VLA Test Memorandum 198

“Standard Field” Observations: 1993–95

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November 21, 1995

Introduction

In the current incarnation of the Standard Field observations, a field at $\alpha = 3^h 10^m$, $\delta = +80°$ (B1950) is observed for $\sim$ 6 hours at X–band and L–band once during each VLA configuration. This has been the case since the A configuration in 1993. Prior to that, the observations had a much broader scope, including observations of that same field at many bands, and pointing tests, among other items. However, it was decided that most of the things being done with the Standard Field observations were better done under different auspices, hence the change. In November 1995, the scope of these observations was again changed, with the Standard Field only observed for a short period ($\sim$ 1 hour) once a year, probably in the D configuration. This memo is intended to summarize the Standard Field observations during the period from 1993 to 1995. Previous to the D configuration of 1992, the Standard Field observations were taken care of by Pat Crane. From that point to the A configuration of 1994, they were taken care of by K. Dwarakanath ("Dwaraka"). From that point until the B configuration of 1995, I took care of them. Currently, Greg Taylor has agreed to take over the reduced Standard Field observations.

When these observations were initiated, this field was a "blank" field to the VLA, i.e., one with no detectable sources. With the increase in sensitivity of the VLA, this is no longer the case. Figures 1 and 2 show images of the field at both frequencies, taken from the D configuration observation in 1995. These figures show that there are many detectable sources at L–band, which extend out into the secondary lobe of the primary beam. There are also several detectable sources at X–band. These sources (at both frequencies) are all greater than 5 times the rms noise in the image.

The last X–band measurements were done in continuum mode with the IFs centered at 8435.1 and 8485.1 MHz (changed from the old values of 8414.9 and 8464.9 MHz as of the B configuration observation in 1995, as per Greg Taylor's email of 10/3/95 regarding changing the X–band default frequencies). The last

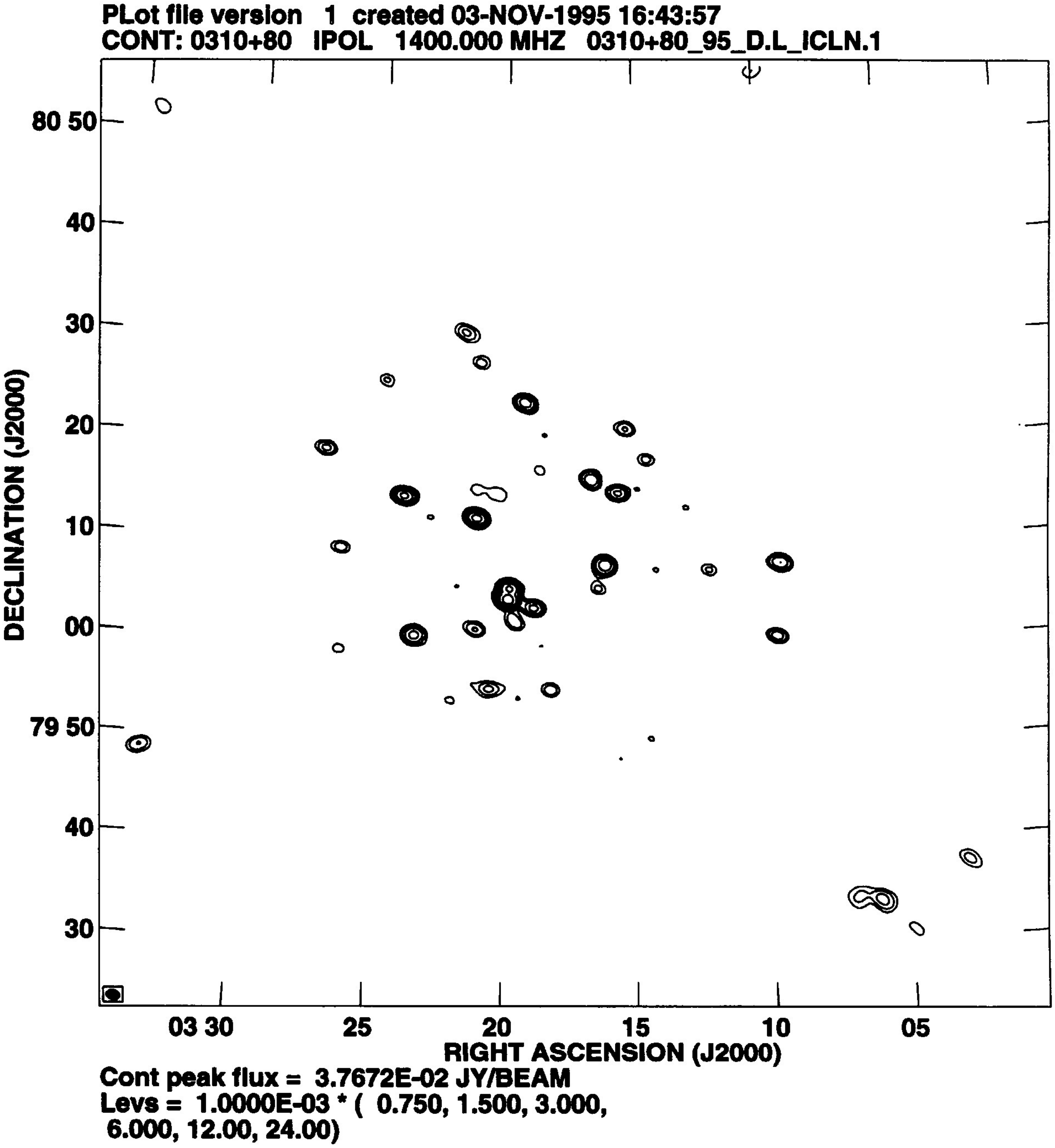

Figure 1: Image of the Standard Field at L–band.

