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Tipping Considerations at the VLA

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Introduction

At the higher frequencies of operation at the VLA, there are considerable elevation effects. One such effect is the variation of total opacity as a function of elevation. Observers at the VLA have the capability to measure this variation, through the use of "tipping" scans. When a tipping scan is executed, the on–line system uses the values of the system temperature ($T_{\rm sys}$) to calculate the zenith opacity (τ_o) and the contribution to $T_{\rm sys}$ by all sources other than the atmosphere (T_o), for each antenna and IF individually. This document describes improvements to this technique, as well as its extension to find values of the noise tube temperatures (the $T_{\rm cal}$ values). First, the operational aspects of tipping scans will be discussed, then the current method of deriving τ_o and T_o will be described briefly. Then, the improvements will be described in some detail.

Tipping Scans

A tipping scan is specified in an OBSERVE file by setting the MODE (in columns 59–60) to "TE" on the source card. For TE source cards, the right ascension position fields are actually interpreted as azimuth, e.g. a specification of: 12 30 30.0000 in columns 24–36 of the source card would be interpreted as an azimuth of 187.625 degrees (nearly due south). The following detailed description comes from a memo from Ken Sowinski (dated April 28, 1995), with annotations of changes which occurred around June 1, 1996:

> The standard tipping scan is now defined to be a single pass between 55 (1.22 air masses) degrees and 19.5 (3.0 air masses) degrees elevation, in either the ascending or descending direction. Frontend synchronous detector voltages are measured at a total of seven points distributed uniformly in secant z. A record is made of these measurements as well as the noise tube temperatures that are recorded in the IF file for the band being observed. When the measurements have been completed, the extinction coefficient and "in vacuo" system temperature is solved for, for each IF for each antenna. A tabulation is made of these results as well as an RMS for each of the fits. Reports are suppressed for antennas which appear not to be working. Ignoring antenna slew time, about eight minutes is now required to perform a standard (with

the default //OF parameters) tipping scan.

It is possible for the observer to use a //OF card to modify the number of points sampled and whether the scan in elevation only has a single pass, or both a descending and ascending pass. If the elevation scan is requested to go both directions, the number of points requested are split evenly between the descending and ascending pass and interleaved in secant z. I define here the necessary contents of the //OF card.

cc1–4 //OF

c8–10 ONE (the default) if only a single pass is desired;
TWO if both a descending and ascending pass are desired.

cc12–14 TIP

cc41–45 The total number of samples desired. This must not be greater than 17 or less than four.

As described previously, the azimuth at which the tipping scan is performed is specified on the observe card in the RA field. There is no provision for the observer to modify the initial or final elevation. If a serious case can be made for such flexibility, it can be added. The direction of the initial pass is determined by the elevation, specified on the observe card in the DEC field. If the elevation is closer to the lower limit in elevation (19.5 deg.), then the tipping scan begins at that lower limit and the initial pass is ascending. If the elevation is closer to the upper limit in elevation (55 deg.), then the tipping scan begins at that upper limit and the initial pass is descending.

Additional samples (beyond the default seven) require about 40–50 seconds of additional time per sample for completion of the tipping scan.

The files containing the tipping scan results will be transfered to a Unix box in the AOC on an irregular basis. Until a formal mechanism is in place to access these files, requests for tipping scan results should go to Bill Sahr (bsahr) or to me [Ken Sowinski].

Any questions or suggestions for modifications to the tipping scan program should be addressed to me.

Finding T_o, τ_o (and $T_{\rm cal}$)

The Current Way

The current method of calculating τ_o and T_o is based upon a technique described in Spangler (1982). In a nutshell, $T_{\rm sys}$ is assumed to be of the form:

$$T_{\rm sys} = T_o + T_{\rm atm}\,(1 - e^{-\tau_o\,x}) \quad , \tag{1}$$

where $T_{\rm atm}$ is the effective atmospheric temperature, and x is the airmass ($x = \sec z$ for zenith angle z, as long as z is not too large). An expansion of the exponential term is then used to simplify equation (1) to:

$$T_{\rm sys} = T_o + T_{\rm atm}\,(\tau_o\,x - \frac{1}{2}\,\tau_o^2\,x^2) \quad . \tag{2}$$

Then, for antenna a, given several values of the system temperature measured at airmasses x_i, $T_{{\rm sys}_{a,i}}$, this equation can be solved in a least–squares sense to find estimates of τ_{o_a} and T_{o_a}. Again, currently, this is done for each antenna and IF independently.

A General Solution

It is clear that the assumption that $1 - e^{\tau_o\,x} = \tau_o\,x - \frac{1}{2}\,\tau_o^2\,x^2$ breaks down for large values of the quantity: $\tau_o\,x$. Terms as large as $(\tau_o\,x)^3/6$ are being thrown out. The current default tipping scans go down to an elevation of 12.8, or an airmass of 4.5. In this case, given an opacity of 0.1, the full expression gives a value of ~ 0.3624, while the clipped expansion gives a value of ~ 0.3488. Given a value of $T_{\rm atm} = 260$ K, this gives an error of ~ 3.5 K. This is probably tolerable. However, increase the opacity to 0.2 (which is easily possible at 49 GHz), and you increase the error term to ~ 25.5 K! This is certainly not acceptable.

Given *any* number of "antennas" (from here on, I treat each IF of each antenna as a separate "antenna"), N_a, and assuming that τ_o is constant across these antennas, the value of τ_o, and all of the values of the T_{o_a} may be found by minimizing the χ^2 quantity:

$$\chi^2 = \sum_{a=1}^{N_a}\,\sum_{i=1}^{N_i}\,[T_{{\rm sys}_{a,i}} - T_{o_a} - T_{\rm atm}\,(1 - e^{-\tau_o\,x_i})]^2 \quad , \tag{3}$$

where $T_{\mathrm{sys}_{a,i}}$ is the measured system temperature of antenna a at airmass x_i, T_{o_a} is the contribution to the system temperature from all non–atmospheric sources for antenna a, T_{atm} is the effective atmospheric temperature, and N_i is the number of samples in airmass. In the following, all sums over i will be assumed to go from 1 to N_i, and all sums over a will be assumed to go from 1 to N_a, unless explicitly shown otherwise. To minimize, take the derivative of χ^2 with respect to each of the unknowns (the N_a values of T_{o_a}, and τ_o) and set it equal to 0:

$$\left\{\frac{\partial\,\chi^2}{\partial\,T_{o_a}}\right\}_{a=1,N_a} = 0 \quad , \tag{4}$$

and

$$\frac{\partial\,\chi^2}{\partial\,\tau_o} = 0 \quad . \tag{5}$$

From equation (4) (using $E_i = 1 - e^{-\tau_o\,x_i}$):

$$\frac{\partial\,\chi^2}{\partial\,T_{o_a}} = -2\sum_i^{N_i}\left(T_{\mathrm{sys}_{a,i}} - T_{o_a} - T_{\mathrm{atm}}\,E_i\right) = 0 \quad , \tag{6}$$

which implies:

$$T_{o_a} = \frac{1}{N_i}\left[\left(\sum_i T_{\mathrm{sys}_{a,i}}\right) - T_{\mathrm{atm}}\left(\sum_i E_i\right)\right] \quad . \tag{7}$$

From equation (5):

$$\frac{\partial\,\chi^2}{\partial\,\tau_o} = -2\,T_{\mathrm{atm}}\sum_a\sum_i x_i\,e^{-\tau_o\,x_i}\left(T_{\mathrm{sys}_{a,i}} - T_{o_a} - T_{\mathrm{atm}}\,E_i\right) = 0 \quad , \tag{8}$$

which implies (using $X_i = x_i\,e^{-\tau_o\,x_i}$):

$$\sum_a T_{o_a} = \frac{\left(\sum_a\sum_i X_i\,T_{\mathrm{sys}_{a,i}}\right) - T_{\mathrm{atm}}\,N_a\left(\sum_i X_i\,E_i\right)}{\sum_i X_i} = G(\tau_o) \quad . \tag{9}$$

But, from equation (7), we know that:

$$\sum_a T_{o_a} = \frac{1}{N_i}\sum_a\left[\left(\sum_i T_{\mathrm{sys}_{a,i}}\right) - T_{\mathrm{atm}}\left(\sum_i E_i\right)\right] \quad , \tag{10}$$

or, rearranging,

$$\sum_a T_{o_a} = \frac{\left(\sum_a\sum_i T_{\mathrm{sys}_{a,i}}\right) - T_{\mathrm{atm}}\,N_a\left(\sum_i E_i\right)}{N_i} = H(\tau_o) \quad . \tag{11}$$

So, the minimization of χ^2 has been reduced to solving the equation $G(\tau_o) - H(\tau_o) = 0$ to find the value of τ_o. This can be done quite easily with any of a number of root finding methods. In practice, a simple secant method works well, converging to a solution in only a few iterations. Note that it is simple to enforce positivity on the value of τ_o. This can be achieved by introducing the change of variable $\tau_o = \tau^2$. Now, $\partial\chi^2/\partial\tau = (\partial\chi^2/\partial\tau_o)\cdot(\partial\tau_o/\partial\tau)$, and since $\partial\tau_o/\partial\tau = 2\tau$, the above equations for $G(\tau_o)$ and $H(\tau_o)$ are not changed, except for the replacement of τ_o by τ^2. Once the value of τ has been found (and hence τ_o, which is just τ^2), the values of the T_{o_a} are found via equation (7).

