PIE TOWN AT 86GHZ

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ABSTRACT

Efficiency = 18 ± 2 % with the prototype subreflector. The efficiency should be above 25% with production subreflectors.

THE OBSERVATIONS

The efficiency of the Pie Town VLBA antenna has been measured at 86 GHz. The receiver is an uncooled, non-phase-locked mixer with a system temperature of about 1400 K. It was built by John Payne and his group at the NRAO lab in Tuscon. There are two channels to allow beam switching, but the measurements reported here were made in an unswitched mode to avoid confusion between the two beams, which are separated by about 1!5 on the sky. Earlier measurements showed that the "off source" beam could see about 10% as much source power as the "on source" beam.

The sources observed were Jupiter and Venus, with the final numbers being based almost entirely on Jupiter. Both planets are much larger than the expected beam size of 29". That expected beam size was obtained both from theory (Napier) and from scaling the beam size measured at 22 GHz. At the time of the observations, Jupiter had a size of about 44" and Venus had a size of 40"6 (geometric mean of major and minor axes). With these combinations of beam size and planet size, we only expect to see about half the total flux density from each planet because of beam dilution. The expected observed flux densities used for the efficiency calculations were obtained using the Kitt Peak program PLANETS which was provided by Phil Jewell. The program's calculations agree to within a few percent with our own analytic and numerical integrations of a Gaussian over a circular disk. However, all of these calculations require the value of the beam size. As will be shown later, we were unable to determine the beam size from our observations of these large planets, so the theoretical/scaled beam size had to be used. The flux density assumed for Jupiter was 1422 Jy total (179 K at 4.19 au) with 712 Jy in our beam and for Venus was 2511 Jy (367 K at 0.411 au) with 1375 in our beam (Venus was especially close the time). Probably the largest source of uncertainty in our efficiency results is the calculation of the beam dilution.

Most of the measurements were made by observing a 3×3 raster centered on a pointing position determined a few minutes to hours earlier. Off source positions were observed after each azimuth row of the raster which was frequently enough that the accuracy of the results is limited by pointing fluctuations rather than total power fluctuations. The spacing of grid points was 0'.4 in most cases which is about half of the width of the convolved planet and beam. A number of focus positions were tried and it appears that the optimum focus is a function of elevation. No attempt was made to find the optimum subreflector position in rotation so it is possible that further improvements could be made by adjusting this parameter. An interpolated position and peak amplitude from each raster was determined using the same routine that we use for pointing observations at lower frequencies. A few of the measurements were made with larger grids with finer spacing to study the beam in more detail.

The final measurements were made on Dec. 13-14, 1989. Just before the observations, the system temperature was measured using hot-cold loads, assuming temperatures of 274.6 K and 77 K for the two loads. Simple rectangular pieces of absorber were used for the loads so impedance mismatch may have degraded the accuracy of the measurements by an unknown amount. For the IF distributer total power, which was the signal finally used, the measured system temperature was 1344 K. All other measurements done with the BBC's or done just using a hot load gave higher numbers by factors up to about 10%. Therefore, from this point of view, the reported results are conservative in that the number used gives the lowest efficiency. However any error in the measurement due to impedance mismatch will have the other sign. The atmospheric opacity was also measured by comparing the total power at the zenith and at 30 degrees elevation. It was found to be about 4% and our results have been corrected for this. Recall that Pie Town is in arid country at nearly 8000 ft elevation and the observations were made at night in winter.

THE RESULTS

The measurements from Dec. 13-14, 1989 are presented in Figure 1. The interpolated peak amplitude from each raster measurement is presented in terms of IF distributer total power counts. Off-source, the IF distributer had a total of about 16400 counts, a number that varied by about 2% during the course of the observations. Observations over a range of focus positions are shown so the upper envelope shows the performance as a function of elevation for the subreflector rotation position used (more on this later). There is a clear elevation effect with the peak efficiency occuring near 60 degrees. The peak amplitude on Jupiter was 262 counts, which gives an antenna temperature of 21.5 K when multiplied by the ratio of system temperature to total power counts. Assuming that the observed flux density should be 712 Jy reduced by a 4% opacity, the efficiency is 18%. Since several measurements at about this level were made, and it is hard for measurement errors to yield too high an efficiency, we consider this to be a conservative value for the peak efficiency at this frequency. The value is probably accurate to about $\pm 10\%$, giving our final result of 18 ± 2 % efficiency.