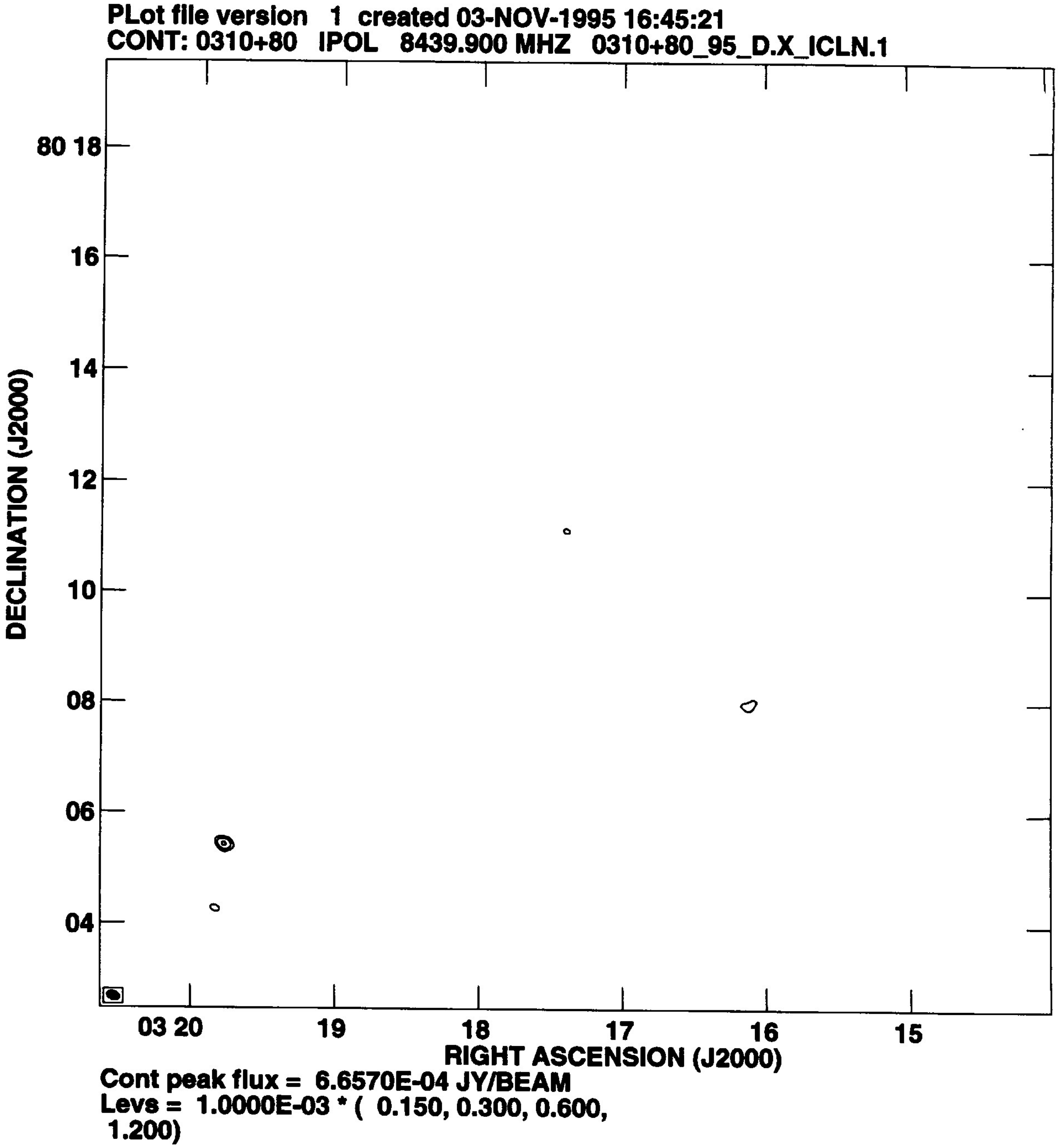

Figure 2: Image of the Standard Field at X-band.

several L–band measurements were done in continuum mode, with one of the IF's centered at 1364.9 MHz, and the other at either 1435.1 or 1485.1 MHz (see discussion later). Prior to the D configuration observation in 1995, the L–band measurements had been done in spectral line mode, bandwidth code 0, yielding 7 Hanning smoothed channels of 6.25 MHz each. The older observations were done in two separate IFs (A and B), with bands centered on 1464.9 and 1385.1 MHz, respectively. The modifications that were made to the L–band measurements over time will be discussed later. Calibration was done in a mostly standard fashion, with the absolute scale being set by an observation of 3C286 or 3C48, and complex gains calibrated by observation of the calibrator 0212+735 (B1950). For the spectral line L–band observations, the absolute flux calibrator was also used to calibrate the bandpass. After editing, the Standard Field (0310+80) was split out into a single source file.

X–band

A quantity of interest is the rms variation of the observed visibilities. Since at X–band the field is nearly blank, there is really no need to even map the field to estimate the noise characteristics of the instrument (although it is always done anyway). The rms variation on a two–antenna, single–multiplier, correlation interferometer observing weak sources is given by (Crane and Napier 1994):

$$\Delta S = \frac{\sqrt{2}\, k_b\, T_{sys}}{A\, \eta_a\, \eta_c \sqrt{\Delta t\, \Delta \nu}} \quad , \tag{1}$$

where k_b is Boltzmann's constant, T_{sys} is the system temperature, A is the physical aperture size, η_a is the aperture efficiency, η_c is the correlator efficiency, Δt is the visibility integration time, and $\Delta\nu$ is the bandwidth of observation. Now, for a complex correlator, with real and imaginary outputs, each of the outputs will have the same amount of gaussian noise, characterized by the same standard deviation, ΔS. Figure 3 shows a histogram plot of real, imaginary, and amplitude values of the visibilities for one of the Standard Field experiments. The real and imaginary distributions are clearly gaussian, with near 0 mean. Because of this, the amplitude distribution (which follows a Rice distribution in general) is Rayleigh distributed. However, there are generally some "bad" data points (from interference, e.g.), which need to be taken out of the visibility data set (flagged). In order to do this, a good estimate of the clipping level is needed. It is fairly simple to calculate the number of visibilities expected to have amplitudes greater than some value above the mean amplitude. For the Standard Field observations at X-band, the mean amplitude is given by (Thompson *et al.* 1991, no-signal case):

$$\langle z \rangle = \sqrt{\frac{\pi}{2}}\, \Delta S \quad , \tag{2}$$

and the fraction with amplitudes greater than $\langle z \rangle + n\,\Delta S$, for $n = 2$, 3, and 4 is: .005032, .000118, and .000001. So, given 50,000 visibilities (which is typical for these observations) in a data set, only 6 visibilities should have amplitudes greater than $\langle z \rangle + 3\,\Delta S = (\sqrt{\pi/2} + 3)\,\Delta S \sim 4.253\,\Delta S$. For that reason, I use the criteria that a visibility is "bad" if its amplitude is $> 4.253\,\Delta S$, where ΔS is measured from the data set itself, and live with the fact that I'm actually rejecting a few valid visibilities. After that clipping is performed, new values of ΔS can be estimated directly from the real and imaginary portions of the visibilities, and from that, the quantity:

