

VLBA SENSITIVITY UPGRADE MEMO 21

FINAL REPORT FOR THE VLBA 22 GHZ AMPLIFIER UPGRADE PROJECT

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ABSTRACT:

The low noise amplifiers in the VLBA 22 GHz receivers were replaced with Cryo-3 amplifiers from the NRAO Central Development Laboratory. The receiver temperatures were reduced by about a factor of about 2.4. Taking into account the contributions from spillover and the atmosphere, the sensitivity of the array was increased by a factor of 1.6. The reduction in system equivalent flux density (SEFD) by about 38% significantly exceeded the project goal of 30%. The improvement is equivalent to increasing the bandwidth or integration time by a factor of 2.5. The new amplifiers also made the effect of the atmospheric water vapor line at 22 GHz obvious so a new standard observing frequency was established at 23.8 GHz, away from the peak of the line. For continuum observations in winter conditions, the sensitivity at that frequency is about 1.8 times greater than with the old system at 22.2 GHz. The expected benefit in wetter seasons should be even greater. Major funding for the project has been provided by the Max-Planck-Institut für Radioastronomie.

THE UPGRADE:

The amplifiers used in the receivers on the VLBA represented the state-of-the-art in the 1980s when they were designed. For the higher frequency bands, there has been much progress in the technology of low noise amplifiers since that time and it is now possible to improve the receivers significantly by updating the low noise amplifiers (LNAs). In early 2007, a project was proposed to improve the 22 GHz (K-band) system temperatures on the VLBA by changing the amplifiers to new Cryo-3 devices from the NRAO Central Development Lab. See the proposal, which is available as VLBA Sensitivity Upgrade Memo #10, for most of the technical details of what was planned. A primary scientific driver for the project was to support the efforts to measure the Hubble constant using observations of H₂O mega-masers near the central black holes of various galaxies. But also, 22 GHz is one of the most popular observing bands, accounting for about 16% of all observing in recent years, so many projects will benefit. The project was funded by the Max-Planck-Institut für Radioastronomie and carried out during 2007, with completion in January 2008. The results of the project, in terms of the improvement in performance, are reported in this memo.

To facilitate this project, a new EVERETT (Expanded VLA Enhanced Receiver Evaluation Test Terminal) receiver evaluation rack was purchased so that the receiver characteristics could be measured without impacting the on-going construction of EVLA receivers. Also a technician was hired to do the work. These measures, which were part of the original proposal, allowed the project to be completed in one year without adverse

impact on the EVLA project.

