

GBT Commissioning Memo: Gain and Efficiency at S-band

Keywords: Low Frequency Gregorian Gain and Efficiency

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May 10, 2001

Summary

Gain and aperture efficiency at 2 GHz are derived from observations of calibrators made on March 21-22 and 23-24 of 2001. The observing conditions were less than ideal, and there were instabilities in the gains and system temperatures. We hope to repeat the measurements under better conditions and track down any systematic problems. Nevertheless, the data indicate the expected performance of about 70 % aperture efficiency. T_{sys}/G is about 10 Jy. A slight drop in gain at low elevations is consistent with atmospheric attenuation, and an increase of T_{sys} at low elevations is consistent with atmospheric emission. There are apparently no elevation-dependent gain effects that can be attributed to structural flexing.

Introduction

For any antenna, the relation between the flux density (S) of an unresolved radio source and the antenna temperature (T_a) due to that source is given by:

$$S = 2kT_a/(eA)$$

in which k is Boltzmann's constant, e is the aperture efficiency, and A is the geometric area of the aperture. Converting to units in which S is in Janskys, T_a in Kelvin, A in sq.meters, the equation becomes:

$$S(\text{Jy}) = 2761 * T_a/(eA)$$

We define the gain (G) as: $G = T_a/S$

Since A for the GBT is 7854 m², we have:

$$G = 2.845e$$

We will determine G and e from observations of standard radio sources and consider how these quantities vary with elevation.

Related matters, such as main beam efficiency, side lobes, spillover, and surface errors, will be discussed in another memo.

Observations

Measurements were made on March 21-22 and 23-24 of 2001 at a frequency of 2.0 GHz, using linear polarization. Observations were made of several well-known calibration sources from the list by Ott et al. (Astron. Astrophys. **284**, 331, 1994). Only the sources with angular size less than 1 arcmin were used. The sources are listed in Table 1, along with their flux densities at 2.0 GHz, calculated from the spectral fits given by Ott et al.

Table 1: Calibration Sources

Source Name	Extension	S(Jy) at 2.0 GHz	Elevation range	Number of observations
3C123	23" x 5"	35.66	25°	1
3C147	1" x 1"	16.61	7-25°	7
3C218	47" x 15"	30.70	9-27°	5
3C286	1.5" x 1.5"	12.37	33-79°	10
3C295	5" x 1"	16.31	46-76°	22
3C309.1	1.5" x 1.5"	5.86	49-57°	17

All sources were observed with the “peak” procedure, in which two scans, forward and back, were done in RA, then a similar two in DEC. After the RA scans, gaussian fits were done to the data to find pointing offsets, which were used for the DEC scans. In this way, any imperfections in pointing due either to the pointing or refraction models were eliminated. Baselines were subtracted and gaussian models were fit. The average of the amplitudes of the two DEC scans was used for the gain calculations described later. Focus tracking was enabled using the focus tracking calibration described in Ghigo et al. (GBT commissioning memo March 29, 2001).

Observing was done while switching the noise cal at a 2 Hz rate. Data were processed using “gbtmsfiller” and “GO_point”, which produces amplitudes in units of T_{cal} . The appropriate T_{cal} values were determined by M. Stennes for the 2-3 GHz receiver. Interpolating his values to 2.0 GHz gives:

$$T_{cal}(Xpol) = 2.06 \text{ K} \quad T_{cal}(Ypol) = 1.90 \text{ K}$$

for the two linearly polarized channels.

Baselines were multiplied by T_{cal} to obtain T_{sys} , and gaussian amplitudes multiplied by T_{cal} to obtain T_{ant} . The gain and efficiency are given by:

$$G = T_{ant}/S \quad \text{and} \quad e = G/2.845$$

and the system-equivalent flux density (SEFD) is T_{sys}/G .

The fitted amplitudes are slightly too low because of the smearing effect of the time constant (0.5 seconds) and the scanning rate (90 arcmin/minute). Referring to Howard 1961 (AJ

66, p521), this effect reduces the amplitude about 3%. The gains we quote here should thus be increased by about 3%.

Several scans were not used because of RFI or problems with the baselines as seen in plots of the individual scans. Table 1 lists the number of gain measurements used for each source, and the range of elevations over which that source was observed.