This method can still be used to do a separate solution for τ_o for each antenna (simply set $N_a = 1$ and do the solution). However, except for rare instances (when operation at these high frequencies is probably hosed anyway), it seems sensible that the opacity seen at all of the antennas will be the same. In this case, the global solution is the preferred one.

An Even More General Solution

In the most general case, it is not necessary to assume that the system has provided accurate values of the system temperature. The system temperature of a VLA antenna is given by:

$$T_{\rm sys} = 15\,T_{\rm cal}\frac{V_{TP} - V_{TP_o}}{V_{\rm sd} - V_{sd_o}} \quad , \tag{12}$$

where $T_{\rm cal}$ is the noise diode temperature (also called the noise tube temperature), $V_{\rm sd}$ is the measured sync detector voltage, V_{TP} is the measured total power voltage, V_{sd_o} and V_{TP_o} are the DC offsets of the two voltage detectors, and the factor of 15 is a DC gain factor applied in the electronics. The sync detector voltage measures the difference between the voltage levels when the noise diode is on and when it is off. The total power voltage measures the voltage level when the noise source is off. This voltage level (V_{TP}) is constrained by the ALC to be near 3.0 V. So, the true measurement, or data value, is the value of $V_{\rm sd}$. In the most general case, you could take the data from an appropriate tipping scan, and derive *all* of the unknowns from them. However, there are several assumptions which make the solution of the problem much simpler, while not introducing particularly large errors. These assumptions are: $V_{TP} = 3.0$; $V_{TP_o} = V_{sd_o} = 0.0$, i.e., that the ALC's are functioning correctly (keeping V_{TP} near 3.0 V), and that the two DC offsets are near 0.0 V. With these assumptions, equation (12) reduces to:

$$T_{\rm sys} = 45\,\frac{T_{\rm cal}}{V_{\rm sd}} \quad , \tag{13}$$

or, for antenna a at airmass x_i,

$$T_{\mathrm{sys}_{a,i}} = 45\,\frac{T_{\mathrm{cal}_a}}{V_{\mathrm{sd}_{a,i}}} \quad . \tag{14}$$

Now, substitute equation (14) into equation (3):

$$\chi^2 = \sum_{a=1}^{N_a} \sum_{i=1}^{N_i} \left[\frac{45}{V_{\mathrm{sd}_{a,i}}} - \frac{T_{o_a}}{T_{\mathrm{cal}_a}} - \frac{T_{\mathrm{atm}}}{T_{\mathrm{cal}_a}} \left(1 - e^{-\tau_o\, x_i}\right) \right]^2 \quad . \tag{15}$$

I have not been able to come up with an exact method of minimizing this χ^2 equation similar to what I did in the above section. However, if we assume that the value of τ_o is known, then we proceed in a similar manner, by taking the derivatives and setting them equal to 0:

$$\left\{ \frac{\partial\,\chi^2}{\partial\,T_{o_a}} \right\}_{a=1,N_a} = 0 \quad , \tag{16}$$

and,

$$\left\{ \frac{\partial\,\chi^2}{\partial\,T_{\mathrm{cal}_a}} \right\}_{a=1,N_a} = 0 \quad . \tag{17}$$

Note that the problem can now be solved for each antenna independently.

So, for antenna a, we have (using $P_{a,i} = 45/V_{\mathrm{sd}_{a,i}}$, and, again, $E_i = 1 - e^{-\tau_o\, x_i}$):

$$\frac{\partial\,\chi^2}{\partial\,T_{o_a}} = -2 \sum_i \left(P_{a,i} - \frac{T_{o_a}}{T_{\mathrm{cal}_a}} - \frac{T_{\mathrm{atm}}}{T_{\mathrm{cal}_a}}\, E_i \right) = 0 \quad , \tag{18}$$

and,

$$\frac{\partial\,\chi^2}{\partial\,T_{\mathrm{cal}_a}} = 2 \sum_i \left(P_{a,i} - \frac{T_{o_a}}{T_{\mathrm{cal}_a}} - \frac{T_{\mathrm{atm}}}{T_{\mathrm{cal}_a}}\, E_i \right) \left(\frac{T_{o_a} + T_{\mathrm{atm}}\, E_i}{T_{\mathrm{cal}_a}^2} \right) = 0 \quad . \tag{19}$$

Now, using the following definitions:

$$A_a = \sum_i P_{a,i} \quad , \quad B = \sum_i E_i \quad , \quad C = \sum_i E_i^2 \quad , \quad D_a = \sum_i E_i\, P_{a,i} \quad ,$$

equation (18) becomes:

$$T_{o_a} = \frac{T_{\mathrm{cal}_a}\, A_a - T_{\mathrm{atm}}\, B}{N_i} \quad . \tag{20}$$

But, from equation (19):

$$T_{\mathrm{cal}_a} = \frac{N_i\, T_{o_a}^2 + 2\, T_{o_a}\, T_{\mathrm{atm}}\, B + T_{\mathrm{atm}}^2\, C}{T_{\mathrm{atm}}\, D_a + T_{o_a}\, A_a} \quad . \tag{21}$$

So, substituting this into (20) yields:

$$T_{o_a} = \frac{T_{\rm atm}(C\,A_a - B\,D_a)}{N_i\,D_a - B\,A_a} \quad . \tag{22}$$

Once T_{o_a} is known, $T_{{\rm cal}_a}$ can be calculated from equation (21).

So, the most general solution of the problem that I have formulated here involves an iterative minimization of equation (15), where the steps are as follows:

do until converged

find τ_o via the procedure outlined in the preceding section, given the current estimates of the $T_{{\rm sys}_{a,i}}$

using that τ_o, calculate values of T_{o_a} and $T_{{\rm cal}_a}$ for all antennas via the procedure outlined in this section, and use the new $T_{{\rm cal}_a}$ to get new estimates of the $T_{{\rm sys}_{a,i}}$

check for convergence

od

The convergence criterion I am currently using is a combination of a test of the absolute value of χ^2, the value of the change of χ^2 from iteration to iteration, and the value of the parameter residual (how much the parameters are changing from iteration to iteration).

Implementation

Both of these more general solutions have been implemented in off–line programs which reside on my computer at the AOC. These programs will read in the output from a tipping scan, and calculate the appropriate quantities. The output must be obtained from Bill Sahr, who can download it from its location on the computers at the site.

Along with the solution for T_{o_a}, τ_o, (and $T_{{\rm cal}_a}$, if that program is run), the off–line programs perform several checks to try to find “bad” antennas. A “bad” antenna may be due to several causes, including: broken electronics, shadowing (which the on–line system currently doesn’t check for in it’s solution, and there are no plans to implement this, since it would be a great pain), and bad $T_{\rm cal}$ values, among others. Electronics problems can usually be found by checking the absolute values of $T_{\rm sys}$ (or, equivalently, the sync detector voltage values), to make sure that they are sensible. Shadowing is now accounted for in the off–line fitting program, using the supplied pad positions, and pointing directions (azimuth and elevations) available in the output from the tipping scan. Bad $T_{\rm cal}$ values are also accounted for in the most general fit (the correct values are just solved for). More specifically, the current version of the off–line fitting programs make the following checks:

- all of the values of $V_{\rm sd}$ are examined, and if any of the $V_{{\rm sd}_{a,i}}$ are $< V_{min}$ (where V_{min} is some appropriately low value), then antenna/IF a is marked as "bad"
- all of the antennas are checked for shadowing, and if any antenna is shadowed by $> f_{max}$ (where f_{max} is the maximum allowed shadowing fraction) by any other antenna, then all of the IF's for that antenna are marked as "bad"
- an initial fit is done for each of the individual antennas/IF's separately, and if that fit gives an unreasonable value for either T_o or τ, that antenna/IF is marked as "bad"
- during the global fit, if at any point in the iterative solution, an antenna/IF is fit with an unreasonable value of T_o, then that antenna/IF is marked as "bad"

Currently, the off–line programs use the following values for the checks: $V_{min} = 0.1$, $f_{max} = 0.0$, and the following definitions for "reasonable" values: $10.0 < T_{o_a} < 400.0$, $\tau_o > 0.002$.

Assumptions/Problems/Caveats

Any spillover effects have been ignored in this treatment (the assumption is that the spillover variations can be absorbed into the values of T_o and τ_o). This will certainly cause problems for low elevation (large airmass) measurements.

Both the current method and the proposed revision use the expression for the effective atmospheric temperature:

$$T_{\rm atm} = 256.9 + 0.445\, T_{\rm surf} \quad , \tag{23}$$

where $T_{\rm surf}$ is the surface temperature in Celsius (see the Appendix of Ulvestad *et al.* 1987). This needs some work, as it is unclear if this relation is appropriate for the VLA site, and it probably varies as a function of frequency. Ulvestad *et al.* (1987) claim that errors in their estimate of $T_{\rm atm}$ should have small effect on derived system parameters, but it is not clear that this is true in all cases. Examine, for instance, the values of the T_{o_a} in the most general solution, which go linearly with $T_{\rm atm}$. Again, further work is probably warranted.

Not all "bad" antennas will be found by the checks listed above. Pathological cases will certainly arise. It is incredibly hard to make a general, robust method for finding *all* such cases, and I have not attempted to do so.