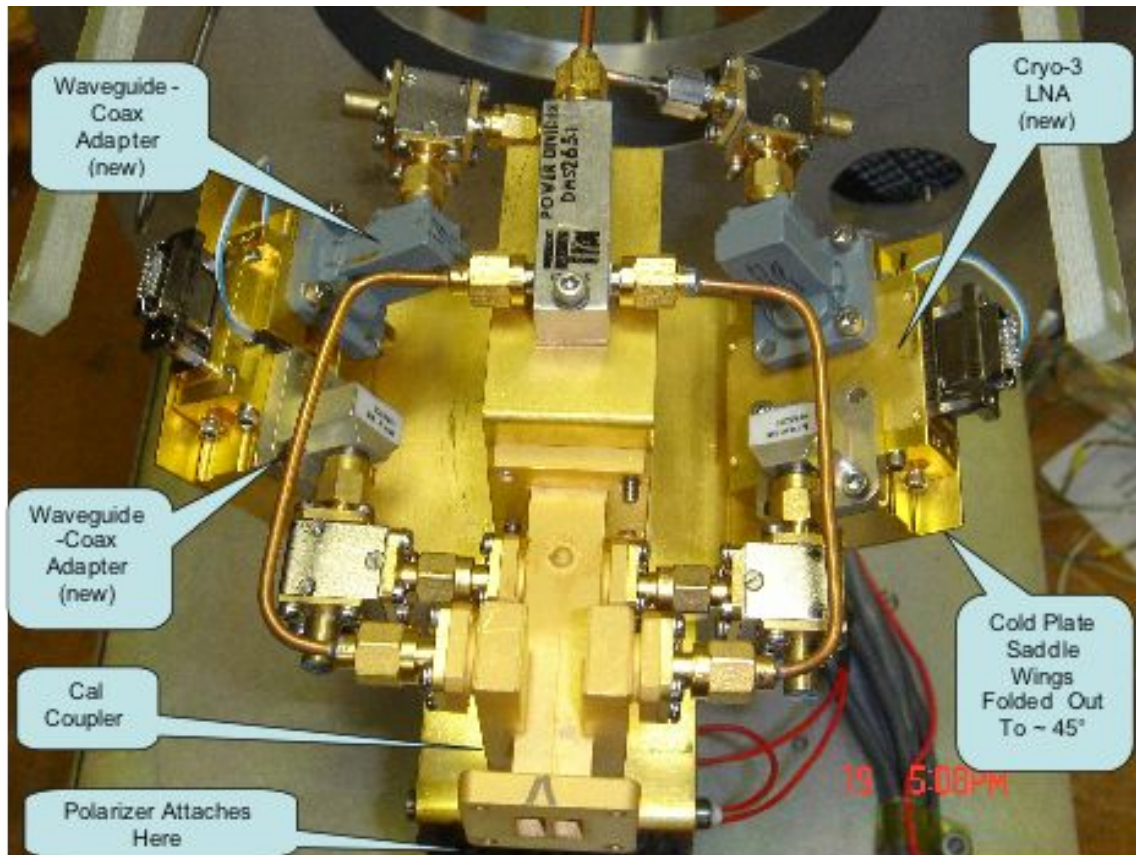


Figure 1: A photograph of an updated VLBA 22 GHz receiver.

A photograph of an upgraded receiver is shown in Figure 1. New elements of the receiver are labeled. The new LNA's required somewhat more room, so the mounting plates were modified. A small additional improvement could have been obtained by replacing some of the coax elements with waveguide, but this was not deemed to be cost-effective.

The gain in receiver performance is demonstrated in Figures 2 through 5. These plots show measurements of the receiver temperatures before and after the upgrade as a function of frequency. Average values for each receiver, plus an overall average, are presented as a bar graph in Figure 6. The improvement in average receiver temperature was a factor of 2.4. Prior to the upgrade, the average receiver temperature was 49K. After, it was just over 20K, a very significant improvement.

The installation of the new receivers provoked new determinations of the subreflector focus and rotation settings, which were found to not have been optimal at all antennas before the project. These were optimized, providing some additional improvement in overall sensitivity beyond that provided by just the receiver upgrades.

Figure 7 shows the zenith SEFD measured using most of the pointing and gain observations taken between October 2006 and January 2007, before the upgrade, and between January and April, 2008, after the upgrade. The SEFD is a good measure of the