Results

Figures 1-4 show the gain, efficiency, T_{sys} , and SEFD plotted against elevation. The "A" figure (1A, 2A, etc) in each case shows the X component of linear polarization ("Rcvr 0"), and the "B" figure shows the Y component ("Rcvr 1"). Table 2 shows the means and standard deviations of these quantities.

Table 2. Statistics of Measured Data.

	Receiver 0 (X-pol)		Receiver 1 (Y-pol)	
Quantity	Mean	Std. Deviation	Mean	Std. Deviation
Gain (K/Jy)	2.03	0.08	1.85	0.07
Aperture Efficiency (%)	71.3	2.7	65.1	2.5
T_{sys} (K)	21.6	3.6	20.2	3.2
SEFD (Jy)	10.7	2.1	10.9	2.0

There are some apparent systematic problems that will need to be investigated further. It is not clear if the difference in gain of the two polarizations is significant. The gain for some sources differed by 4% or so between the two nights of observation. This could be due to instabilities in the noise cal generator. One may also note that the T_{sys} and SEFD plots are double-valued (see Figures 3 and 4). Apparently there was a systematically higher T_{sys} (by 20%) on the second night of observing, probably not due to problems with the noise generator because T_{cal} cancels out in calculating SEFD. Conditions were not ideal on either night. There was light snow on the first of the two nights. Conditions seemed better the second night, but the T_{sys} and gains seem to have been worse. The differences in T_{sys} (about 20%) are greater than one would expect from weather at 2 GHz. The observations should be repeated under better conditions to see if we can get more consistent results.

Note that in all these plots, the error bars show plus and minus one sigma errors, calculated from the combination of error in the baseline fit and error of the amplitude fit to a gaussian beam.

Figure 1A: Gain for X-pol (Rcv0)

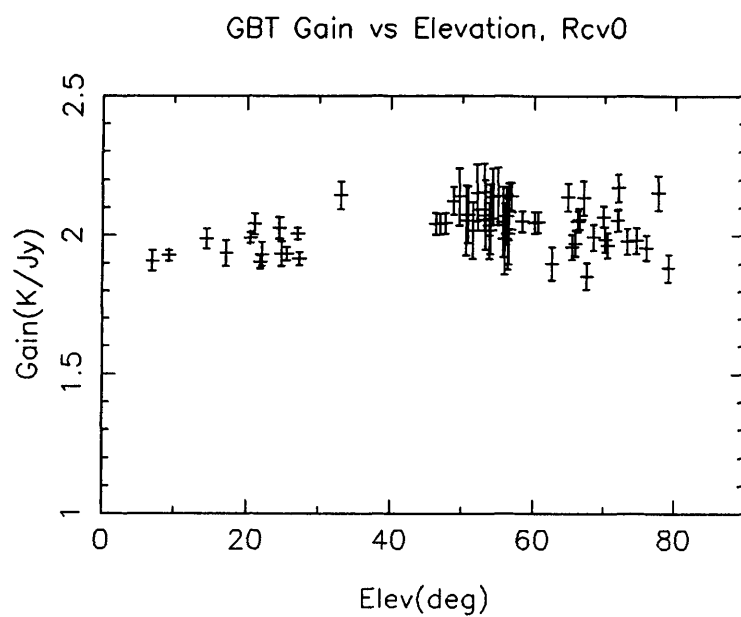


Figure 1B: Gain for Y-pol (Rcv1)

