Science Goals and First Pixel Test Results

K band Focal Plane Array Development Project

January 30, 2009 Critical Design Review Summary

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GBT observations at 18 to 26 GHz have been conducted for many important reasons, including spectral line studies for astro-chemistry, mega-maser observations for cosmology and VLBI observations to measure the velocities of components of jets near black holes. The K-band focal plane array must be able to perform these tasks and greatly improve on the mapping speed and quality of GBT observations.

We quickly review the science goals for the project and then present the results of first tests of the single pixel (K1) on the GBT.

Science Goals

The science goals for the K-band Focal Plane Array (KFPA) remain as described in *Science Case for a K-Band Focal Plane Array for the Green Bank Telescope* [1] Contributed to by Larry Morgan, D.J. Pisano, Jay Lockman, James Di Francesco, Jeff Wagg, & Jurgen Ott (dated 9/24/2007). Here we summarize and annotate that document.

The prime science motivation is mapping the structure of star forming regions to understand the process of star formation and the associated molecular processes. KFPA will be the best instrument for study of the chemical processes which create larger and larger molecular species. By allowing observers to go beyond simple study of regions of peak molecular emission, the KFPA will be a key instrument for revealing the processes by which the interstellar medium forms pre-biotic molecules.

First observations will reveal both the masses and dynamics of starless cores in large samples, and thus give key insights into the origin of stellar mass, using temperatures and line velocities derived from NH_3 observations. Our 7 pixel array will yield almost an order of magnitude increase in efficiency when mapping at K-band. This increase would, in turn, allow a large number of cores in nearby star-forming regions, already located from sub-millimeter continuum surveys, to be

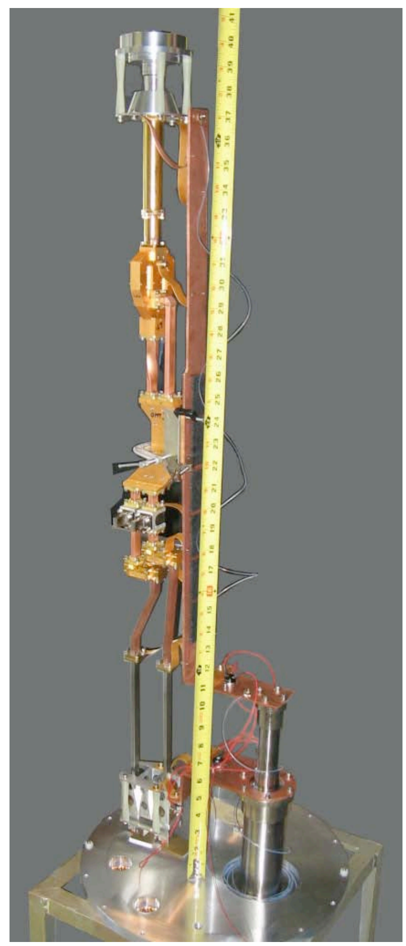
[1] At: https://safe.nrao.edu/wiki/pub/Kbandfpa/SciPlanning/KbandScienceLong.pdf

studied. The array's angular extent is well matched to the sizes of core-bearing filaments in the Gould Belt clouds. The resolution of the GBT at 24 GHz is equivalent to the Jeans length of gas at 10 K and 10^6 cm^3 towards the nearest molecular clouds at 125 pc (i.e., Taurus and Ophiuchus), allowing turbulent fragmentation to be directly probed; more distant clouds can benefit from combination with EVLA data to reach such resolutions. Of all single-dish K-band telescopes in the world, only the GBT with a multi-pixel array has the resolution and sensitivity to make large-scale observations of NH_3 across populations of starless cores needed to understand the origins of stellar mass and dynamical motions.

A prime science goal for the KFPA is chemical studies of star-forming regions and the Galactic Center. A second prime goal is study of Sub-millimeter and Millimeter peaked Galaxies (SMG) which are actively undergoing star formation. Because of the “negative K-correction” in the strongly self-absorbed star forming regions, the SMG galaxies can be observed out to z > 4 with the GBT.

The large format array (61 > N > 7) will be used to make the first complete survey of masers in Local Group galaxies.