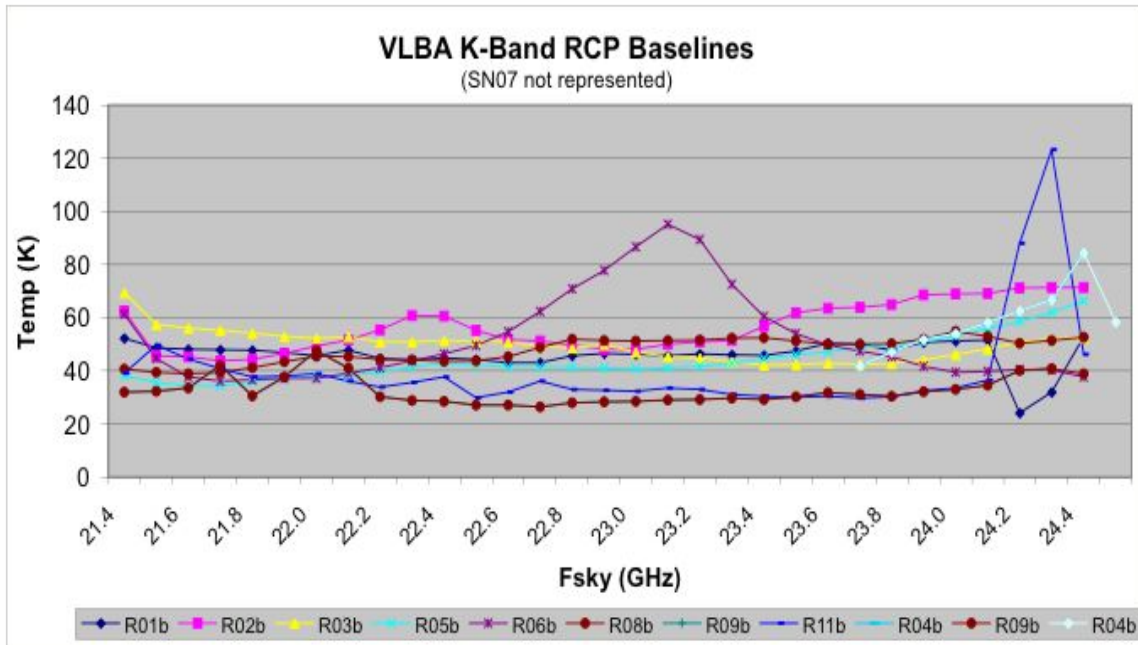


Figure 2: RCP receiver temperatures as a function of frequency before the upgrade for most, but not all, receivers. Each set of data points, connected by a line, is from the receiver of the serial number listed in the legend at the bottom. For most cases, the receiver temperatures were above 40K. The two exceptions are among the 4 receivers whose RCP channels had previously been upgraded to KH style amplifiers.

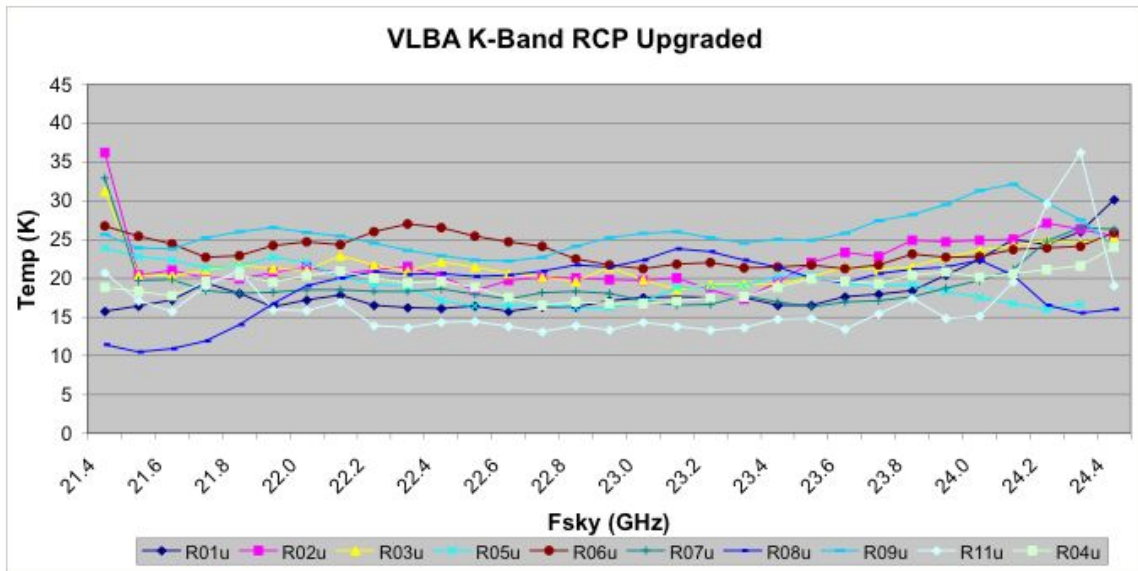


Figure 3: RCP receiver temperatures as a function of frequency after the upgrade. Now all receivers are between about 13K and 27K over most of the band.

overall sensitivity of an antenna taking into account the telescope gain, the receiver temperature, and the additional contributions to system temperature from sources outside the receiver such as spillover and the atmosphere. Because of the fitting methods used in the data analysis, the results presented correspond to the performance under the best conditions encountered during the period of the analysis. The average across sites of the zenith SEFD at 22.2 GHz before the upgrade was 796 Jy. After the upgrade, the average