If there are enough antennas with particularly bad values for $T_{\rm cal}$, the global solutions above will of course fail. This is because the assumption is that in the first step of the iterative solution, a value will be found for τ_o which is close to the correct one. It doesn't have to be exact, but needs to be close. Then the perturbations in the following iterations will converge to the correct values for all of the parameters. If enough of the $T_{\rm cal}$ values are grossly out of whack, then the initial solution for τ_o will be incorrect, and the following iterations will converge to incorrect values for all of the parameters.

How Far Down Should You TIP?

In order to minimize unmodelled effects on $T_{\rm sys}$ at low elevations (like spillover), it would be nice to have some idea of how low you can run a tipping scan before these effects begin to kick in. I have investigated this by running the off–line fitting program on *all* of the tipping scan data from May 1995 to May 1996, allowing the maximum airmass to vary during the fits. Figure 1 shows the result of this exercise, for all of the bands from L to Q (the data marked as 22 GHz (*) are from several K–band tipping scans done in a test on May 16, 1996). What is plotted is the "mean normalized χ^2_ν" versus the maximum airmass used in the fit. I'll now explain what I mean by "mean normalized χ^2_ν". The reduced chi square is given by:

$$\chi^2_\nu = \frac{\chi^2}{\nu} \quad , \tag{24}$$

where χ^2 is given in equation (15) above, and ν is the number of degrees of freedom in the fit. The number of degrees of freedom is: $\nu = N - n$, where N is the total number of data points ($N = N_a\, N_i$), and n is the number of fit parameters ($n = 2\, N_a + 1$), so, $\nu = N_a\,(N_i - 2) - 1$. For each individual tipping scan, I accumulated the values of $\chi^2_{\nu_r}$ for a number of runs with different maximum airmasses, x_{max_r}. Then, in order to account for differences from scan to scan (e.g., for tipping scans on different days), I normalized the values for a particular run via:

$$\overline{\chi^2_{\nu_r}} = \frac{\chi^2_{\nu_r}}{\chi^2_{\nu_{max}}} \quad , \tag{25}$$

where

$$\chi^2_{\nu_{max}} = \max\left\{\chi^2_{\nu_r}\right\}_{r=1,N_{run}} \quad . \tag{26}$$

I call the value from equation (25) the "normalized χ^2_ν". Then, given the values of the normalized χ^2_ν for all of the scans, from all of the different days/times, I just calculated the mean of those values for each of the different maximum airmass values. I call this value the "mean normalized χ^2_ν". The values of the maximum airmass which I chose were: $x_{max_r} = 10.0, 4.0, 3.5, 3.0, 2.5, 2.0$. Ignoring the L–band result (where there are obvious extreme unmodelled $T_{\rm sys}$ effects [Bagri 1993; Lilie 1994]), all of the frequencies display the same overall behavior. The fits are worst using all of the data ($x_{max} = 10.0$), and get better to some point, but then begin to get worse again as the data is constrained to lower airmasses. The best fits generally occur using only data with airmasses less than 2.5–3.0.

What are the Best Azimuths to TIP at?

Of course, the azimuth to take data for the tipping scan may be determined by the particular location your source is at, but given that observers may just want to get an azimuth which has no shadowing, regardless of source location, those azimuths should be provided. Since I have the capability to check shadowing at any azimuth and elevation, it is a simple thing to use the standard configurations, and check for azimuths which have no shadowing at a given elevation. In the A and B configurations, there is no possibility of any shadowing anyway (Crane 1981), so I obviously didn't check those. In the C configuration, going all the way down to an elevation of 8 degrees (the limit for normal observing), there are several azimuths which have no shadowed antennas: 37–44, 127–133, 218–219, 222–224, and 307–313. In the D configuration, it is much more difficult to find good azimuths. At an airmass of 2.5 (elevation of $\sim$ 23.5 deg.), the following azimuths have no shadowing: 27–30, 141–143, 207–210, and 321–323. Going down to an airmass of 3.0 (elevation of $\sim$ 19.5 deg), there is no azimuth at which all of the antennas have no shadowing. The best azimuth at that airmass is 143 deg., where the maximum blockage of one antenna by another is 0.016 (1.6%). The maximum airmass with an azimuth with no shadowed antennas is 2.75 (elevation $\sim$ 21.25 deg.); that azimuth being 29 deg. Figure 2 shows a plot of the number of shadowed antennas at each azimuth in the D configuration. The results are plotted for 4 elevations: 23.5 deg (dotted line); 19.5 deg (dot–dashed line); 12.8 deg (dashed line); and 8.0 deg (solid line).

Examples

Appendix A shows an example of the output from a typical K–band tipping scan, with the old solutions attached. Appendix B shows the result of running the exact solution independently for each antenna/IF for that same set of data. Appendix C shows the result of doing the global solution for τ_o. Appendix D shows the result of doing the global solution for τ_o, and then iteratively fitting for the values of the T_{cal_a} and τ_o (using only data with airmass < 3). It is clear that the difference, while not gross, is appreciable, even for this low opacity.

Appendices E–H show a similar set of solutions for a Q–band run, near 49 GHz. Here, the effect of dropping the cubic and higher terms in the expansion of the exponential is clear. Figure 3 shows a plot of the data and the fits for antenna 6, IF A. Five fit types are shown: the old, Spangler method with all of the data (fit type 1); the old, Spangler method using only data with airmass < 3.0 (fit type 2); the true exponential method for that single antenna/IF with all of the data (fit type 3); the scaled result of the full general fit for that antenna alone, using only data with airmass < 3.0 (fit type 4); and the scaled result of the full general fit (using all antennas), using only data with airmass < 3.0 (fit type 5). The last two fit types must be scaled because of the different derived T_{cal} values, which adjusts the whole T_{sys} scale. It is easily seen that the old technique does a poor job of fitting the data, even when the data is restricted to airmasses < 3.0. The true exponential fit does a better job of matching the data, both for individual and global solutions, but the derived opacity (near 0.35), when all data points are included and the T_{cal} value is assumed right is much higher than it should be theoretically (near 0.2). A much better fit (which matches the data and also gives close to the theoretical value for the opacity) is obtained when the value of T_{cal} is allowed to vary, and slight improvement is obtained when only those data points with airmass < 3.0 are used.

Conclusions

I have derived a more rigorous solution to the problem of finding the atmospheric opacity and values of T_o for all of the antennas/IF's. I have also extended that solution to find the correct values of the noise tube temperatures (the $T_{\rm cal}$'s). This technique could be used to monitor changes in the values of the $T_{\rm cal}$'s, and reflect these changes in the on–line system files. If it proves to be successful, this technique of monitoring the $T_{\rm cal}$ values is much simpler than the current Lunar transfer method (Lilie 1992; Bagri and Lilie 1993), though it would probably be wise to continue to do the Lunar transfer measurements at some interval, as an absolute test/check. Note that this may not work for L–band, since the variation of $T_{\rm sys}$ with elevation there is not due to opacity (at least at low elevations), but rather some other effect (Bagri 1993; Lilie 1994), and the assumption of constant "opacity" on all antennas breaks down.

All of this has been implemented into programs which will read in the results from a tipping scan, and recalculate the appropriate quantities, i.e., this is all done off–line at the moment. In principle, it could be put into the on–line system software, but the decision to do so has not been made at this point.

References

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Crane, P. C., Geometrical Shadowing in the C and D Arrays, VLA Scientific Memorandum No. 134, 1981

Lilie, P., Moon and T_{cal}, T_{sys}, VLA Test Memorandum No. 165, 1992

Lilie, P., VLA L–Band T_{sys} vs. Elevation, report dated May 16, 1994

Spangler, S. R., Correction of VLA K–band Amplitudes for Atmospheric Attenuation, VLA Scientific Memorandum No. 143, 1982

Ulvestad, J. S., G. M. Resch, and W. D. Brundage, X–Band System Performance of the Very Large Array, JPL TDA Progress Report 42–92, 123–137, 1987