$$\frac{T_{\rm sys}}{\eta_a} = \frac{\Delta S\, A\, \eta_c \sqrt{\Delta t\, \Delta\nu}}{\sqrt{2}\, k_b} \tag{3}$$

can be estimated. This quantity is a measure of the performance of the instrument. Table 1 shows the quantity ΔS measured in all of the Standard Field observations with the current setup, at X-band. Values of the parameters used were: $k_b = 1.3805 \times 10^{-23}$ J/K, $A = 491$ m$^2, \eta_c = 0.79, \Delta t = 30$ s$, \Delta\nu = 46$ MHz. For each observation, a value of ΔS is calculated for each polarization (RR, LL, RL, LR) and IF (1 and 2) separately for the real and imaginary portion of the visibilities. An average of the resulting 16 values is then taken, and is what is shown in Table 1. The variation in values of ΔS across real/imaginary, polarization, and IF is very small. Also shown in Table 1 is the value of $T_{\rm sys}/\eta_a$ for each observation.

The value of ΔS varies considerably, mostly due to weather, and hence increased effective $T_{\rm sys}$. However, even the best values observed in the Standard Field

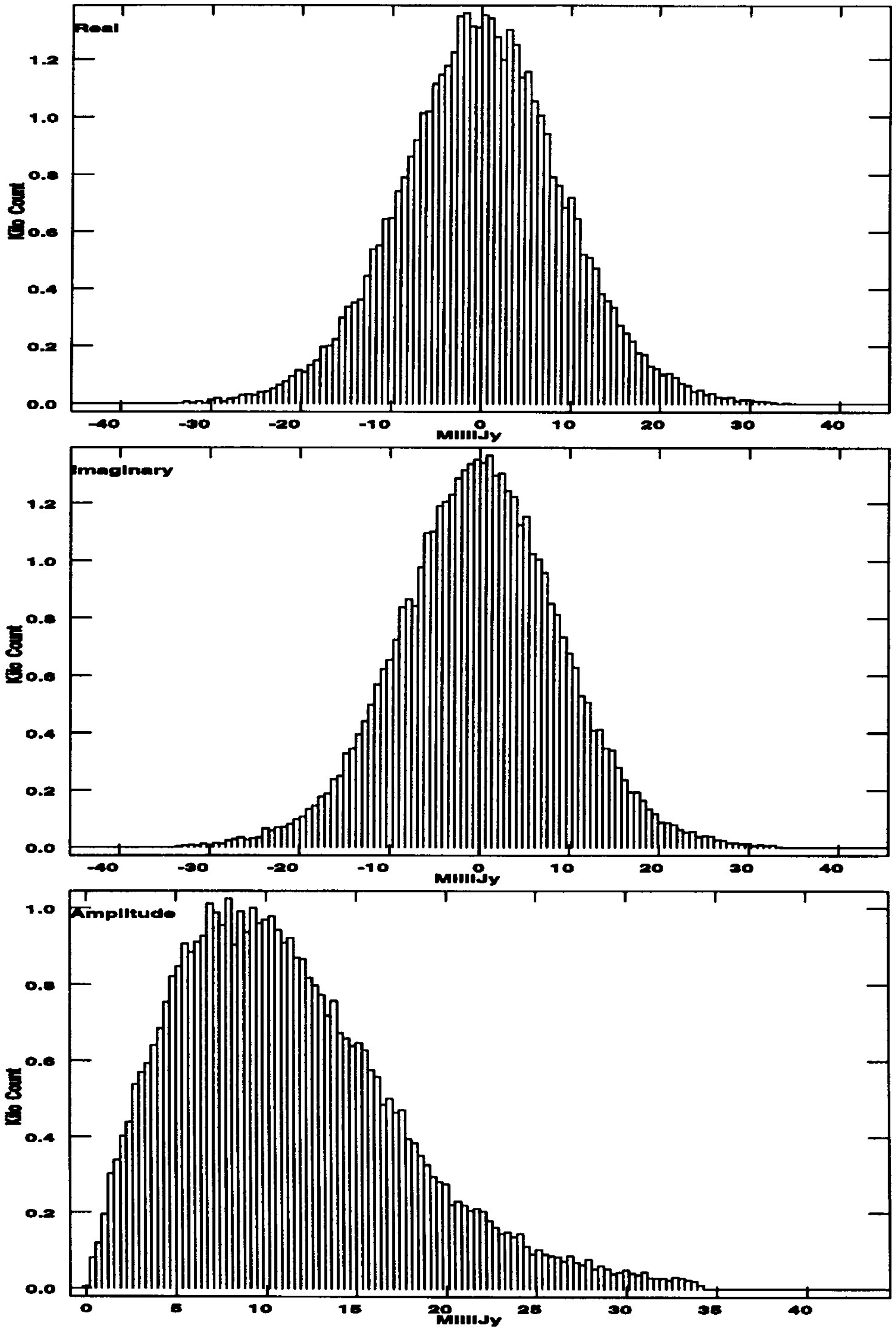

Figure 3: Histogram of X-band visibilities for one Standard Field observation. Real, imaginary, and amplitude spectra are shown.

Table 1: X–band Standard Field noise measurements (visibility based)

date	config	ΔS (mJy)	T_{sys}/η_a (K)	Rick's K (mJy)	weather comments	flux calibrator
1/1/93	A	11.82	87.24	10.35	50% stratus. fog.	3C48
3/29/93	B	9.59	70.78	8.40	50–100% cumulo. drizzle.	3C48
8/21/93	C	14.55	107.39	12.74	100% stratus.	3C48
11/24/93	D	8.36	61.70	7.32	10% stratus.	3C48
4/2/94	A*	15.35	65.41	7.76	70% stratus.	3C286
4/23/94	A*	16.45	70.10	8.32	50% cumulo.	3C286
8/18/94	B	8.72	64.36	7.64	20–35% cumulo. & strato.	3C286
11/12/94	C	18.25	134.70	15.98	100% strato. rain.	3C48
3/18/95	D*	15.72	67.00	7.95	20% strato. fog.	3C48 & 3C286
8/9/95	A*	15.02	64.00	7.59	50–80% cumulo.	3C48
10/27/95	B*	15.88	66.10	7.84	clear skies	3C286

* these observations had $\Delta t = 10$ s

observations (under fairly good weather) are not as good as the values supplied in the VLA Observational Status Summary (OSS). The value of T_{sys}/η_a can be derived from the supplied value K given in the OSS (which is a value obtained from measurements of the noise characteristics at each band made by Rick Perley) and is given by: $T_{sys}/\eta_a = K/0.1186$. For X–band, the OSS gives: $K = 5.6$ mJy (note that this was the value in the 1994 OSS, and was changed to 6.8 in the 1995 OSS), implying a value of $T_{sys}/\eta_a = 47.22$ K. Independent measurements of T_{sys} and η_a yield values of ~ 30 K, and ~ 0.62, respectively (at zenith). These values agree well with the value of T_{sys}/η_a of 47.22 K. However, these numbers are much lower than the values shown in Table 1, where the best (lowest) value is 60.35 K. The inferred value of Rick's K parameter in each standard field experiment is shown in Table 1. Again, they are higher than the value of 5.6 (or 6.8) supplied in the OSS.