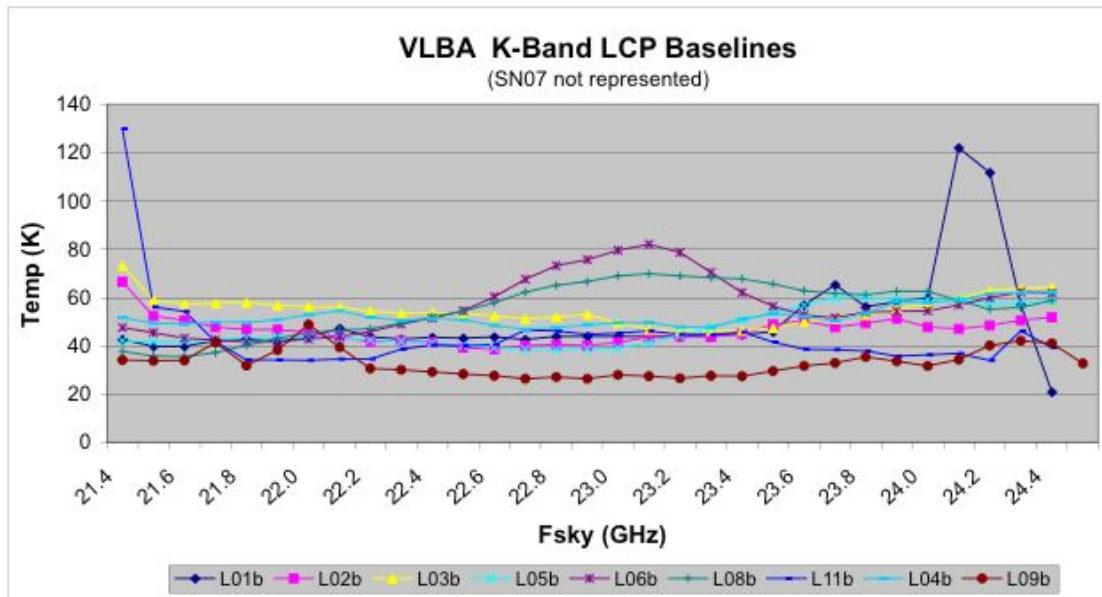


Figure 4: LCP receiver temperatures as a function of frequency before the upgrade. One of the LCP receivers had a previously upgraded amplifier. As with RCP, all others had receiver temperatures above 40K, and some were especially poor in the middle of the frequency range.

