{hot} = Temperature of the hot load inside the tipper's enclosure.
T_{BG} = Temperature of the microwave background (2.8 K).
T_w = Equivalent temperature of atmospheric water vapor.
T_o = Equivalent temperature of atmospheric oxygen.
τ_w = Zenith opacity due to water vapor.
τ_o = Zenith opacity due to oxygen.
τ = Total zenith opacity = $\tau_w + \tau_o$
η_{ms} = main and side-lobe efficiency. $(1 - \eta_{ms})$ is the fraction of the feed illumination that extends beyond the edge of the tipper's mirror..
V_{sky} = Measured voltage from the sky at various values of A.
V_{ecco} and V_{hot} = Measured voltages when the tipper's mirror is pointing at either the eccosorb load or hot load inside the enclosure.
G = Gain of the system with units such that $V = G \cdot T$.

Currently, Aips++ fits the following function to the data from the GBT tipper:

$$V_{sky} = G\left(T_{rcvr} + T_{amb}\tau A\right) \qquad (1)$$

where T_{rcvr} and τ are the parameters fitted and G is assumed to equal $(V_{hot} - V_{ecco}) / (T_{hot} - T_{ecco})$. I believe this model is much too simplistic for any weather conditions except those on very clear, very cold, dry winter conditions. The model I propose is much more realistic and is based on the papers of Kutner (*Astrophysical Letters*, 1978, Vol. 19, pp. 81-87), Ulich (*Astrophysical Letters*, 1980, Vol. 21, pp. 21-28), and Kutner and Ulich (*Astrophysical Journal*, 1981, Vol. 250, pp. 341-348). My modifications to their papers take into consideration the design of the GBT tipper and the simplifying and appropriate assumption that $h\nu < kT$.

As the tipper's mirror spins, it illuminates the sky at a wide range of elevation angles as well as the eccosorb and hot loads within the enclosure. Any spillover is assumed to fall on the eccosorb lining of the enclosure. The measured voltages for the three kinds of targets are:

$$V_{hot} = G\left[T_{rcvr} + \eta_{ms}T_{hot} + \left(1 - \eta_{ms}\right)\cdot T_{ecco}\right] \qquad (2)$$

$$V_{ecco} = G\left[T_{rcvr} + T_{ecco}\right] \tag{3}$$

$$V_{sky} = G\left[T_{rcvr} + \eta_{ms}\left\{T_{BG}e^{-(\tau_w+\tau_o)A} + T_w - \left[T_w - T_o\left(1-e^{-\tau_o A}\right)\right]\cdot e^{-\tau_w A}\right\} + \left(1-\eta_{ms}\right)\cdot T_{ecco}\right] \tag{4}$$

Note that equation (4) can be reduced to (1) if one assumes (in order of the severity of the assumption):

(i) $T_{BG} = 0$ (introduces at most a 1% error in τ_w);
(ii) $\eta_{ms} = 1$ (introduces probably a few percent error in τ_w);
(iii) $T_w = T_o$ (introduces about a 10% error in τ_w); and
(iv) $(\tau_o + \tau_w)\cdot A$ is very small (only reasonable on excellent, cold weather days).

Currently, Mike Stennes and I are considering ways in which we can measure the value of η_{ms}. Because the tipper's feed grossly under illuminates the tipper's mirror, η_{ms} should be extremely close to one. Once η_{ms} is known, and since V_{hot}, V_{ecco}, T_{hot}, and T_{ecco} are measured quantities, one can use equation (2) and (3) to solve for G and T_{rcvr} for every measurement made by the tipper using:

$$G = \frac{\left(V_{hot} - V_{ecco}\right)}{\eta_{ms}(T_{hot} - T_{ecco})}$$

$$T_{rcvr} = \left(V_{ecco} / G\right) - T_{ecco}$$

The above-mentioned papers suggest the following:

- $\tau_o = 0.041 \cdot e^{(-h\,/\,5\,km)} = 0.034$ for the altitude (h) of Green Bank above sea level and for a frequency of 90 GHz
- $T_w = T_{amb} - 10\,K$
- $T_o = T_{amb} \cdot (0.90 + 0.002\,\tau_o A)$

which leaves in equation (4) only τ_w as an unknown parameter that Aips++ needs to fit to the measured sky voltages. In addition to archiving values of $\tau = (\tau_w + \tau_o)$, Aips++ probably should record in the same files the values of η_{ms}, V_{hot}, V_{ecco}, T_{hot}, T_{ecco}, G, T_{rcvr}, τ_o, T_w, T_{amb}, and T_o.