As a test, the rms variations in a map made from visibilities with a given ΔS should be:

$$\Delta I_m = \frac{\Delta S}{\sqrt{N_{\mathrm{vis}}}} \quad , \tag{4}$$

where N_{vis} is the number of visibilities which went into the map. As an example, in the D configuration in 1993, $\Delta S = 9.05$ mJy in the RR polarization of IF 1, and there were 42434 visibilities in that polarization/IF. This implies an image rms of: $\Delta I_m = 43.93\,\mu\mathrm{Jy/bm}$. The resultant dirty map (with natural weight) had a measured rms of: $\Delta I_m = 44.66\,\mu\mathrm{Jy/bm}$, which is pretty close. By comparison, the OSS gives the following to calculate the rms noise in a map:

$$S_{\mathrm{rms}} = \frac{K}{\sqrt{N\,(N-1)\,(n\,\Delta t_{\mathrm{hrs}}\,\Delta\nu_{\mathrm{MHz}})}} \quad , \tag{5}$$

where N is the number of antennas, n is the number of IFs or spectral line channels, Δt_{hrs} is the total observing time in hours, and $\Delta\nu_{\mathrm{MHz}}$ is the observing bandwidth in MHz. The K here is the same value as that described above. An equivalent form of the expression for S_{rms} is:

$$S_{\mathrm{rms}} = \frac{K}{\sqrt{2\,N_{\mathrm{vis}}\,(n\,\Delta t'_{\mathrm{hrs}}\,\Delta\nu_{\mathrm{MHz}})}} \quad , \tag{6}$$

where $\Delta t'_{\mathrm{hrs}}$ is now the individual visibility integration time (still in hours). So, given $K = 5.6\ \mathrm{mJy}, n = 1, N_{\mathrm{vis}} = 42434, \Delta t = 30\ \mathrm{s} = .5/60\ \mathrm{hr}, \Delta\nu_{\mathrm{MHz}} = 46$, then the calculated $S_{\mathrm{rms}} = 31.05\,\mu\mathrm{Jy/bm}$. This is quite a bit lower than that observed (by a factor of $\sim$ 30%) [using $K = 6.8 \rightarrow S_{\mathrm{rms}} = 37.70\,\mu\mathrm{Jy/bm}$, still lower than observed by $\sim$ 15%].

I have since been supplied with 2 more independent verifications of the high values of T_{sys}/η_a. The first was an observation done by Rick Perley to test this on 2/8/95, when the array was in the DnC configuration. In this observation, Rick simply looked at 3C286 and then a nearby presumed blank field. The approximate elevation of the field was 37° at the time of the X–band observations. The measured value of ΔS was 13.89 mJy. The derived value of T_{sys}/η_a is thus 59.19 K (with

Table 2: Ed's X–band noise measurement

elevation (°)	44.5	50.5	55.5	60.5	65.5	70.5	76.0	79.5	81.0	79.5	75.0
ΔS (mJy)	16.8	16.5	16.4	16.4	16.5	16.4	16.4	16.4	16.4	16.4	16.4
elevation (°)	70.5	65.5	60.0	55.5	49.5	44.5	40.0	34.5	30.0	26.0	
ΔS (mJy)	16.4	16.5	16.6	16.8	17.2	17.9	18.2	18.6	19.1	19.6	

Δt = 10 s and other values as above). This is slightly better than any of the standard field observations, but still significantly higher than 47.2 K (from the OSS values, and independent $T_{\rm sys}$ and η_a measurements). The second verification was in sensitivity numbers from one of a number of experiments done by Ed Fomalont. This particular observation was done on 11/6/94, where a blank field near $\delta = +42°$ was tracked for $\sim$ 10 hours. Absolute flux calibration was done with an observation of 3C286, and the phase calibrator 1244+408 was used to calibrate the complex gains. Table 2 shows the resultant measured values of ΔS, as a function of elevation throughout the observation. Note that ΔS vs. elevation is not symmetric about zenith, as sunrise occurred near the middle of the experiment. At any rate, the value of ΔS near zenith is $\sim$ 16.4 mJy, implying a value of $T_{\rm sys}/\eta_a$ of $\sim$ 69.89 K. According to Ed, this was typical of values he got on other "good weather" nights. This number is very similar to the best numbers in Table 1, and again, much higher than 47.2 K. Note also that a gross estimate of how the elevation of the standard field observations is affecting the values derived from them can be obtained from Table 2 (at least for relatively good weather).

In order to investigate what is causing the value of $T_{\rm sys}/\eta_a$ to be relatively high in our measurements, I've gone back and tried to recover the values of $T_{\rm sys}$ for 2 of the observations (B and C configurations of 1994). If the data is FILLMed with the proper parameters (CPARM(2)=2), values are written into the TY table which can be used to recover the value of $T_{\rm sys}$ at the time. At every source change, the on–line system calculates the quantity:

$$I_{\rm sens} = \frac{21.59\ \eta_a}{T_{\rm cal}\ g} \tag{7}$$

for each antenna and IF, where η_a is the dish efficiency at the observed band, T_{cal} is the assumed noise tube temperature (in K) for that antenna/IF, and g (the so–called "peculiar gain") is a fudge factor (see below). The 21.59 is a constant that subsumes the area of the dish, Boltzmann's constant, the front end gain, and other radiometric constants (note that for observations done prior to 1989, this value was 24.32). Now, every 10 seconds, the on–line system calculates the following quantity (the so–called "nominal sensitivity"):