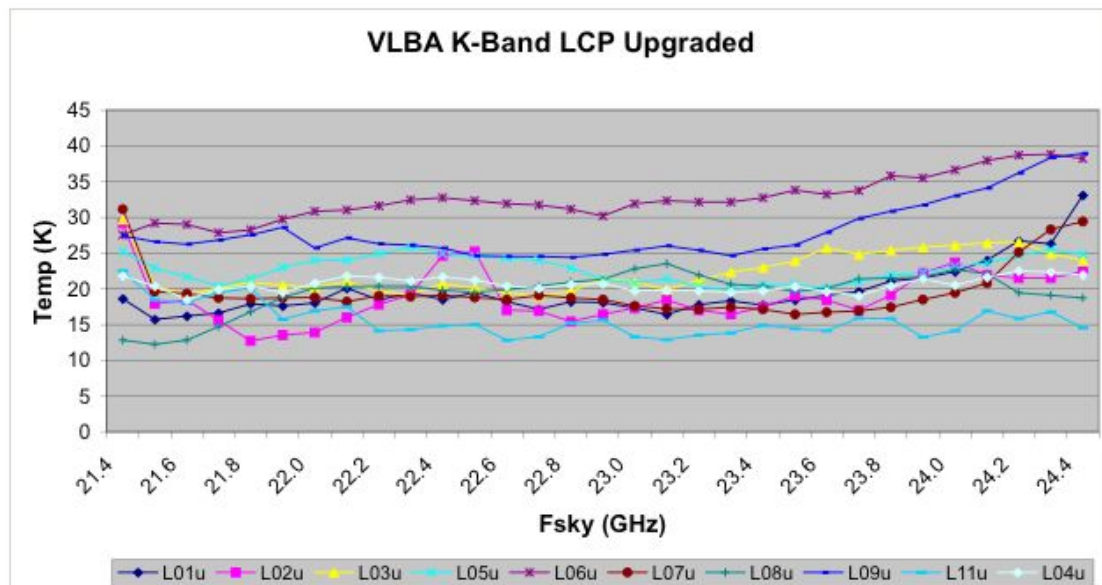


Figure 5: LCP receiver temperatures as a function of frequency after the upgrade. As with RCP, most of the receivers are between 13K and 25K.

zenith SEFD was 502 Jy. This 38% drop in SEFD corresponds to a gain in sensitivity is a factor of 1.6. This exceeds the project goal of a 30% improvement in sensitivity. To emphasize the impact of this improvement, a similar increase in sensitivity would require an increase in bandwidth (not possible for maser observations) or integration time by a factor of 2.5.

After the upgrade, measurements of the SEFD as a function of frequency made the impact of the atmospheric water vapor line at 22.2 GHz clear. See Figure 8 for an

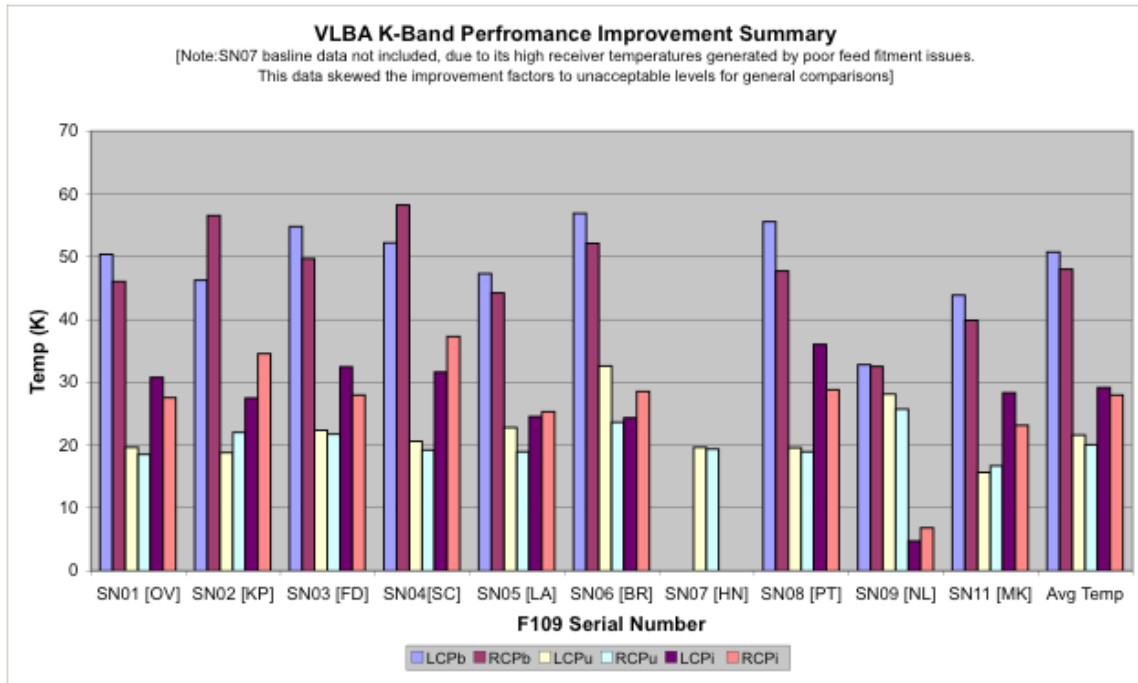


Figure 6: Summary of the receiver temperature improvements achieved with the upgrade by receiver . The antennas listed are the location of the receiver after the upgrade. The first two bars of each set are the receiver temperatures in RCP and LCP before the upgrade. The second two are for after the upgrade. The final two are the difference, indicating the improvement.