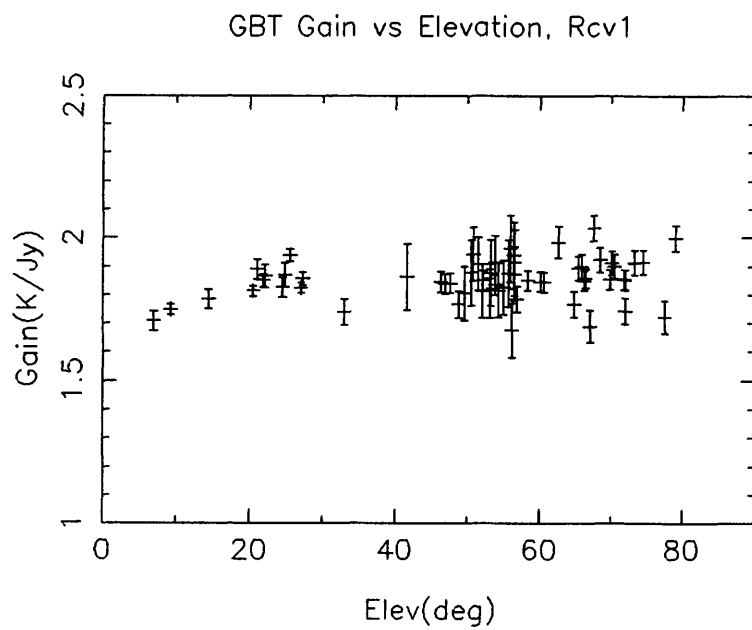


Fig. 2A: Efficiency for X-pol (Rcv0)

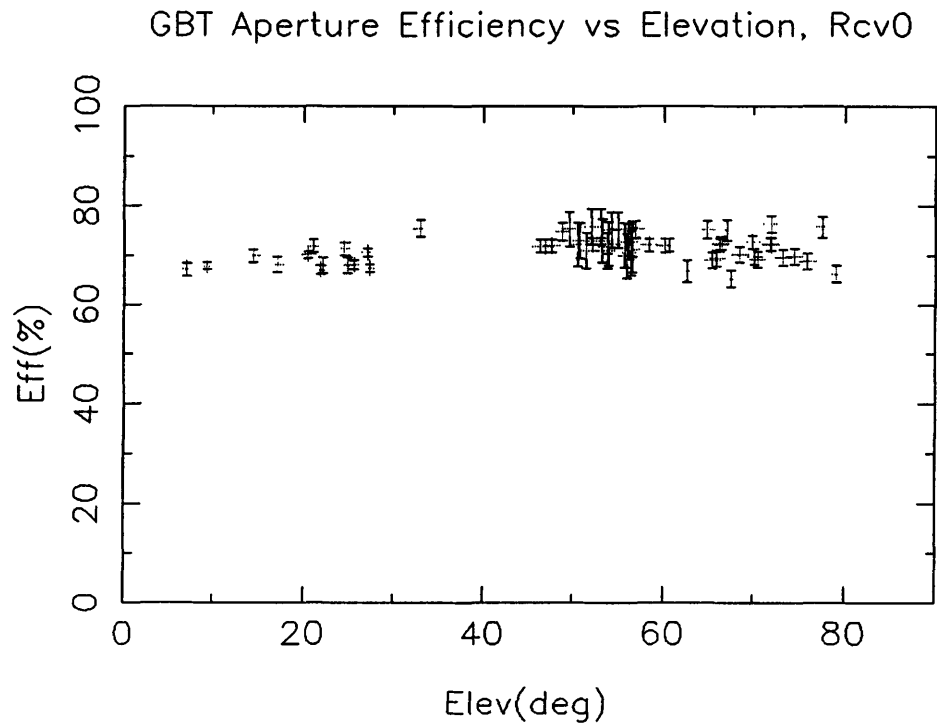


Fig. 2B: Efficiency for Y-pol (Rcv1)