$$I_{\text{corf}} = \frac{3}{V_{\text{sd}}\, I_{\text{sens}}} = \frac{3}{V_{\text{sd}}} \left(\frac{1}{21.59} \frac{T_{\text{cal}}\, g}{\eta_a} \right) \quad , \tag{8}$$

where V_{sd} is the front end synchronous detector voltage for each antenna/IF. For each correlated visibility, the geometric mean of I_{corf} for the two antennas/IFs is used as a multiplicative factor to convert correlation coefficient to 10's of Janskys. This value is what is written to the archive tape, and subsequently to the TY table by FILLM. The values of T_{cal}, η_a, and g are retrieved from files on the on–line system. Now, the values of g are adjusted regularly, so that the observed correlation coefficient converts to the proper number of Janskys for 3C286 or 3C48. Apparently the values of g at X–band are quite stable, and near 1. As an example, during the first week of January 1995, the values of g from the file had maximum and minimum values of 1.46 and 0.89 (out of 112 values, from 28 antennas and 4 IFs). The mean value was 1.022, with a standard deviation of 0.011. By contrast, at this same time, the values of g from the L–band file had maximum and minimum values of 2.54 and 0.79, with mean and standard deviation of 1.526 and 0.211.

Now, the system temperature is given by:

$$T_{\text{sys}} = \frac{15\, T'_{\text{cal}}\, V_{\text{TP}}}{V_{\text{sd}}} \quad , \tag{9}$$

where T'_{cal} is the *actual* (as opposed to assumed) noise tube temperature (in K) for a given antenna/IF, and V_{TP} is the total power voltage input to the correlator. The ALC's constrain V_{TP} to be near 3 V, so this is nearly a constant value. The factor of 15 is strictly an electronics gain factor. So,

$$T_{\text{sys}} \sim \frac{45\, T'_{\text{cal}}}{V_{\text{sd}}} \quad , \tag{10}$$

or,

$$V_{\mathrm{sd}} \sim \frac{45\ T'_{\mathrm{cal}}}{T_{\mathrm{sys}}} \quad . \tag{11}$$

Substituting this into the equation for I_{corf} yields:

$$I_{\mathrm{corf}} \sim \frac{3\ T_{\mathrm{sys}}}{45\ T'_{\mathrm{cal}}} \left(\frac{1}{21.59}\ \frac{T_{\mathrm{cal}}\ g}{\eta_a} \right) \quad , \tag{12}$$

or,

$$T_{\mathrm{sys}} \sim 323.85\ \frac{\eta_a\ T'_{\mathrm{cal}}}{g\ T_{\mathrm{cal}}}\ I_{\mathrm{corf}} \quad . \tag{13}$$

Now, the adjustments to g mentioned above might imply that $g\ T_{\mathrm{cal}} \sim T'_{\mathrm{cal}}$, in which case,

$$T_{\mathrm{sys}} \sim 323.85\ \eta_a\ I_{\mathrm{corf}} \quad . \tag{14}$$

The value of η_a is again taken from the same file which contains the values of g (and T_{cal}). These values are the "standard" numbers, i.e., $\eta_a = 0.62$ for X–band, and 0.51 for L–band. Given this value, the values of T_{sys} can be derived directly from the values written to the TY table (I_{corf}). Note that uncertainties in the value of η_a are unimportant, as long as the η_a which was used by the on–line system is used. Errors are due to fluctuations in T'_{cal}, and in V_{TP}. Of these, fluctuations in T'_{cal} should dominate. There is no good knowledge of how these values fluctuate over short or long time scales, however, current wisdom is that the values are relatively stable (to ~ 10%, see Bagri and Lilie 1993, and Lilie 1992). Therefore, estimating the value of T_{sys} from the values in the TY table should be accurate to ~ 10% for a given antenna, and might be as accurate as a few percent for an average over all antennas. I've made an AIPS task which does the conversion from I_{corf} to T_{sys} (in K) in the TY table, called TYCNV. Figure 4 shows the results of performing this conversion on the TY table for the B configuration experiment in 1994. Table 3 shows the value of $\overline{T_{\mathrm{sys}}}$ for each of the IFs, which is the value of T_{sys} averaged over all antennas and elevations for that IF. The rms is strictly the data scatter, and doesn't take into account the possible fluctuations in T'_{cal}. The fact that the values of T_{sys} make sense is a very loose verification of the conversion algorithm (and TYCNV). However, this then implies that the aperture efficiency, η_a, is not the 0.62 that is advertised at X–band. If T_{sys} is indeed ~ 30 K, and the value of

Table 3: Derived values of T_{sys} for an X-band Standard Field observation

IF	$\overline{T_{sys}}$ (K)	$\sigma_{T_{sys}}$ (K)
A	28.90	2.98
B	28.55	2.51
C	28.63	2.62
D	28.69	2.44

$T_{sys}/\eta_a \sim 62$ K (best value from Table 1), then the inferred aperture efficiency is: $\eta_a \sim 0.48$, at X-band.

A good question to ask is: "why didn't Dwaraka see this?" Well, to check on this, I've gone back through his notes. Table 4 shows values which he used for the parameter K in each observation, the implied theoretical values of the noise S_{rms}, and the measured value of S_{rms} for that observation. Apparently, the value of S_{rms} was estimated from a map made in Stokes I, with both IF's. So, it appears that he was regularly measuring higher noise levels than predicted. There are two reasons why he didn't see an even larger discrepancy. First, you can clearly see that the values of K which he used are higher than what I've used (I'm using the value of 5.6 from the 1994 OSS). The second reason is that Dwaraka used a significantly lower value for the amplitude cutoff when flagging "bad" visibilities. As an example, the clipping level in the A configuration measurements of 1/1/93 was set at 20 mJy, which is only about 5 mJy above the mean value of the amplitudes. Therefore, a significant portion of the tail of the noise distribution was being chopped off, and the measured noise in the final map was necessarily biased down. For comparison, I made a map of that A configuration data, when a clipping level of 50 mJy was used on the visibility amplitudes. The measured rms in the map was: 26.3 μJy/bm. Using Stokes V yielded 26.5 μJy/bm. So, all of the values in columns 5–7 in Table 4 are probably about 10% too low. At any rate, it is clear that the inferred values of T_{sys}/η_a agree well with the values in Table 1, and are