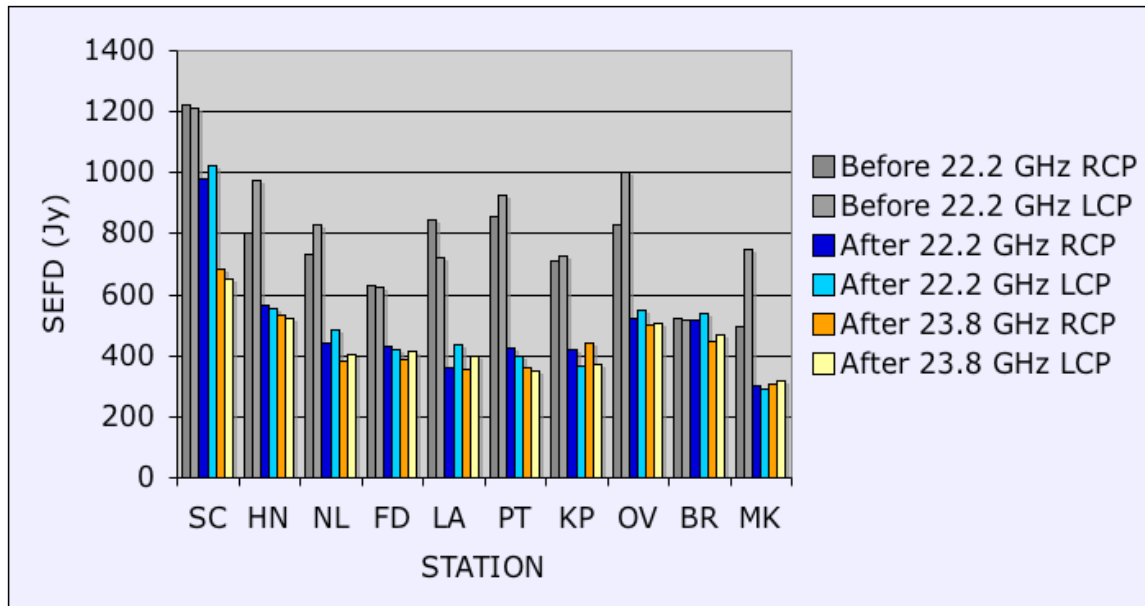
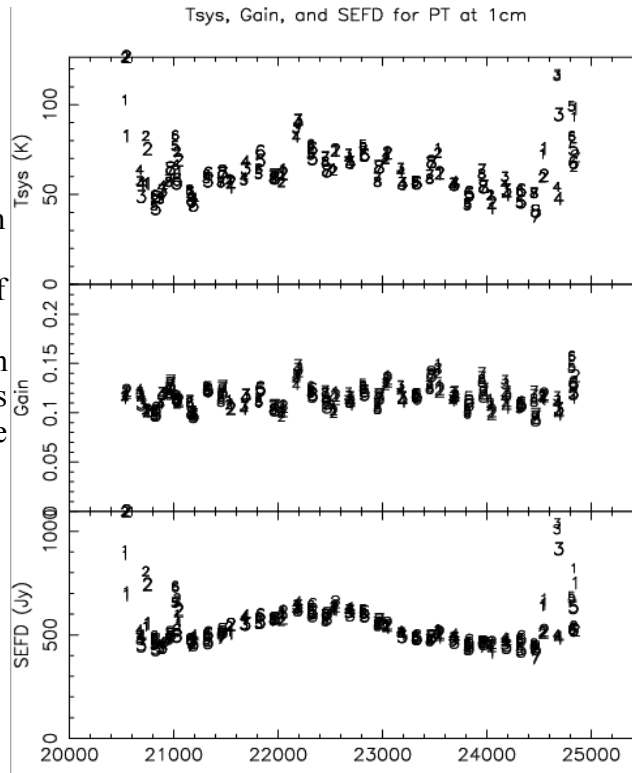


Figure 7: This bar graph shows the improvement in on-sky performance of the 22 GHz upgrade under good weather conditions. The first pair of bars for each station, one for each polarization, shows the SEFD before the upgrade. The second pair shows the SEFD after the upgrade, at 22.2 GHz. The third pair shows the SEFD after the upgrade at 23.8 GHz, off the center of water line. Note that BR had recent model amplifiers before the upgrade which is why it did not see much improvement. The benefit of 23.8 GHz is especially apparent at SC, by far the wettest site at this time of year.