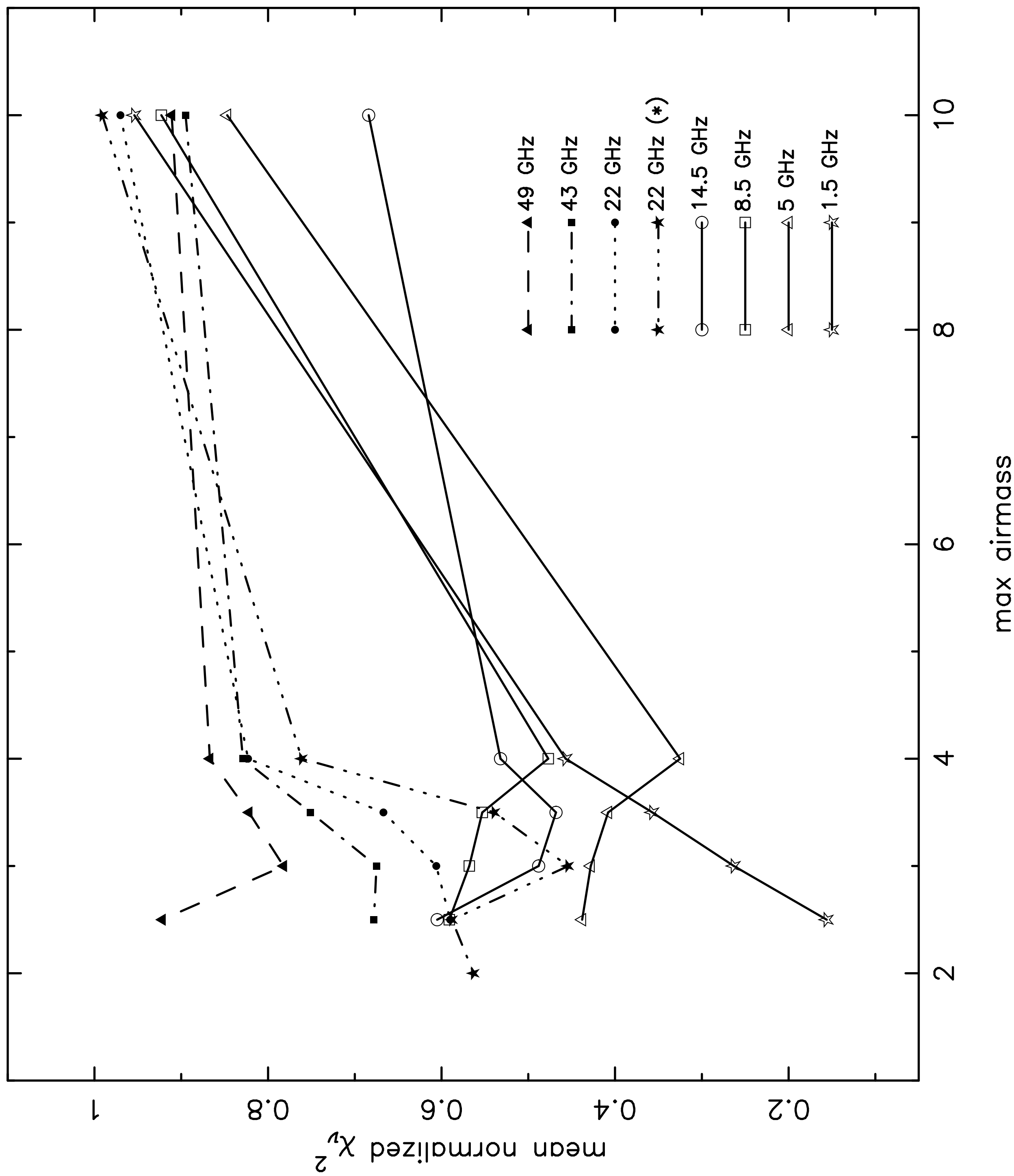

Figure 1: A measure of the quality of the fit for various maximum airmasses, from 1.5–49 GHz.

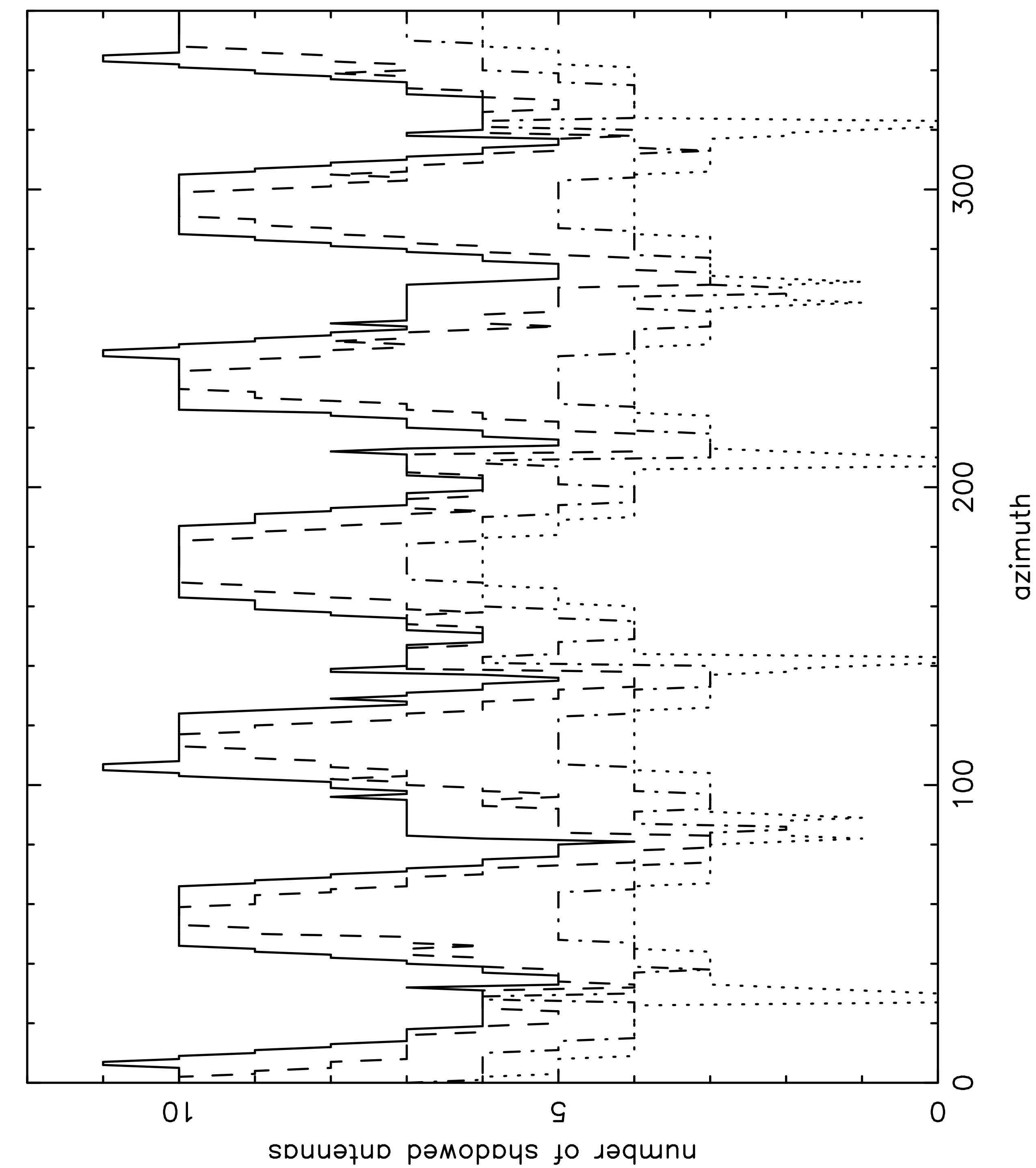

Figure 2: Plot of shadowed azimuths in D configuration, for 4 elevations: 23.5 deg (dotted line); 19.5 deg (dot–dashed line); 12.8 deg (dashed line); and 8.0 deg (solid line).

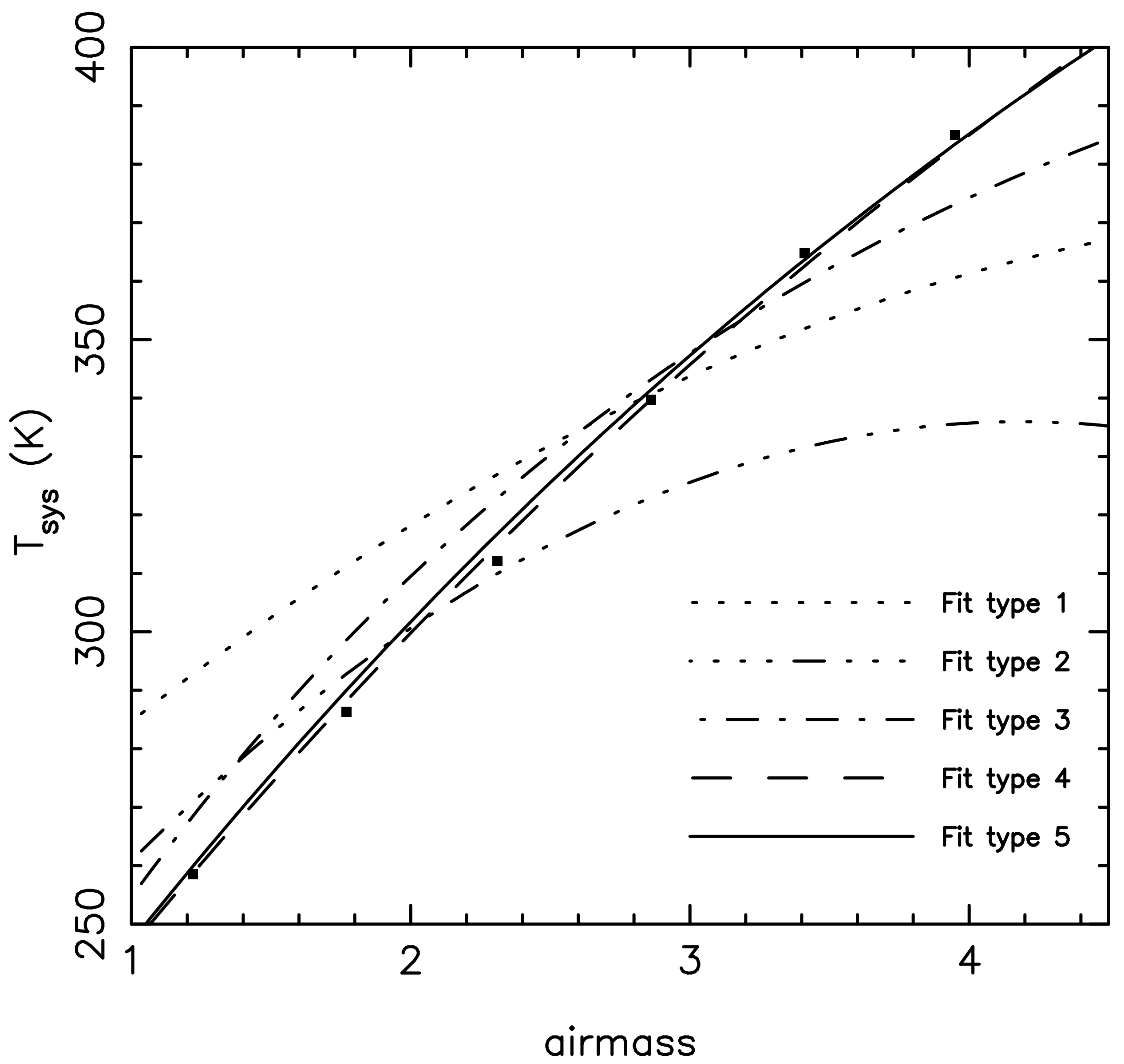

Figure 3: A 49 GHz tipping scan fit example, antenna 6, IF A (see text for explanation of fit types).