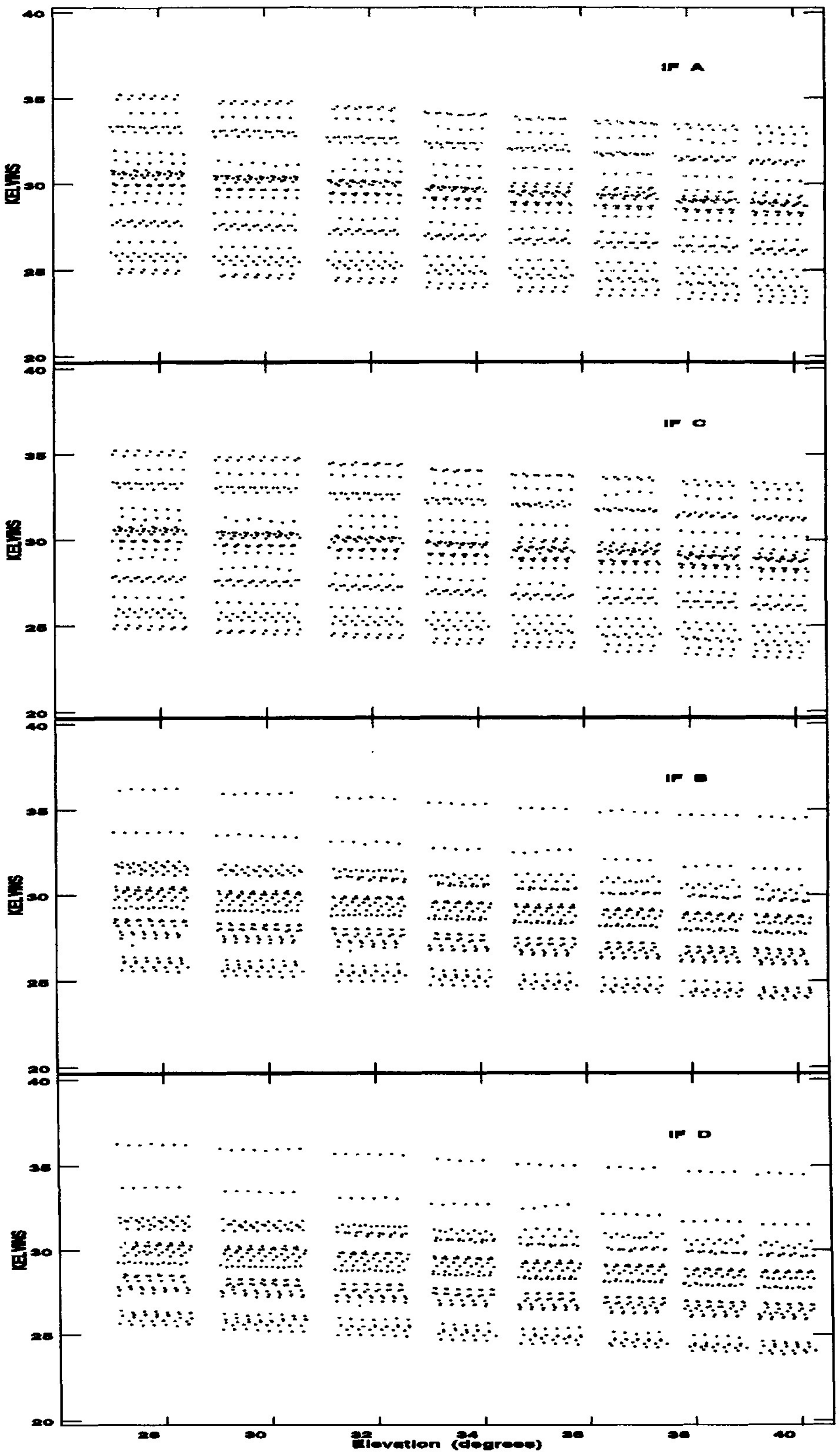

Figure 4: Plot of X-band system temperature (T_{sys}) vs. Elevation for one Standard Field observation. Each antenna is plotted separately in each IF.

Table 4: X–band Standard Field noise measurements (map based)

date	configuration	K (mJy)	theoretical $S_{\rm rms}$ (μJy/bm)	measured $S_{\rm rms}$ (μJy/bm)	inferred K (mJy)	inferred $T_{\rm sys}/\eta_a$
1/1/93	A	7.4	17.2	23.9	10.3	86.7
3/29/93	B	7.4	17.0	20.0	8.7	73.4
8/21/93	C	6.6	16.0	31.1	12.8	108.2
11/24/93	D	6.6	17.7	20.6	7.7	64.8
4/2/94	A	6.3,7.6	32.5,39.6	46.7	9.0	75.6
4/23/94	A	6.3,7.6	22.6,27.6	28.6	7.9	66.4

again higher than presented in the OSS.

So, all indications are that the value of $T_{\rm sys}/\eta_a$ at zenith is higher than currently advertised for the VLA at X–band. Taking into account the variation with elevation indicated from Ed's data, the *best* value of $T_{\rm sys}/\eta_a$ at zenith for the standard field observations in the last two years was $\sim$ 56 K. This is about 15% different than the number obtained by taking the nominal values of $T_{\rm sys} = 30$ K, and $\eta_a = 0.62$. A better value to use is more like $T_{\rm sys}/\eta_a \sim 66$ K, which is an average of all of the measurements presented here excepting the 1993 A configuration data and both epochs of the C configuration data. This implies a value of 7.8 for Rick's K parameter.

Note: Durga Bagri has made some measurements which indicate that the "system efficiency" in interferometric observations seems to be lower than would be expected from the straightforward product of the aperture efficiency and the correlator efficiency (presented in the VLA test meeting of March or April 1995). i.e., the value of $\eta_a\ \eta_c$ in equation (1) should be replaced by some system value, η_s, where $\eta_s = \eta_a\ \eta_c\ \eta_o$, with η_o being "other" system losses, e.g. LO coherence.

This would explain the discrepancy between the rms variations being measured and what we expect theoretically from measurements of η_a, and T_{sys}, and expected values of η_c, if $\eta_o \sim .85$. Durga indicated that the difference in the two efficiencies (single–dish vs. interferometric) was about 12–13%, which agrees well with what the numbers presented here indicate.