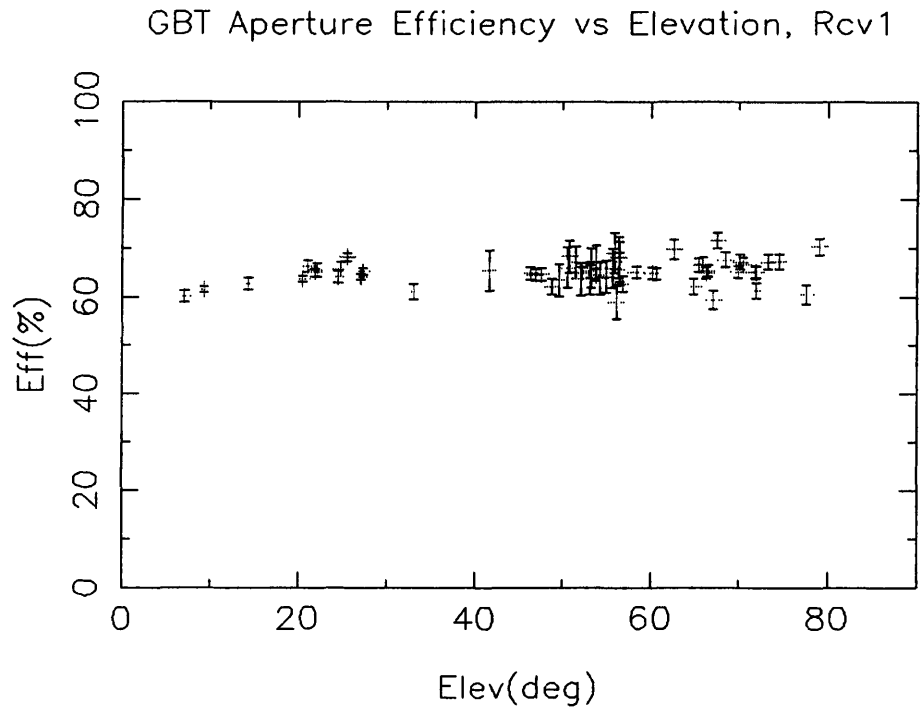


Figure 3A. T_{sys} for X-pol

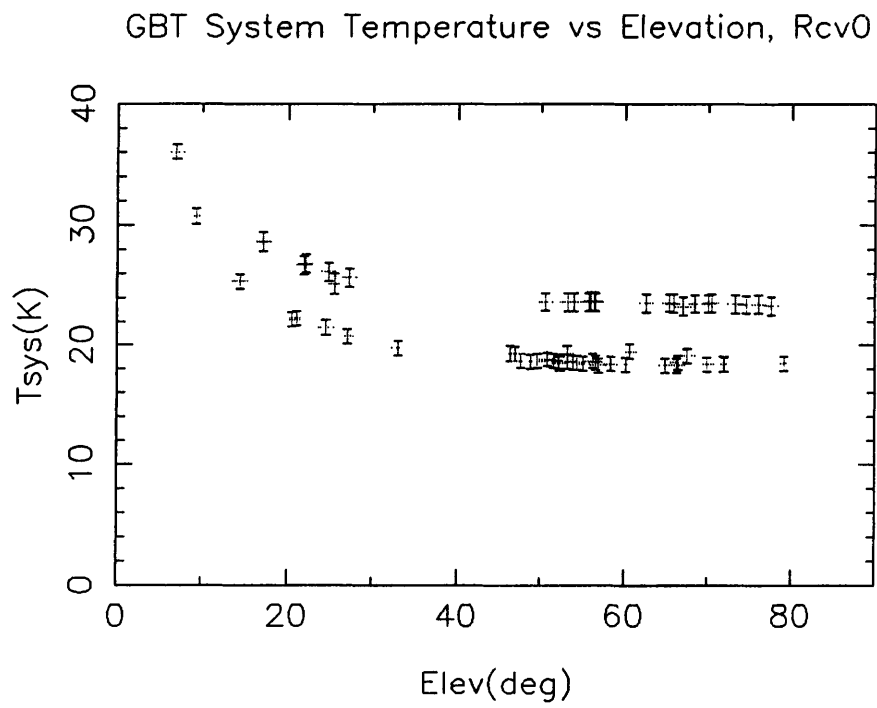


Figure 3B. T_{sys} for Y-pol