All of the observations shown in Figure 1 were made at night. It is possible that thermal distortions during the day significantly degrade the telescope performance. We saw hints of this in earlier attempts to observe during the day, but there were other problems at the time and we never fully understood the cause of the low efficiencies. While getting ready for the Venus observations shown in the figure, we watched a change of pointing of a large amount, perhaps more than 0'.5, occur at sunset. Before serious observing at this frequency is done, the daytime efficiency should be studied.

The top plot of Figure 2 shows the results of 4 scans across Jupiter in the azimuth direction. Measurements were made every 0'.2 and an off-source measurement was made between every on-source measurement. The first scan gave rather lower amplitude than the others for reasons that are not clear. The fitted widths of these scans, and similar results from other rasters, are close to the diameter of the planet. The bottom plot shows that this is expected and that, given the measurement uncertainties, shows that we are unable to extract the beam size from these observations. The plot shows profiles derived by numerically integrating a Gaussian over an offset circular disk for a range of offsets. The five curves are for Gaussian FWHM's of 19, 24, 29, 34, and 39 arcseconds, all done with a planet size of 45.″44 corresponding to the major axis of Jupiter at the time of the observations. The amplitudes for each beam size are very different, but without knowing the efficiency, we cannot use the amplitude to help get the beam size. The plot shows the curves normalized to see if we might constrain the beam size from the shapes of the measured profiles. It is clear that this is not possible over the range of interest, given the errors introduced by pointing fluctuations.

DISCUSSION

The final figure is a reminder from VLBA Test Memo 22 of the efficiency measurements at 22 GHz at Pie Town and Kitt Peak. The Pie Town measurements show an elevation dependence similar to that seen at 86 GHz, although much smaller in amplitude. At Kitt Peak, the 22 GHz gain is flat.