A small note on interference at X–band. It was brought to my attention by Ed Fomalont that he has seen some amount of interference during X–band observations in the C and D configurations when any relatively short N–S baseline involves antenna 6. The interference occurs in only 1 IF–pair (AC). Ed also brought this to the attention of Clint Janes, who is investigating the cause, I believe. At any rate, this effect shows up clearly in the standard field data from C and D configurations in 1993. The effect is much worse in the D configuration. To give a feel for the numbers, remember that the rms variation in the visibilities from that experiment (1993 D) was about 8.36 mJy (Table 1). However, in the corrupted IF, on baseline 6–1, the RR visibilities were apparently edited out by the on–line system, the LL and RL visibilities had an rms variation of $\sim$ 10 mJy, while the LR visibilities had an rms variation of $\sim$ 70 mJy. The effect does not show up in the C configuration data from 1994, the reason being that antenna 6 was at the end of the southeast arm (pad E18), and hence had no short N–S baselines. The effect shows up clearly in the data taken by Rick on 2/8/95, however, even though antenna 6 was still at the end of the SE arm (pad E9). Presumably the N–S baseline between antennas 6 and 17 (on pad E8) was short enough for the interference to occur. I don't know if it's really proper to use the term "interference" to describe this effect, but am merely using the term passed on to me by Ed.

L–band

Estimating the noise in the L–band measurements is slightly more complicated than at X–band. Because there are many detectable sources in the field at L–band, the noise cannot be accurately estimated directly from the fluctuations in the visibilities, but must rather be estimated from an image. Because the sources are sufficiently strong, the image must be deconvolved, and Dwaraka and I have both been using CLEAN (via MX, or, after the A configuration observation in 1995, IMAGR) to do the job. Table 5 shows values of the pixel–to–pixel rms variations in the resultant images for each channel and IF, for all observations prior to the D configuration in 1995. As mentioned in the introduction, these observations were done in 1 IF spectral line mode (switching between modes 1A and 1B), bandwidth code 0, with Hanning smoothing. This yielded 7 channels of 6.25 MHz each, in 1 IF at a time. The two IF's were centered at 1464.9 and 1385.1 MHz, respectively. I could find no noise numbers in Dwaraka's notes for the A configuration experiments of 1994, which is why they are not present in Table 5. Note that the absolute values of the noise should not be compared from IF to IF or from different experiments, since different numbers of visibilities go into each image. However, it is clear from the channel to channel variations that channels 4 and 7 of IF 1 and channels 6 and 7 of IF 2 are consistently high. This is interference, and will be discussed later.

The 1995 observations were all done with at least half of the L–band data taken in continuum mode. During the D configuration observation, some data were taken in 2 IF spectral line mode (mode 2AB), bandwidth code 0, with no Hanning smoothing. This again yielded 8 channels of width 6.25 MHz each, but in 2 IF's simultaneously. Table 5 shows the rms values from that portion of the observation. Also, the central frequencies of the IF's were changed to 1364.9 and 1435.1 MHz, to avoid the interference mentioned above, and to be compatible with the default observing frequencies. During the A configuration observation, some data were taken in 4 IF spectral line mode (mode 4), bandwidth code 0, with no Hanning smoothing. This yields 3 channels of width 12.5 MHz each, in 2 IF's, and in Stokes LL and RR simultaneously. Table 5 also shows the rms values for this data. These different spectral line mode observations were intended to be used as a comparison to the continuum data, to assess the performance of these relatively wide band spectral line modes vs. that of the continuum mode and hence decide in which mode the standard field observations should be done in the future. During the B configuration observation, all L–band data were taken in continuum mode. For this observation, the center frequency of IF 2 was moved up to 1485.1 MHz, which is the frequency used by the L–band survey. Table 5 shows the rms values for all of the continuum data, which are denoted by the asterisks. For the I, Q, U, and V Stokes, an image was made in which the 2 IF's were averaged, which was subsequently CLEANed (if necessary), and from which the rms variation was taken. The RL Stokes images were made with only IF 1.

Also shown in Table 5 is the inferred value of Rick's K, for all of the observations. For the observations prior to the D configuration of 1995, only those channels not affected by interference were used in this estimate. Since all of the observations are done at $\sim 35°$ to $40°$ elevation, and there is a well documented variation of $T_{\rm sys}$ with elevation at L–band (see Lilie 1994, and Bagri 1993), the value of K needs to be corrected for that effect. The value of $T_{\rm sys}$ increases by a factor of ~ 1.3 from zenith to these low elevations, so the inferred values of K need to be multiplied by ~ 0.77 to get the value of K at zenith, which I have denoted as K^* in Table 5. The value of K supplied in the OSS is 7.7 mJy (note that this was the value in the 1994 OSS, and has been changed to 9.1 in the current OSS), which is very close to the values listed in Table 5, excepting the 1994 C configuration value, and the 1995 D configuration value (where confusion is starting to contribute to the "noise"). So there is no problem similar to X–band in our published sensitivities at L–band. From the value of K^*, the value of $T_{\rm sys}/\eta_a$ at zenith can then be obtained from: $T_{\rm sys}/\eta_a = K/0.1217$ (different from above, since the correlator efficiency in spectral line mode is $\eta_c \sim 0.77$). Using the nominal value of $\eta_a = 0.51$ at L–band gives values of $T_{\rm sys}$ near 30 K, which matches the engineering measurements at zenith. Again, no problem like that at X–band.

As far as the interference in the early line observations is concerned, there is no particular mystery surrounding it. The interference in IF 2 was caused by the well–known and documented internal birdie at 1400 MHz (see Crane 1982, Perley

Table 5: L–band Standard Field noise measurements (map based)