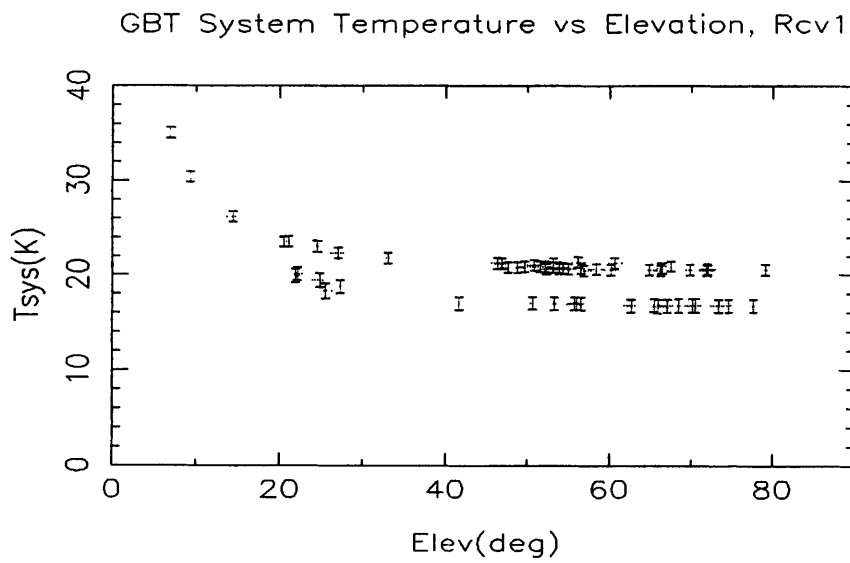


Figure 4A. SEFD for X-pol

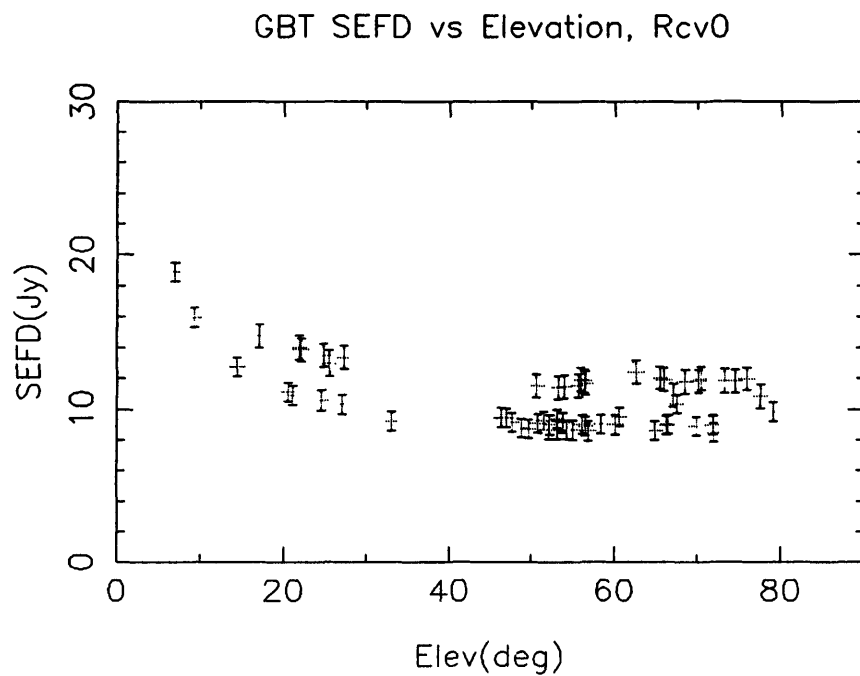
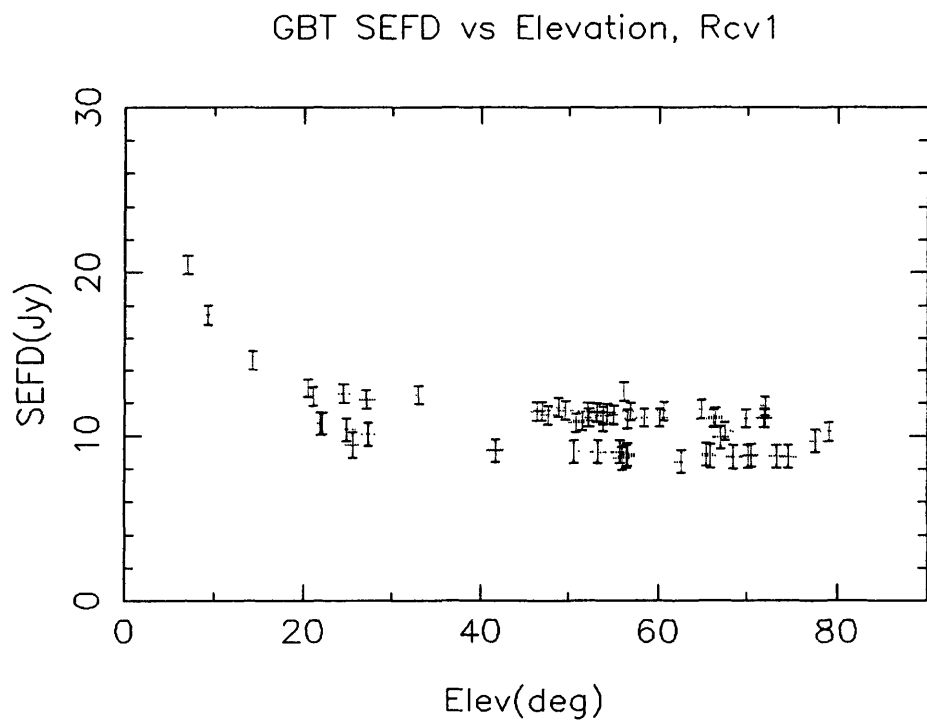