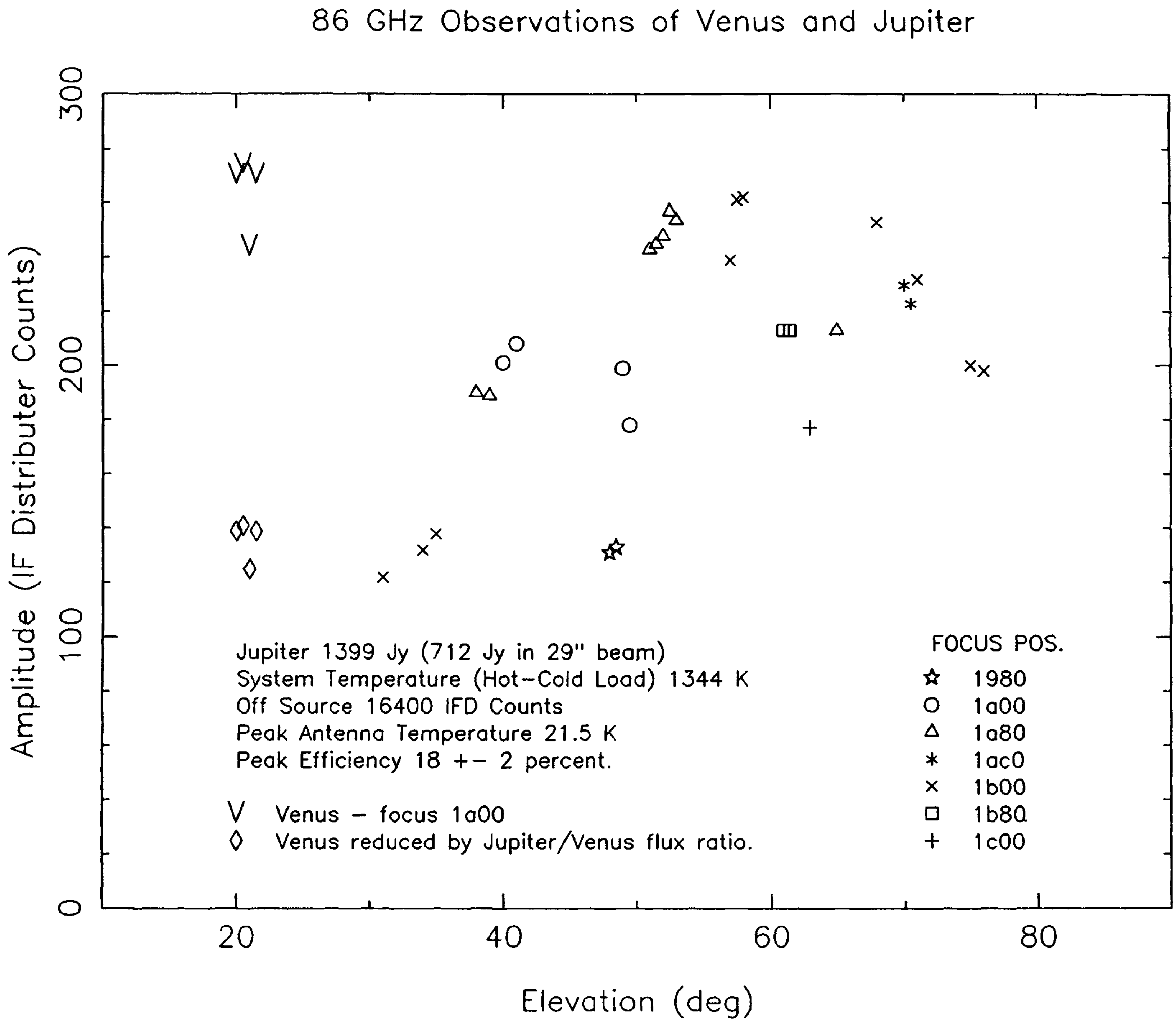
A table of expected efficiencies at 43 and 86 GHz is given on page 5-10 of the VLBA Project Book. For the prototype subreflector at Pie Town, the efficiency was expected to be 11% under nominal precision pointing conditions or 21% in the absence of any gravity, thermal, or wind effects. Our results are in the upper part of this range. Since our observations were made at night, in winter, and in fairly calm conditions, they are just about what might be expected. For subreflectors which meet the specification, which all others do, the same table gives an efficiency of 18% under precision conditions and 36% in the absence of gravity, thermal and wind effects. Since Pie Town has been shown to perform according to theory, the other antennas should also. Therefore it is likely that efficiencies greater than 25% will be realized at 86 GHz at other VLBA sites. This should also be true at Pie Town once the prototype subreflector is replaced with a production unit that meets spec. Note that this makes a VLBA antenna equivalent to at least an 18 m fully efficient mm antenna at this frequency, larger than most of the antennas currently used for mm VLBI.