Appendix A

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TIPPER: VER 3.0  START TIME: 16 MAY 96 20:58:39  OBSERVER ID: TEST    BAND: KK
 START OF TIPPING RUN FOR SUBARRAY  1
 SIGNED SUM OF THE LOs, IFs A-D: 22.460 22.410 22.460 22.410 AZIMUTH: 157.5
 NOISE TUBE TEMPERATURES
  18    16.3    16.3    17.8    17.8
  13    10.5    10.5    16.0    16.0
   8    12.4    12.4    11.8    11.8
   3    13.9    13.9    12.7    12.7
  12    18.2    18.2    19.0    19.0
   2    13.0    13.0    12.9    12.9
  28    16.0    16.0    21.6    21.6
   5    14.1    14.1    10.2    10.2
  10    11.8    11.8    11.1    11.1
  17    15.4    15.4    14.0    14.0
   7     7.0     7.3    10.0    10.3
  16    18.2    18.2    16.9    16.9
   4     8.6     8.6     8.3     8.3
  22    15.4    15.4    17.5    17.5
  19    11.2    11.2    13.5    13.5
   6    10.7    10.7     9.7     9.7
  21    12.9    13.9    12.6    14.1
  26    16.1    16.1    12.5    12.5
  24    11.5    11.5     8.9     8.9
  23    15.1    15.1    18.0    18.0
  27     9.6     9.6    11.8    11.8
  15    14.1    15.3    12.5    13.0
  25    16.9    16.9    15.0    15.0
  14    14.0    14.0    14.7    14.7
   1    24.8    24.8    24.7    24.7
  20    11.8    11.7    11.8    12.3
   9    11.0    11.0    11.7    11.7
 DATA ACQUISITION COMPLETE
 TEMP:   28.6  DEW POINT:   14.0  START TIME:  20.99  STOP TIME:  21.11


 CAL VALUES AS A FUNCTION OF ELEVATION
  ELEVATION (DEGREES)      55.1  34.5  25.6  20.5  17.1  14.7  12.8
  AIRMASS                  1.22  1.77  2.31  2.86  3.41  3.95  4.50

 ANTENNA 18 AT DW1  IF A:  5.26  4.88  4.40  4.02  3.71  3.49  3.32
                       B:  4.48  4.14  3.74  3.40  3.13  2.94  2.80
                       C:  3.78  3.61  3.38  3.16  2.97  2.83  2.72
                       D:  3.52  3.34  3.09  2.89  2.72  2.59  2.49

 ANTENNA 13 AT DW4  IF A:  4.73  4.37  4.08  3.85  3.62  3.43  3.26
                       B:  4.46  4.14  3.86  3.64  3.44  3.25  3.10
                       C:  4.94  4.60  4.30  4.07  3.84  3.64  3.47
                       D:  4.78  4.45  4.16  3.94  3.71  3.51  3.36