date	config	IF or Stokes	1	2	3	4	5	6	7	K (mJy)	K^* (mJy)	T_{sys}/η_a (K)
1/1/93	A	1	135	134	138	142	142	143	155	10.0	7.8	64.1
		2	137	138	142	142	146	149	162			
3/29/93	B	1	120	122	124	134	129	127	146	9.5	7.6	62.4
		2	131	133	137	135	137	156	163			
8/21/93	C	1	130.3	132.8	134.4	153.9	136.5	131.9	152.7	9.2	7.2	59.2
		2	115.7	120.1	126.5	120.8	123.7	155.7	158.8			
11/24/93	D	1	172.7	168.2	168.2	276.3	174.7	173.7	255.9	11.4	8.8	72.3
		2	184	177	178	187	187	341	316			
8/19/94	B	1	127.7	128.5	131.5	146.2	138.4	139.8	159.3	10.4	8.1	66.2
		2	140.5	141.1	144.3	143.7	145.6	192.4	198.2			
11/12/94	C	1	186.6	188.4	192.9	240.9	194.2	200.4	246.1	14.7	11.4	94.1
		2	237.1	243.2	242.1	242.0	244.7	296.9	287.7			
3/18/95	D	1	303.8	324.8	266.8	296.3	295.0	305.8	326.3	19.6	15.1	123.9
		2	346.8	352.0	320.4	316.1	303.6	323.2	359.3			
3/18/95	D*	I	172.9							41.9	32.2	265.0
3/18/95	D*	Q	68.57							16.6	12.8	105.2
3/18/95	D*	U	81.38							19.7	15.2	124.9
3/18/95	D*	V	62.2							15.1	11.6	95.3
8/9/95	A	1+2 (V)	62.4	75.7	81.5					11.2	8.6	70.5
8/9/95	A*	I	146.3							50.2	38.6	317.0
8/9/95	A*	Q	32.2							11.0	8.5	69.8
8/9/95	A*	U	31.9							10.9	8.4	69.1
8/9/95	A*	V	33.8							11.6	8.9	73.2
8/9/95	A*	RL	63.8							10.9	8.4	69.1
10/27/95	B*	I	100.7							34.5	26.5	217.6
10/27/95	B*	Q	36.9							12.6	9.7	79.8
10/27/95	B*	U	38.1							13.0	10.0	82.4
10/27/95	B*	V	45.0							15.4	11.8	96.9
10/27/95	B*	RL	71.0							12.2	9.4	77.2

* continuum observations

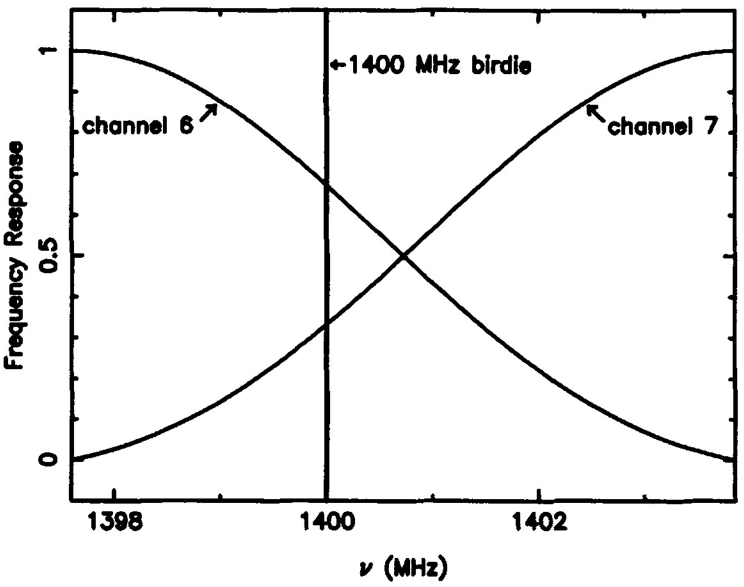

Figure 5: Frequency response for channels 6 and 7 of IF 2 in the L–band standard field observations. The 1400 MHz birdie is also shown.

et al. 1983, and Janes 1995). Since the frequency responses of both channel 6 and 7 were significant at 1400 MHz, the interference was picked up in both channels (see Figure 5). The interference in channels 4 and 7 of IF 1 were probably caused by U.S.F.S. microwave transmissions (see Janes 1995). The "channel edges" of channel 4 were 1461.775 and 1468.025 MHz, and of channel 7 were 1480.525 and 1486.775 MHz, which picked up two of the U.S.F.S. microwave transmission frequencies. The interference in IF 2 was much stronger than that in IF 1, evidenced by inspection of the images. The interference showed up in the images as striping, but at a much lower level in IF 1. As a matter of fact, if you averaged the 7 channel maps into one map, in IF 1 the interference stripes were at the level of the noise (you couldn't see them by visual inspection). In IF 2, this was not the case, and in the averaged map, the stripes were clearly present. The significant thing about the interference in IF 1, in my opinion, was in the repeatability of the effect. This was not intermittent interference, but seemed to be present in every observation.

Table 6: Q–band noise measurement (map based)

Stokes	$S_{\rm rms}$ (mJy/bm)
I	0.761
Q	0.757
U	0.730
V	0.775

Q–band

In order to see if Q–band observations could be made part of the Standard Field tests, I did a short observation of 0212+735 at Q–band in the 1995 A configuration run. This confirmed earlier measurements of that source, showing it to be a suitable Q–band calibrator (Chandler 1995). So, I observed the Standard Field at Q–band in the 1995 B configuration run. Mars was used to set the absolute scale, with an observation of 3C286 as confirmation of the scale. Images made of the data showed that there were indeed no measurable sources in the field at Q–band. So, again, the performance could be measured by the fluctuations in the visibilities. The value of ΔS, averaged over all IF's, Stokes, and Real and Imaginary, was $\sim$ 203 mJy. This implied a value of $T_{\rm sys}/\eta_a$ of $\sim$ 865 K, and a value of $\sim$ 103 for Rick's K parameter. Note that this was at an elevation of $\sim 30°$, however, so these values cannot be compared easily with numbers at zenith. The values of the noise in the images is shown in Table 6, where the images were made with both IF's averaged. There were about 19000 visibilities in each "IF", so the predicted noise in the images from the value of ΔS was $\sim$ 0.740 mJy/bm, very close to the observed values.

References

Bagri, D. S., Noise Performance of the Upgraded L–Band System, VLA Test Memorandum No. 167, 1993

Bagri, D. S., and P. Lilie, System Temperature and Noise Cal Measurements Using Moon, VLA Test Memorandum No. 170, 1993

Chandler, C., VLA Calibrators at Q–band, VLA Test Memorandum No. 192, 1995

Crane, P. C., Observations of the Ubiquitous 1400 MHz Birdie, VLA Test Memorandum No. 133, 1982

Crane, P. C., and P. J. Napier, Sensitivity, in *Synthesis Imaging in Radio Astronomy*, (R. A. Perley, F. A. Schwab, and A. H. Bridle, Eds.), pp. 139–165, Astronomical Society of the Pacific Conference Series, San Francisco, CA., 1994

Janes, C., Strong Interference at the VLA, 1994, VLA–VLBA Interference Memorandum No. 5, 1995

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

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

Perley, R. A., J. van Gorkom, and A. Rots, Radio Interference in the 20–cm Band, VLA Test Memorandum No. 139, 1983

Thompson, A. R., J. M. Moran, and G. W. Swenson, Jr., *Interferometry and Synthesis Imaging in Radio Astronomy*, Krieger Publishing Co., Malabar, 1991