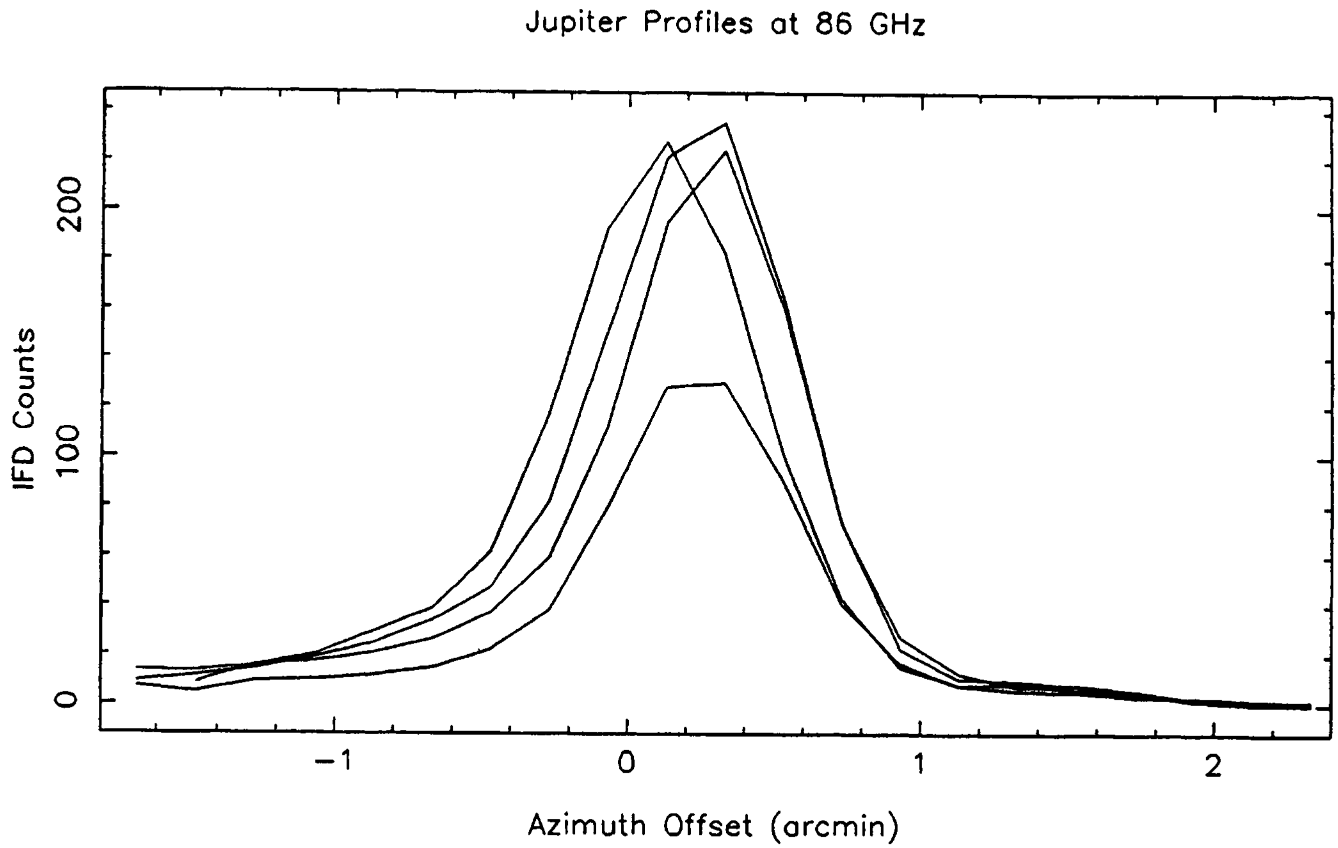
The pronounced gain variation with elevation is probably an effect of lateral motion of the subreflector support structure with elevation due to gravity. In fact, Peter Napier calculates that we should see the efficiency drop by 0.6 at low elevation relative to the optimum unless compensation is made for this motion. This is not far from the factor of 0.55 that we see between the Venus and Jupiter observations. The telescope is set for optimum performance at 50 degrees elevation which accounts for the efficiency peak that we see. The efficiency loss with elevation due to lateral motion can be compensated for by rotating the subreflector. The 86 GHz receiver position is on the elevation axis on the feed circle so that rotation of the subreflector, normally used to change frequencies, can be used to compensate for sag of the quadrupod at this frequency. With proper rotation of the subreflector, plus some change in focus, most of the elevation dependence of efficiency can be removed in theory. Testing this will be a major effort that we do not intend to undertake until we get serious about 86 GHz VLBI observations.