 ANTENNA  8 AT DW8  IF A:  4.54  4.16  3.90  3.66  3.47  3.27  3.09
                       B:  4.65  4.26  4.00  3.75  3.56  3.34  3.17
```

	C:	4.54	4.14	3.87	3.61	3.40	3.20	3.02
	D:	4.36	3.97	3.72	3.47	3.28	3.06	2.90
ANTENNA 3 AT DW2	IF A:	4.01	3.76	3.52	3.33	3.14	2.98	2.84
	B:	3.74	3.50	3.28	3.10	2.92	2.77	2.64
	C:	3.68	3.44	3.22	3.04	2.89	2.73	2.61
	D:	3.58	3.36	3.13	2.96	2.80	2.65	2.54
ANTENNA 12 AT DW6	IF A:	7.36	6.71	6.25	5.85	5.50	5.18	4.89
	B:	6.52	5.94	5.53	5.17	4.86	4.58	4.32
	C:	6.57	6.08	5.72	5.40	5.11	4.84	4.61
	D:	5.61	5.19	4.87	4.60	4.35	4.12	3.92
ANTENNA 2 AT DW7	IF A:	4.02	3.70	3.47	3.27	3.10	2.93	2.78
	B:	4.06	3.73	3.50	3.30	3.13	2.94	2.80
	C:	3.40	3.15	2.97	2.80	2.65	2.51	2.39
	D:	3.19	2.95	2.78	2.62	2.49	2.35	2.24
ANTENNA 28 AT DW5	IF A:	2.59	2.59	2.59	2.59	2.59	2.59	2.59
	B:	2.94	2.94	2.94	2.94	2.94	2.94	2.94
	C:	2.52	2.52	2.52	2.52	2.52	2.52	2.52
	D:	2.52	2.52	2.52	2.52	2.52	2.52	2.52
ANTENNA 5 AT DW9	IF A:	4.16	3.82	3.58	3.37	3.20	3.01	2.85
	B:	4.41	4.06	3.81	3.57	3.40	3.19	3.04
	C:	2.99	2.72	2.55	2.35	2.29	2.15	2.04
	D:	3.20	2.88	2.68	2.48	2.41	2.25	2.13
ANTENNA 10 AT DW3	IF A:	4.08	3.78	3.52	3.30	3.10	2.92	2.78
	B:	3.86	3.56	3.31	3.11	2.91	2.75	2.60
	C:	3.73	3.48	3.24	3.05	2.87	2.72	2.60
	D:	3.49	3.26	3.04	2.87	2.71	2.56	2.44
ANTENNA 17 AT DE3	IF A:	4.66	4.36	4.08	3.87	3.64	3.47	3.27
	B:	4.77	4.48	4.20	3.98	3.76	3.59	3.42
	C:	3.13	2.98	2.83	2.72	2.60	2.49	2.41
	D:	3.16	3.00	2.86	2.75	2.61	2.51	2.42
ANTENNA 7 AT DE2	IF A:	2.32	2.17	2.03	1.93	1.82	1.73	1.66
	B:	2.44	2.30	2.15	2.04	1.93	1.83	1.75
	C:	3.34	3.13	2.93	2.77	2.61	2.47	2.37
	D:	3.44	3.22	3.02	2.86	2.69	2.55	2.44
ANTENNA 16 AT DE4	IF A:	5.21	4.92	4.63	4.39	4.15	3.95	3.80
	B:	5.07	4.79	4.51	4.27	4.05	3.85	3.70
	C:	4.91	4.61	4.33	4.11	3.88	3.69	3.55
	D:	4.39	4.13	3.90	3.70	3.50	3.33	3.21
ANTENNA 4 AT DE8	IF A:	2.20	2.08	1.97	1.88	1.79	1.71	1.66
	B:	2.29	2.17	2.06	1.96	1.87	1.78	1.73
	C:	2.21	2.10	1.99	1.89	1.80	1.71	1.66
	D:	2.19	2.07	1.96	1.88	1.79	1.71	1.66
ANTENNA 22 AT DE7	IF A:	5.86	5.47	5.11	4.80	4.51	4.26	4.08

	B:	5.53	5.17	4.82	4.53	4.25	4.02	3.85
	C:	6.14	5.70	5.30	4.97	4.65	4.38	4.19
	D:	5.55	5.16	4.80	4.51	4.23	3.98	3.81
ANTENNA 19 AT DE6 IF	A:	3.25	3.07	2.90	2.76	2.61	2.49	2.39
	B:	3.27	3.09	2.93	2.78	2.64	2.51	2.41
	C:	4.17	3.92	3.68	3.49	3.30	3.13	3.02
	D:	4.15	3.90	3.67	3.46	3.27	3.09	2.99
ANTENNA 6 AT DE1 IF	A:	3.11	2.92	2.76	2.62	2.48	2.36	2.26
	B:	3.16	2.96	2.80	2.65	2.51	2.38	2.29
	C:	2.85	2.66	2.51	2.37	2.24	2.12	2.04
	D:	2.45	2.29	2.15	2.04	1.92	1.83	1.76
ANTENNA 21 AT DE9 IF	A:	4.75	4.41	4.10	3.84	3.61	3.39	3.25
	B:	4.60	4.28	3.99	3.74	3.52	3.31	3.18
	C:	4.81	4.48	4.19	3.94	3.72	3.51	3.37
	D:	4.87	4.53	4.23	3.98	3.75	3.53	3.39
ANTENNA 26 AT DE5 IF	A:	4.09	3.86	3.64	3.47	3.30	3.14	3.04
	B:	3.82	3.61	3.41	3.24	3.07	2.93	2.83
	C:	3.23	3.05	2.88	2.74	2.61	2.49	2.41
	D:	3.32	3.14	2.97	2.82	2.68	2.55	2.47
ANTENNA 23 AT CN6 IF	A:	4.49	4.23	3.95	3.73	3.55	3.34	3.22
	B:	4.17	3.93	3.68	3.48	3.31	3.12	3.00
	C:	4.40	4.17	3.93	3.72	3.55	3.37	3.24
	D:	4.08	3.86	3.63	3.45	3.29	3.12	3.00
ANTENNA 27 AT CN4 IF	A:	2.22	2.10	1.99	1.89	1.81	1.72	1.66
	B:	2.06	1.94	1.83	1.74	1.66	1.57	1.53
	C:	2.98	2.81	2.63	2.49	2.37	2.24	2.16
	D:	2.84	2.68	2.52	2.38	2.25	2.14	2.06
ANTENNA 15 AT CN8 IF	A:	5.25	4.92	4.55	4.25	4.02	3.77	3.59
	B:	5.31	4.98	4.60	4.30	4.06	3.80	3.62
	C:	4.23	4.00	3.71	3.47	3.30	3.11	2.96
	D:	3.98	3.76	3.50	3.27	3.12	2.93	2.80
ANTENNA 25 AT CN2 IF	A:	5.17	4.82	4.51	4.27	4.03	3.82	3.67
	B:	5.11	4.78	4.48	4.25	4.00	3.80	3.65
	C:	5.43	5.03	4.67	4.41	4.14	3.90	3.72
	D:	5.37	4.98	4.63	4.36	4.10	3.86	3.68
ANTENNA 14 AT CN3 IF	A:	3.71	3.51	3.34	3.20	3.04	2.91	2.81
	B:	3.70	3.51	3.33	3.17	3.03	2.88	2.78
	C:	4.13	3.89	3.66	3.48	3.31	3.14	3.04
	D:	4.22	3.97	3.74	3.55	3.37	3.20	3.09
ANTENNA 1 AT CN9 IF	A:	5.96	5.95	5.94	5.95	5.95	5.94	5.95
	B:	5.66	5.64	5.65	5.65	5.65	5.65	5.65
	C:	8.28	8.28	8.26	8.27	8.27	8.27	8.27
	D:	8.37	8.38	8.37	8.37	8.37	8.37	8.36

ANTENNA 20 AT CN5	IF	A:	4.94	4.59	4.26	3.99	3.75	3.51	3.36
		B:	4.71	4.38	4.06	3.79	3.56	3.34	3.20
		C:	3.04	2.87	2.73	2.62	2.50	2.39	2.32
		D:	2.95	2.81	2.69	2.58	2.46	2.36	2.29
ANTENNA 9 AT CN7	IF	A:	4.71	4.77	4.79	4.78	4.80	4.80	4.81
		B:	4.91	4.97	4.98	4.98	4.99	5.00	5.00
		C:	5.02	5.05	5.09	5.09	5.08	5.08	5.06
		D:	5.06	5.09	5.12	5.13	5.12	5.12	5.10

***** SUMMARY OF ANTENNAS *****

		*** A IF ***			*** B IF ***			*** C IF ***			*** D IF ***		
ANT	STA	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS
18	DW1	92.6	0.153	3.98	121.0	0.166	8.98	165.0	0.152	4.82	183.0	0.164	7.61
13	DW4	80.3	0.062	0.38	85.2	0.065	0.40	115.4	0.094	1.02	118.4	0.100	1.20
8	DW8	96.5	0.083	0.97	94.6	0.080	0.94	89.2	0.086	1.00	92.6	0.091	1.18
3	DW2	22.8	0.102	1.43	130.2	0.115	1.78	123.5	0.099	1.19	126.0	0.105	1.21
12	DW6	85.7	0.081	0.73	94.8	0.098	1.06	105.0	0.080	0.71	120.2	0.103	1.22
2	DW7	114.6	0.100	1.15	113.1	0.100	1.28	133.2	0.119	1.89	141.2	0.133	2.63
5	DW9	117.7	0.112	1.80	112.1	0.101	1.35	118.1	0.117	2.07	108.4	0.116	1.82
10	DW3	100.0	0.093	1.15	104.0	0.105	1.44	105.5	0.088	0.76	112.4	0.095	1.28
17	DE3	117.6	0.096	1.58	117.5	0.085	1.01	170.9	0.092	0.92	168.7	0.093	1.09
7	DE2	110.2	0.080	0.84	108.2	0.078	1.06	107.9	0.084	0.89	107.8	0.081	0.87
16	DE4	127.8	0.090	0.98	131.4	0.092	0.99	125.6	0.091	0.88	140.4	0.101	1.24
4	DE8	147.8	0.088	0.81	142.3	0.082	0.88	140.1	0.087	1.07	144.6	0.081	0.73
22	DE7	93.8	0.075	0.74	98.7	0.081	0.87	98.0	0.093	1.10	107.9	0.105	1.40
19	DE6	127.3	0.083	0.91	127.1	0.080	0.99	118.1	0.084	0.82	117.7	0.087	1.05
6	DE1	126.5	0.087	0.93	123.9	0.088	0.98	122.8	0.094	1.06	140.9	0.118	1.61
21	DE9	94.6	0.085	0.83	104.8	0.096	1.08	94.2	0.073	0.61	102.7	0.086	0.83
26	DE5	146.5	0.097	0.94	154.4	0.110	1.43	144.9	0.093	0.88	140.6	0.090	1.00
23	CN6	120.8	0.094	1.20	130.0	0.102	1.42	149.1	0.107	1.66	159.4	0.122	2.01
27	CN4	160.2	0.106	1.32	168.8	0.129	2.07	141.2	0.112	1.52	146.7	0.122	1.87
15	CN8	93.2	0.083	1.11	98.5	0.094	1.42	104.2	0.086	1.22	114.6	0.098	1.53
25	CN2	117.5	0.093	0.87	119.2	0.092	0.92	97.0	0.085	0.80	97.7	0.087	0.88
14	CN3	143.5	0.080	0.83	142.0	0.084	0.92	132.4	0.088	0.81	129.1	0.087	0.79
20	CN5	83.4	0.073	0.76	86.1	0.078	0.85	149.5	0.080	0.63	161.3	0.080	0.96

	A IF	**C IF**
MEAN EXT COEFF:	0.091	0.095
SIGMA:	0.018	0.017

END OF TIPPING RUN STARTED FOR SUBARRAY 1
START TIME: 16 MAY 96 20:58:39 END TIME: 16 MAY 96 21:07:03

Appendix B

***** SUMMARY OF ANTENNAS *****

		*** A IF ***			*** B IF ***			*** C IF ***			*** D IF ***		
ANT	STA	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS
18	DW1	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00
13	DW4	80.8	0.060	0.28	85.9	0.063	0.28	117.1	0.090	0.67	120.5	0.094	0.78
8	DW8	97.8	0.080	0.79	95.6	0.078	0.79	90.8	0.083	0.70	94.1	0.087	1.02
3	DW2	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00
12	DW6	86.7	0.078	0.57	96.6	0.092	0.73	105.8	0.077	0.53	122.0	0.096	0.77
2	DW7	116.1	0.094	0.82	114.6	0.094	0.98	136.1	0.110	1.11	144.2	0.121	1.33
28	DW5	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00
5	DW9	120.1	0.104	1.22	114.1	0.095	0.93	121.7	0.106	1.77	112.0	0.106	1.80
10	DW3	101.5	0.089	0.73	105.9	0.099	0.96	106.7	0.084	0.53	114.0	0.090	0.82
17	DE3	119.1	0.091	1.26	118.8	0.082	0.60	173.0	0.088	0.75	170.7	0.089	0.96
7	DE2	111.4	0.076	0.49	110.1	0.075	0.69	109.0	0.079	0.69	109.1	0.079	0.73
16	DE4	129.3	0.085	0.80	132.8	0.088	0.82	127.0	0.087	0.67	142.4	0.096	0.88
4	DE8	149.3	0.083	0.64	143.4	0.079	0.78	142.1	0.082	0.98	145.9	0.078	0.64
22	DE7	94.5	0.073	0.60	99.6	0.079	0.69	99.8	0.088	0.79	110.3	0.098	0.96
19	DE6	129.0	0.080	0.77	128.4	0.078	0.85	119.8	0.080	0.68	119.2	0.083	0.93
6	DE1	127.8	0.083	0.76	125.4	0.084	0.75	124.5	0.089	0.80	143.9	0.108	0.83
21	DE9	95.8	0.082	0.69	106.8	0.090	0.82	95.2	0.070	0.47	103.8	0.082	0.68
26	DE5	148.1	0.091	0.74	156.9	0.102	0.93	146.4	0.087	0.56	141.6	0.086	0.81
23	CN6	122.6	0.088	0.97	132.0	0.095	1.07	151.5	0.100	1.08	162.6	0.111	1.25
27	CN4	162.8	0.099	0.92	172.9	0.117	1.31	144.6	0.104	1.04	150.8	0.112	1.19
15	CN8	94.3	0.080	0.89	100.0	0.089	1.13	105.4	0.083	1.06	116.4	0.092	1.26
25	CN2	119.2	0.088	0.54	120.9	0.087	0.68	98.1	0.082	0.64	99.0	0.083	0.65
14	CN3	145.0	0.077	0.68	143.8	0.081	0.82	133.4	0.084	0.69	130.0	0.083	0.63
1	CN9	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00
20	CN5	84.3	0.071	0.67	87.2	0.075	0.67	150.5	0.077	0.61	162.5	0.077	0.82
9	CN7	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00

Appendix C

the one, true, opacity = 0.0872

***** SUMMARY OF ANTENNAS *****

		*** A IF ***		*** B IF ***		*** C IF ***		*** D IF ***	
ANT	STA	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS
18	DW1	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
13	DW4	64.3	5.16	71.1	4.61	118.5	0.81	124.6	1.44
8	DW8	93.6	1.50	89.9	1.89	88.3	1.03	94.3	1.02
3	DW2	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
12	DW6	81.3	1.73	99.6	1.16	99.8	1.90	127.3	1.75
2	DW7	120.0	1.42	118.7	1.55	148.8	3.87	162.7	5.45
28	DW5	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
5	DW9	129.5	3.02	118.4	1.59	132.4	3.60	122.8	3.64
10	DW3	102.4	0.79	112.6	2.21	105.1	0.72	115.6	0.95
17	DE3	121.3	1.43	115.6	1.14	173.4	0.76	171.7	1.01
7	DE2	105.0	2.03	102.7	2.37	104.2	1.62	104.1	1.71
16	DE4	128.3	0.86	133.2	0.83	126.8	0.67	147.3	1.68
4	DE8	147.2	0.91	138.7	1.63	139.1	1.34	140.4	1.81
22	DE7	85.9	2.69	94.6	1.68	100.1	0.79	116.3	2.04
19	DE6	124.6	1.53	123.1	1.83	115.7	1.43	117.0	1.14
6	DE1	125.7	1.00	123.4	0.98	125.8	0.88	155.7	3.55
21	DE9	92.5	1.21	108.6	0.97	85.2	3.12	100.9	1.11
26	DE5	150.2	0.97	165.2	2.61	146.3	0.56	140.9	0.84
23	CN6	123.2	0.99	136.5	1.74	158.7	2.40	176.1	4.11
27	CN4	169.5	2.18	189.3	4.88	154.2	3.01	164.5	4.15
15	CN8	90.3	1.51	101.3	1.19	102.7	1.34	119.3	1.53
25	CN2	119.6	0.56	120.8	0.68	94.9	1.18	96.5	1.02
14	CN3	139.0	1.96	140.2	1.38	131.4	0.93	127.7	0.94
1	CN9	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
20	CN5	74.6	3.06	80.2	2.25	144.4	1.97	156.7	1.97
9	CN7	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00

Appendix D

the one, true, opacity = 0.0824

***** SUMMARY OF ANTENNAS *****

		*** A IF ***		*** B IF ***		*** C IF ***		*** D IF ***	
ANT	STA	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS
13	DW4	108.9	0.22	110.3	0.19	117.5	0.24	117.9	0.26
8	DW8	103.8	0.37	104.3	0.41	95.3	0.36	96.2	0.47
3	DW2	123.7	0.33	122.6	0.24	119.7	0.24	119.1	0.52
12	DW6	94.5	0.31	93.1	0.29	117.4	0.27	115.0	0.24
2	DW7	109.5	0.33	109.2	0.42	119.3	0.28	117.2	0.31
5	DW9	106.7	0.37	106.4	0.28	89.6	0.68	82.1	0.48
10	DW3	104.2	0.18	101.6	0.13	111.1	0.36	115.4	0.34
17	DE3	123.8	0.31	128.0	0.33	176.2	0.42	180.0	0.29
7	DE2	125.1	0.39	128.8	0.55	122.7	0.32	125.2	0.21
16	DE4	137.6	0.43	137.3	0.48	131.3	0.26	139.0	0.16
4	DE8	154.3	0.19	156.8	0.30	155.1	0.54	159.5	0.41
22	DE7	113.0	0.35	112.6	0.43	104.3	0.28	106.8	0.29
19	DE6	146.6	0.26	149.0	0.32	130.9	0.32	128.2	0.41
6	DE1	139.0	0.03	135.0	0.15	127.0	0.15	126.8	0.20
21	DE9	103.5	0.31	107.6	0.33	113.3	0.22	111.4	0.18
26	DE5	145.1	0.30	145.3	0.32	145.4	0.26	147.2	0.35
23	CN6	123.2	0.60	127.7	0.53	141.2	0.62	140.8	0.49
27	CN4	150.2	0.32	140.8	0.20	128.6	0.54	132.4	0.53
15	CN8	103.0	0.81	103.0	0.84	112.0	1.09	113.9	1.05
25	CN2	119.5	0.22	125.4	0.26	106.3	0.34	106.3	0.24
14	CN3	167.2	0.19	157.7	0.34	137.7	0.30	136.6	0.22
20	CN5	102.6	0.37	100.0	0.51	166.2	0.38	189.3	0.07

	OLD				*NEW*			
ANT	Tcal A	Tcal B	Tcal C	Tcal D	Tcal A	Tcal B	Tcal C	Tcal D
13	10.5	10.5	16.0	16.0	14.1	13.5	15.7	15.3
8	12.4	12.4	11.8	11.8	13.0	13.4	12.2	11.8
3	13.9	13.9	12.7	12.7	13.4	12.3	11.9	11.6
12	18.2	18.2	19.0	19.0	19.6	17.2	20.9	17.5
2	13.0	13.0	12.9	12.9	12.1	12.1	10.9	10.1
5	14.1	14.1	10.2	10.2	12.2	12.9	7.7	7.6
10	11.8	11.8	11.1	11.1	11.8	10.9	11.4	11.0
17	15.4	15.4	14.0	14.0	15.5	16.3	14.1	14.4
7	7.0	7.3	10.0	10.3	7.8	8.4	11.0	11.6
16	18.2	18.2	16.9	16.9	19.0	18.4	17.2	16.1
4	8.6	8.6	8.3	8.3	8.8	9.3	8.9	9.0
22	15.4	15.4	17.5	17.5	18.1	17.1	17.8	16.4
19	11.2	11.2	13.5	13.5	12.5	12.7	14.5	14.2
6	10.7	10.7	9.7	9.7	11.4	11.3	9.7	8.3
21	12.9	13.9	12.6	14.1	13.7	13.7	14.9	14.9
26	16.1	16.1	12.5	12.5	15.5	14.6	12.3	12.8
23	15.1	15.1	18.0	18.0	14.9	14.3	16.4	15.1
27	9.6	9.6	11.8	11.8	8.7	7.6	10.3	10.0
15	14.1	15.3	12.5	13.0	15.1	15.3	13.1	12.5
25	16.9	16.9	15.0	15.0	16.7	17.2	15.9	15.8
14	14.0	14.0	14.7	14.7	15.9	15.1	15.0	15.2
20	11.8	11.7	11.8	12.3	14.1	13.2	12.9	14.1

Appendix E

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TIPPER: VER 3.0  START TIME: 19 DEC 95 18:32:34  OBSERVER ID: BBTST   BAND: QQ
 START OF TIPPING RUN FOR SUBARRAY  1
 SIGNED SUM OF THE LOs, IFs A-D: 49.240 49.310 49.240 49.310 AZIMUTH: -90.0
 NOISE TUBE TEMPERATURES
  13     7.7     7.7     5.9     5.9
   8     5.5     5.5     9.2     9.2
   3     8.9     8.9     8.8     8.8
  12     8.1     8.1     8.5     8.5
  16    13.5    13.5    12.2    12.2
   4     7.0     7.0     9.2     9.2
  22     6.1     6.1     5.7     5.7
   6     7.7     7.7     7.9     7.9
  11     6.0     6.0     6.0     6.0
  27     7.1     7.1     5.1     5.1
  25     9.5     9.5     8.2     8.2
  14     7.2     7.2     6.9     6.9
  20     6.0     6.0     6.0     6.0
 DATA ACQUISITION COMPLETE
 TEMP:    5.4  DEW POINT:   -5.2  START TIME:  18.55  STOP TIME:  18.67


 CAL VALUES AS A FUNCTION OF ELEVATION
  ELEVATION (DEGREES)      55.1  34.5  25.6  20.5  17.1  14.7  12.8
  AIRMASS                  1.22  1.77  2.31  2.86  3.41  3.95  4.50

 ANTENNA 13 AT BW1  IF A:  1.88  1.67  1.51  1.39  1.29  1.21  1.16
                       B:  1.77  1.58  1.42  1.30  1.22  1.15  1.08
                       C:  0.88  0.82  0.78  0.73  0.70  0.67  0.64
                       D:  0.86  0.80  0.75  0.71  0.68  0.65  0.62

 ANTENNA  8 AT BW2  IF A:  1.40  1.24  1.12  1.03  0.96  0.91  0.87
                       B:  1.42  1.26  1.14  1.05  0.98  0.94  0.89
                       C:  2.72  2.42  2.20  2.03  1.89  1.79  1.71
                       D:  2.61  2.33  2.13  1.96  1.85  1.74  1.67

 ANTENNA  3 AT BW3  IF A:  3.29  2.99  2.75  2.56  2.41  2.29  2.20
                       B:  2.83  2.58  2.37  2.21  2.08  1.98  1.89
                       C:  2.43  2.22  2.06  1.93  1.82  1.74  1.67
                       D:  2.14  1.96  1.83  1.70  1.61  1.54  1.48

 ANTENNA 12 AT BW4  IF A:  1.17  1.08  1.01  0.95  0.90  0.86  0.83
                       B:  1.08  1.01  0.94  0.88  0.84  0.80  0.77
                       C:  1.46  1.31  1.20  1.10  1.04  0.98  0.93
                       D:  1.42  1.27  1.16  1.08  1.01  0.96  0.91

 ANTENNA 16 AT BE1  IF A:  2.73  2.42  2.18  2.01  1.87  1.77  1.68
                       B:  2.40  2.14  1.94  1.79  1.67  1.56  1.50
                       C:  1.34  1.21  1.10  1.02  0.97  0.92  0.87
                       D:  1.05  0.95  0.87  0.81  0.77  0.73  0.69

 ANTENNA  4 AT BE2  IF A:  1.29  1.27  1.24  1.21  1.18  1.15  1.13
```