Figure 4B. SEFD for Y-pol



Elevation Dependent Effects

In Figure 5, we plot gain versus elevation for the X-polarization, including only data from the first day of observing (because data on the second day were inconsistent, as noted earlier). The downturn at low elevations can be fit with an atmospheric attenuation model of the form:

$$G = G_0 e^{-\tau A}$$

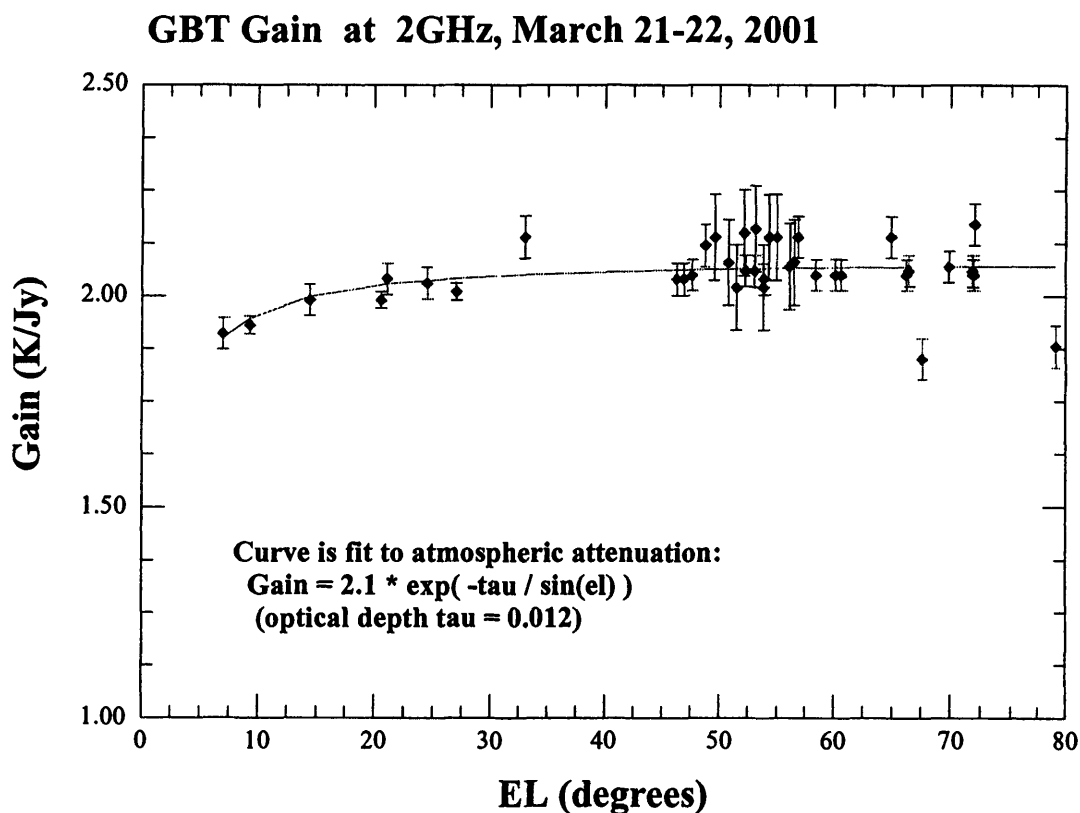
where τ is the optical depth, and A is the airmass, assumed to be $A = 1/\sin(\text{elev})$. Fitting for G_0 and τ , as illustrated in Figure 5, yields

$$\tau = 0.012 \text{ (0.003)} \quad \text{and} \quad G_0 = 2.10 \text{ (0.02) K}$$

(The standard deviations are in parentheses.)

This value of τ is reasonable for this frequency, by comparison with the value $\tau=0.011$ found at 1.42 GHz by van Zee et al (AJ 113, 1638, 1997).

Figure 5.