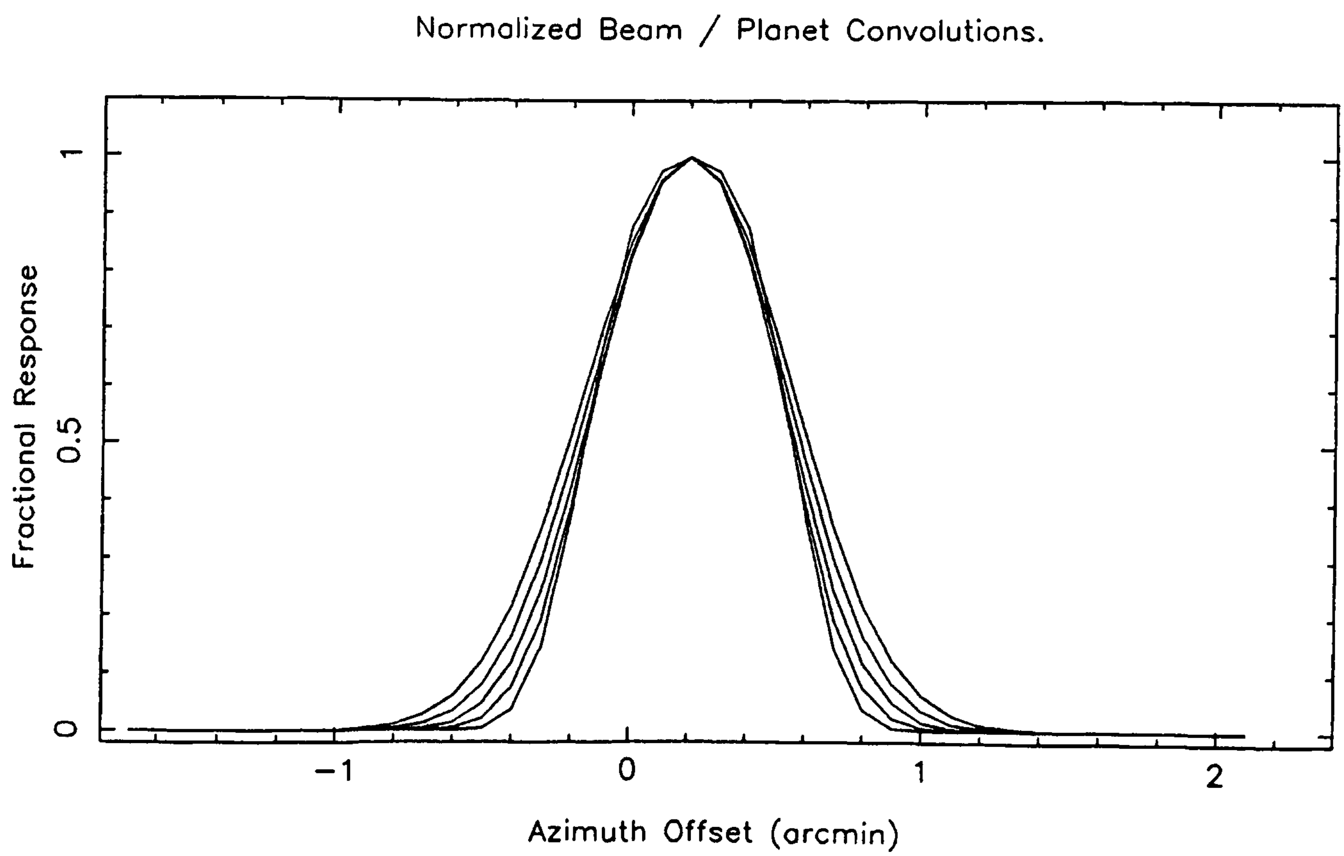
FUTURE PLANS

At present, we do not intend to do further 86 GHz observations at Pie Town. We have confirmed the basic performance of the antenna, which was the goal of these observations. We may attempt to observe Venus when it gets to a higher declination and to a more distant position (eg. smaller) in order to check the beam size. This should happen next summer.