Figure 8: Measurements of the system temperature (T_{sys}), gain, and SEFD over the full frequency range of the first of the upgraded receivers, that at Pie Town. The higher scatter in the T_{sys} and gain measurements is the result of uncertainties in the temperature of the calibration noise source. The SEFD is the ratio of T_{sys} and gain so is independent of the cal, and is smoother. Note the clearly visible atmospheric water vapor line centered at 22.2 GHz.



example of measurements over the full receiver bandwidth from Pie Town. Additional sensitivity for continuum projects could be obtained by observing at a frequency offset from the water line. Therefore, a new standard observing frequency was established at 23.8 GHz, in the 23.6-24.0 GHz protected band. With the upgraded receivers, the average zenith SEFD at that frequency is 441 Jy under good conditions. The sensitivity at 23.8 GHz is now a factor of 1.8 greater than the pre-upgrade sensitivity at 22.2 GHz, which should significantly benefit continuum projects. Traditionally 22 GHz systems have been far less sensitive than the lower frequency systems because of the difficulty of building the amplifiers and because of the high atmospheric contribution. But 441 Jy is starting to approach the 300 Jy typical SEFD seen in at the lower frequencies on the VLBA. That may encourage the use of the the 23.8 GHz band for projects that would previously have been done using the lower frequency receivers, but which could benefit from the higher resolution of the higher frequency. Note that, in wetter conditions, such as summer, the absolute sensitivity will be worse because of added water vapor. But the difference between 22.2 and 23.8 GHz will be even higher than the winter numbers shown in Figure 7 indicate, making it even more beneficial to shift continuum projects to 23.8 GHz.

The upgraded receivers have approximately the same overall frequency coverage as the old VLBA receivers, as shown in Figure 8. This frequency coverage is set primarily by the polarizer which was not changed. A possible future VLBA enhancement would be to increase the bandwidth, probably by installing EVLA style receivers. But such a project would be several times more expensive than the current upgrade.

INSTALLATION:

The upgrade was accomplished with minimal impact on on-going VLBA observations,

even at the 22 GHz observing frequency. This was done by taking advantage of the fact that there is a spare receiver so that there could always be at least one receiver in the lab being upgraded while there were frequent periods when there were working 22 GHz receivers at all antennas. Taking into account the time needed for shipping, this required that there be periods when one receiver was in shipment while another was being worked on, so there were periods when 22 GHz projects with all 10 antennas could not be scheduled. But those periods were of limited duration. Since the large majority of VLBA projects are dynamically scheduled, it was not hard to avoid scheduling 22 GHz projects during these periods.

The upgraded receivers became operational on the following dates:

- 1) Pie Town 2007 Feb. 6
- 2) Los Alamos 2007 Apr. 3
- 3) Kitt Peak 2007 May 10
- 4) Fort Davis 2007 May 29
- 5) Owens Valley 2007 Jun. 25
- 6) Brewster 2007 Aug. 7
- 7) North Liberty 2007 Sep. 12
- 8) Hancock 2007 Oct. 17
- 9) Mauna Kea 2007 Nov. 15
- 10) St. Croix 2007 Dec. 18
- 11) Spare 2008 Jan. 15

SUMMARY

The 22 GHz LNA upgrade project has been completed and has provided a very significant increase in the performance of the VLBA in the 1.3 cm band. The project goal of a 30% performance increase was exceeded, with an achieved increase of 38% under good observing conditions. The gains for many continuum projects will be even greater with the establishment of a new standard observing frequency of 23.8 GHz, which is significantly less affected by atmospheric water vapor.

ACKNOWLEDGMENT

We gratefully acknowledge the funding from the the Max-Planck-Institut für Radioastronomie that made this project possible. The improved performance should significantly enhance a number of science programs being carried out by MPIfR scientists as well as the rest of the user community.