	B:	1.14	1.13	1.09	1.07	1.05	1.03	1.01
	C:	2.94	2.64	2.39	2.21	2.06	1.94	1.85
	D:	2.70	2.43	2.21	2.03	1.90	1.80	1.71
ANTENNA 22 AT BE4	IF A:	0.83	0.76	0.69	0.64	0.61	0.58	0.54
	B:	0.82	0.75	0.69	0.64	0.61	0.58	0.54
	C:	0.85	0.78	0.72	0.66	0.62	0.59	0.56
	D:	0.74	0.67	0.62	0.58	0.55	0.52	0.50
ANTENNA 6 AT BE3	IF A:	1.34	1.21	1.11	1.02	0.95	0.90	0.86
	B:	1.30	1.17	1.07	0.98	0.92	0.88	0.84
	C:	1.46	1.33	1.22	1.15	1.08	1.04	0.99
	D:	1.24	1.12	1.04	0.97	0.92	0.88	0.83
ANTENNA 11 AT BN3	IF A:	1.94	1.74	1.56	1.44	1.34	1.26	1.20
	B:	1.73	1.56	1.41	1.30	1.21	1.13	1.08
	C:	1.07	0.99	0.93	0.87	0.82	0.79	0.76
	D:	1.03	0.96	0.89	0.84	0.79	0.75	0.73
ANTENNA 27 AT BN2	IF A:	1.69	1.50	1.37	1.26	1.17	1.11	1.05
	B:	1.44	1.27	1.16	1.06	0.99	0.93	0.89
	C:	0.74	0.69	0.64	0.61	0.58	0.55	0.53
	D:	0.68	0.63	0.59	0.56	0.53	0.50	0.48
ANTENNA 25 AT BN1	IF A:	1.51	1.34	1.21	1.11	1.03	0.98	0.92
	B:	1.48	1.31	1.18	1.08	1.01	0.95	0.90
	C:	1.09	0.96	0.88	0.81	0.75	0.72	0.68
	D:	1.18	1.06	0.97	0.89	0.83	0.79	0.75
ANTENNA 14 AT BN4	IF A:	1.40	1.29	1.19	1.11	1.06	1.00	0.96
	B:	1.20	1.10	1.02	0.95	0.91	0.86	0.82
	C:	1.05	0.98	0.91	0.85	0.81	0.77	0.74
	D:	1.00	0.93	0.86	0.82	0.77	0.74	0.70
ANTENNA 20 AT BN5	IF A:	1.55	1.41	1.31	1.22	1.15	1.09	1.04
	B:	1.50	1.36	1.26	1.16	1.11	1.05	1.00
	C:	1.29	1.21	1.14	1.08	1.03	0.98	0.95
	D:	0.82	0.83	0.82	0.83	0.83	0.82	0.82