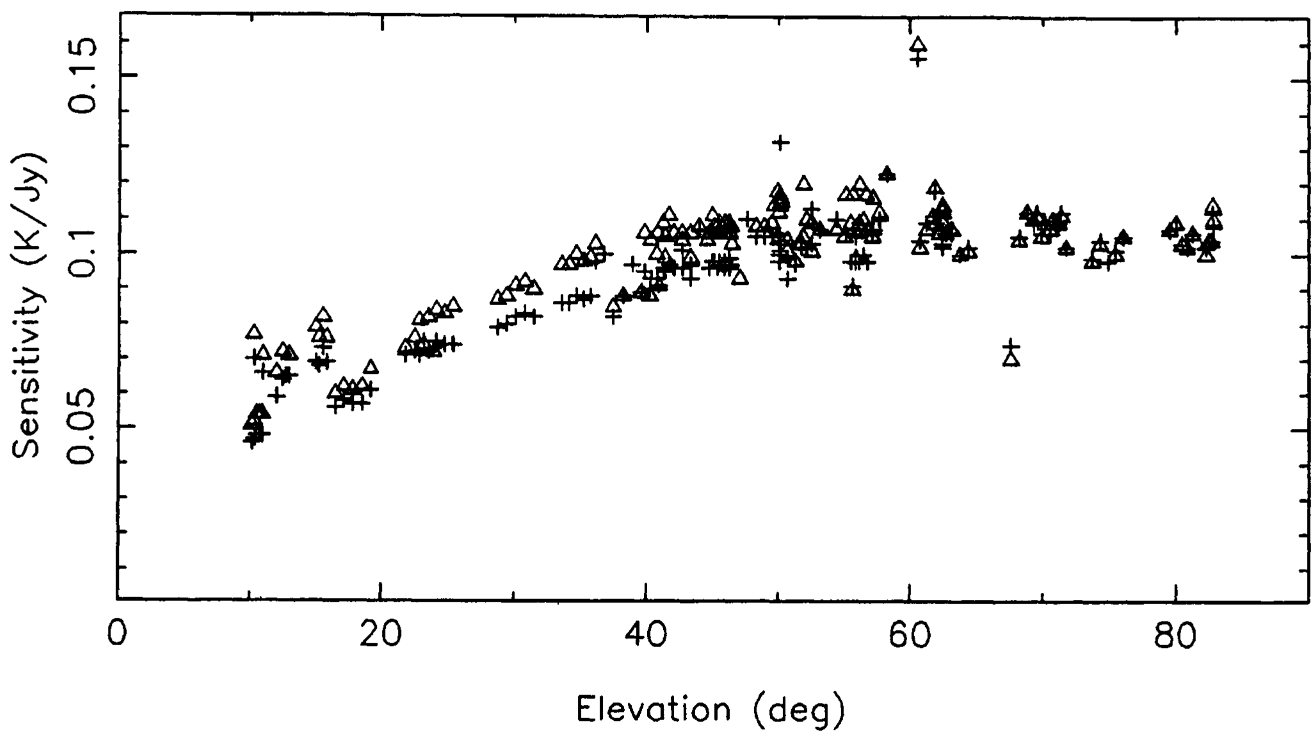
Note that the prospects for VLBI observations at 86 GHz on the VLBA in the near future are poor. The receiver used for these observations has very poor sensitivity and is not phase locked. Proper 86 GHz receivers for the VLBA are not included in the construction budget so it is likely that they will have to be funded from elsewhere after the project is done. Also, this memo has discussed the efficiency only. In order to measure the efficiency, it was necessary to observe a raster of positions on the sky and to shift the center of that raster several times. The pointing is very far from good enough for routine observations at this frequency. Perhaps with proper "peak up and sit" software, it would be possible to observe sources bright enough to see in total power. The pointing seems to be stable enough to use over periods of an hour or more. However, a lot of work is needed before the pointing, the required subreflector motions, and thermal distortions are understood well enough for routine 86 GHz observations. The good news is that the basic structure of the VLBA telescopes seems to be sufficiently good to allow this to be done eventually.


86 GHz Observations of Venus and Jupiter
Amplitude (IF Distributer Counts)
Elevation (deg)
0
100
200
300
20
40
60
80
Jupiter 1399 Jy (712 Jy in 29" beam)
System Temperature (Hot-Cold Load) 1344 K
Off Source 16400 IFD Counts
Peak Antenna Temperature 21.5 K
Peak Efficiency 18 +- 2 percent.
V Venus - focus 1a00
◊ Venus reduced by Jupiter/Venus flux ratio.
FOCUS POS.
1980
1a00
1a80
1ac0
1b00
1b80
1c00


Jupiter Profiles at 86 GHz
IFD Counts
0
100
200
-1
0
1
2
Azimuth Offset (arcmin)


Normalized Beam / Planet Convolutions.
Fractional Response
0
0.5
1
-1
0
1
2
Azimuth Offset (arcmin)

Tant / Measured Flux (All Sources) Pie Town 1.3 cm



Tant / Measured Flux (All Sources) Kitt Peak 1.3 cm