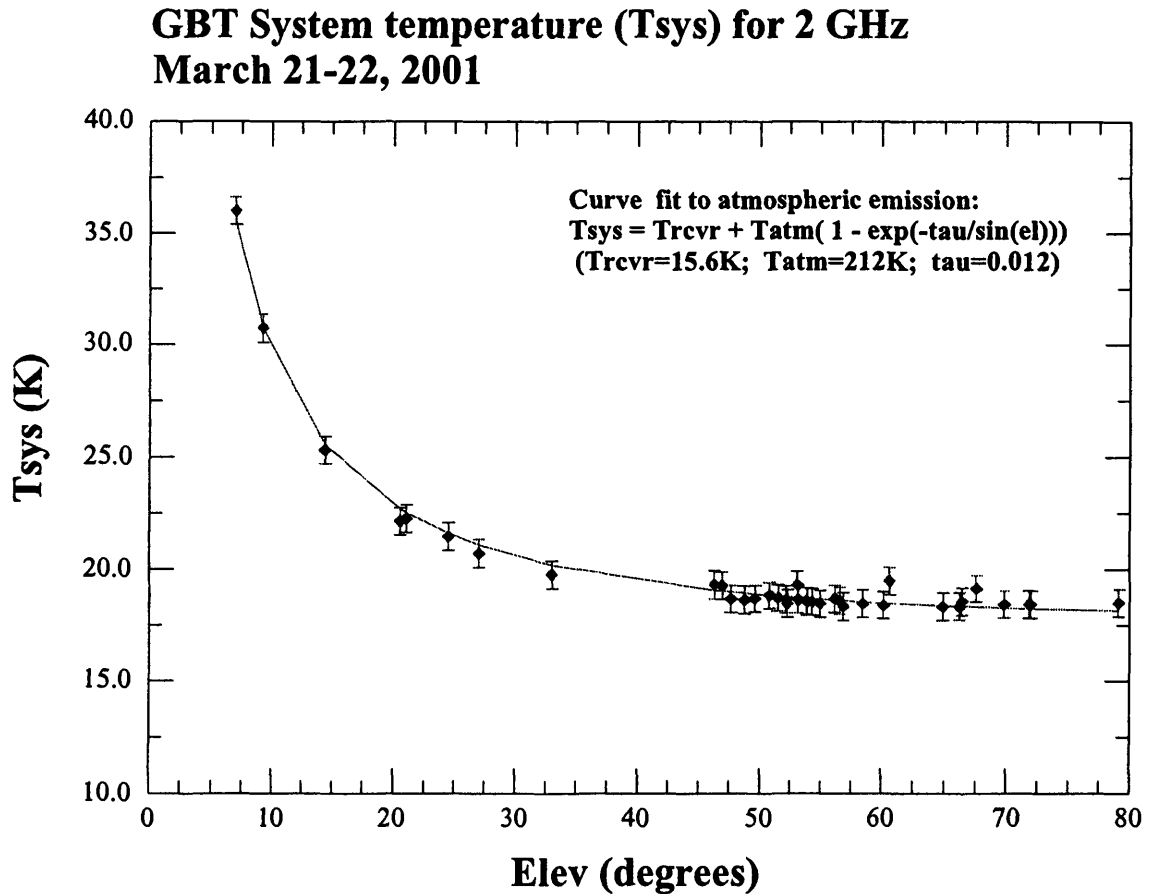
System temperatures (T_{sys}) are shown in Figure 6, plotted against elevation. Again, these data are from only the first night of observing (March 21-22). A model of atmospheric emission is shown as the solid line. The model is of the form:

$$T_{sys} = T_{rcvr} + T_{atm} (1 - e^{-\tau A})$$

Using $t = 0.012$, as found from the fit to the gain data, we can fit for T_{rcvr} and T_{atm} with the results: $T_{rcvr} = 15.6 (0.1)$ and $T_{atm} = 212 (3)$ K.

Although an atmospheric temperature $T_{atm} = 212$ K may seem unreasonably low, we should note that this fit cannot determine t and T_{atm} independently. A value of t as low as 0.009 is still consistent with the gain data, in which case T_{atm} would be 283 K.

Figure 6.



Conclusions

Despite some unresolved instabilities, it seems that we can conclude that the aperture efficiency is about 70 %, the Gain is about 2 K/Jy, and G/T_{sys} is about 0.1. Elevation-dependent effects are explainable by atmospheric attenuation and emission.