***** SUMMARY OF ANTENNAS *****

		*** A IF ***			*** B IF ***			*** C IF ***			*** D IF ***		
ANT	STA	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS
13	BW1	154.6	0.173	13.82	169.8	0.173	16.67	268.6	0.170	12.87	278.7	0.172	14.79
8	BW2	143.4	0.173	11.05	139.3	0.172	9.77	110.5	0.169	5.30	116.8	0.169	5.33
3	BW3	91.8	0.101	0.38	102.9	0.131	0.55	120.2	0.147	1.03	140.9	0.164	3.22
12	BW4	288.4	0.173	18.55	316.8	0.174	20.65	249.1	0.174	24.44	258.0	0.175	24.73
16	BE1	205.2	0.175	21.53	243.0	0.175	26.66	433.9	0.176	47.61	572.1	0.175	64.83
4	BE2	228.8	0.047	0.91	258.4	0.051	1.00	96.9	0.162	3.61	111.0	0.167	5.19
22	BE4	329.0	0.175	33.11	330.5	0.173	30.80	290.1	0.174	27.47	345.4	0.175	31.88
6	BE3	243.3	0.175	24.05	253.7	0.175	24.87	214.3	0.173	13.97	269.0	0.175	20.69
11	BN3	96.1	0.165	4.52	115.6	0.167	7.25	216.5	0.170	10.42	228.8	0.170	12.13
27	BN2	158.4	0.172	12.99	204.3	0.174	21.47	282.2	0.173	15.73	318.3	0.171	22.57

25	BN1	286.5	0.175	34.93	295.5	0.176	36.98	356.1	0.176	41.85	316.1	0.175	34.85
14	BN4	196.3	0.172	10.73	243.9	0.172	16.01	268.9	0.174	16.86	286.1	0.172	18.45

	A IF	**C IF**
MEAN EXT COEFF:	0.156	0.170
SIGMA:	0.040	0.008

END OF TIPPING RUN STARTED FOR SUBARRAY 1
START TIME: 19 DEC 95 18:32:34 END TIME: 19 DEC 95 18:40:40

Appendix F

***** SUMMARY OF ANTENNAS *****

		*** A IF ***			*** B IF ***			*** C IF ***			*** D IF ***		
ANT	STA	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS	TSYS0	GAMMA	RMS
13	BW1	104.9	0.293	2.73	111.1	0.326	4.83	229.4	0.259	3.67	230.4	0.290	3.99
8	BW2	106.0	0.257	0.86	110.7	0.229	0.92	103.1	0.172	0.44	110.3	0.170	0.69
3	BW3	94.6	0.093	0.88	108.0	0.115	0.53	127.1	0.124	0.63	142.1	0.148	0.73
12	BW4	225.6	0.341	5.73	252.0	0.351	8.82	180.8	0.365	11.86	189.0	0.368	11.91
16	BE1	137.7	0.363	8.52	173.8	0.369	13.44	362.8	0.384	34.55	0.0	0.000	0.00
4	BE2	227.6	0.049	0.99	259.6	0.050	1.26	97.2	0.150	0.41	104.7	0.168	0.54
22	BE4	259.4	0.371	20.32	261.7	0.367	18.93	222.8	0.364	15.25	273.7	0.376	17.17
6	BE3	175.9	0.362	11.23	183.9	0.372	11.11	164.9	0.292	2.23	203.0	0.357	8.57
11	BN3	92.8	0.159	0.62	101.1	0.188	1.35	187.7	0.227	1.78	188.3	0.262	3.02
27	BN2	111.9	0.284	2.70	137.1	0.360	8.26	227.0	0.316	5.12	254.8	0.344	10.24
25	BN1	216.1	0.377	22.06	224.8	0.379	23.81	284.4	0.383	29.15	245.1	0.377	22.00
14	BN4	164.0	0.238	2.05	186.2	0.322	5.01	210.5	0.325	5.59	226.2	0.333	7.58
20	BN5	129.4	0.154	0.51	131.9	0.168	1.09	171.1	0.128	0.79	0.0	0.000	0.00

Appendix G

the one, true, opacity = 0.322

***** SUMMARY OF ANTENNAS *****

		*** A IF ***		*** B IF ***		*** C IF ***		*** D IF ***	
ANT	STA	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS	TSYS0	RMS
13	BW1	96.8	2.94	112.2	4.84	210.5	4.58	221.3	4.20
8	BW2	86.5	2.62	81.6	3.99	51.6	8.17	57.9	8.38
3	BW3	0.0	18.82	29.6	14.72	53.5	13.43	80.1	10.59
12	BW4	230.7	5.80	259.6	8.95	191.9	12.14	200.8	12.23
16	BE1	148.3	8.79	185.9	13.78	378.3	35.08	0.0	0.00
4	BE2	111.4	26.37	144.3	26.02	35.7	10.50	51.2	8.69
22	BE4	272.0	20.66	273.2	19.22	233.7	15.51	287.4	17.59
6	BE3	186.2	11.47	196.7	11.49	156.4	2.48	212.1	8.76
11	BN3	35.6	9.51	56.3	7.11	158.0	4.56	170.5	3.89
27	BN2	101.1	3.07	147.0	8.50	225.3	5.13	260.6	10.31
25	BN1	230.0	22.49	239.3	24.28	299.8	29.68	259.0	22.43
14	BN4	138.2	4.14	186.4	5.01	211.3	5.60	229.2	7.60
20	BN5	69.8	10.14	78.5	8.71	99.3	13.14	0.0	0.00