Equipping the GBT with a K-band focal plane array will complement the capabilities of the EVLA by providing the context for higher angular resolution studies with the latter. Combining GBT and EVLA observations will provide a complete picture of molecular emission at all spatial scales. The GBT is already the premier telescope at K-band and is vastly oversubscribed given the available time at these frequencies.



With a full 61 pixel focal plane array, the GBT will be able to map the sky, at these frequencies, almost two orders of magnitude faster than any other telescope in the world.

First Pixel Testing

The first step in developing the full 61 pixel array is prototyping the first pixel hardware. The development of the first pixel required extensive design and construction expertise by the NRAO engineering groups. The tests involved astronomical observations of point sources of known brightness, spectral line observations of bright galactic radio sources and first mapping tests with the single pixel.[2]

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[2] At: https://safe.nrao.edu/wiki/bin/view/Kbandfpa/SinglePixelTesting

First Astronomical Tests - September 11, 2008

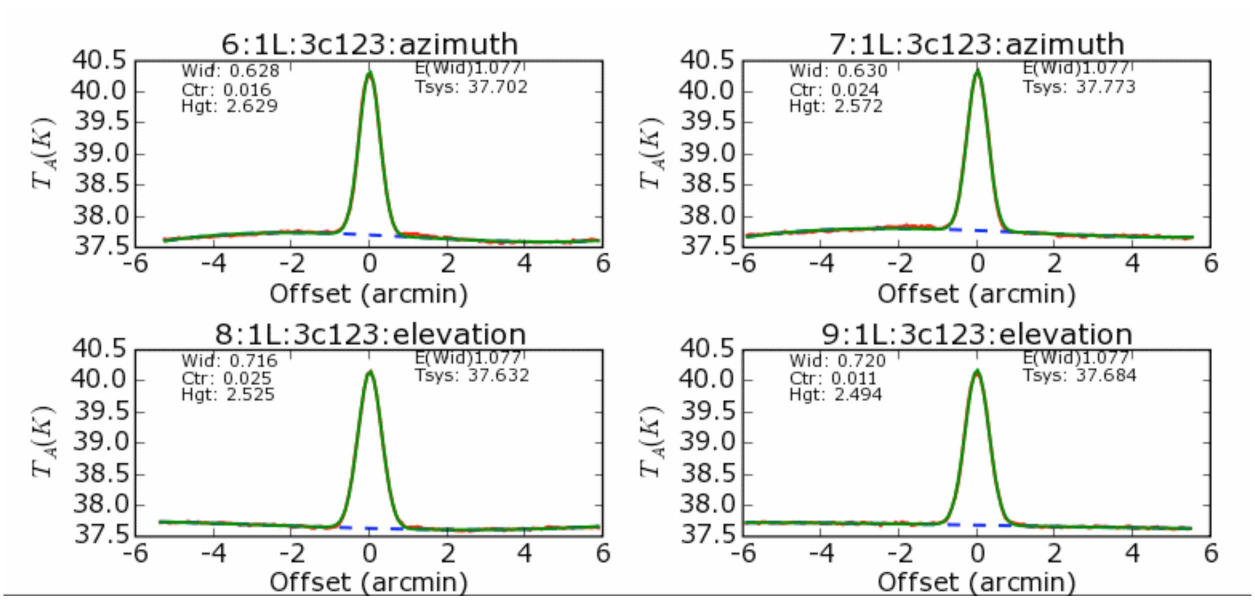
The first pixel hardware was built in 2008 and put on the antenna on September 9, 2008. The first astronomical tests were from 1:00 AM to 9:00 AM on September 11, 2008. In general, these tests were successful, and pointed out additional efforts that are required to completely validate the first pixel hardware. Below is a list of tests/checks that were performed, with notes on results.

The First Pixel Dewar was placed in the C-band slot in the GBT turret. Since the C-band Front end is a single pixel front end, the GBT observing system was configured, using ASTRID as though the C-band Rx was still in place, then CLEO was used to update the signal path connections to route the signals to the back-ends.

There were extensive tests of the First Pixel hardware, required to set the proper voltages, gains and temperatures for proper functioning of the Dewar and electronics. A web page was created to allow monitoring of the hardware
(See http://172.23.1.79/index.html, only visible from an NRAO network)

These tests indicated that there was insufficient gain in one of the two polarizations. The cause of the low power was unknown at the time of the tests. The remaining results are based on use of a single good channel.

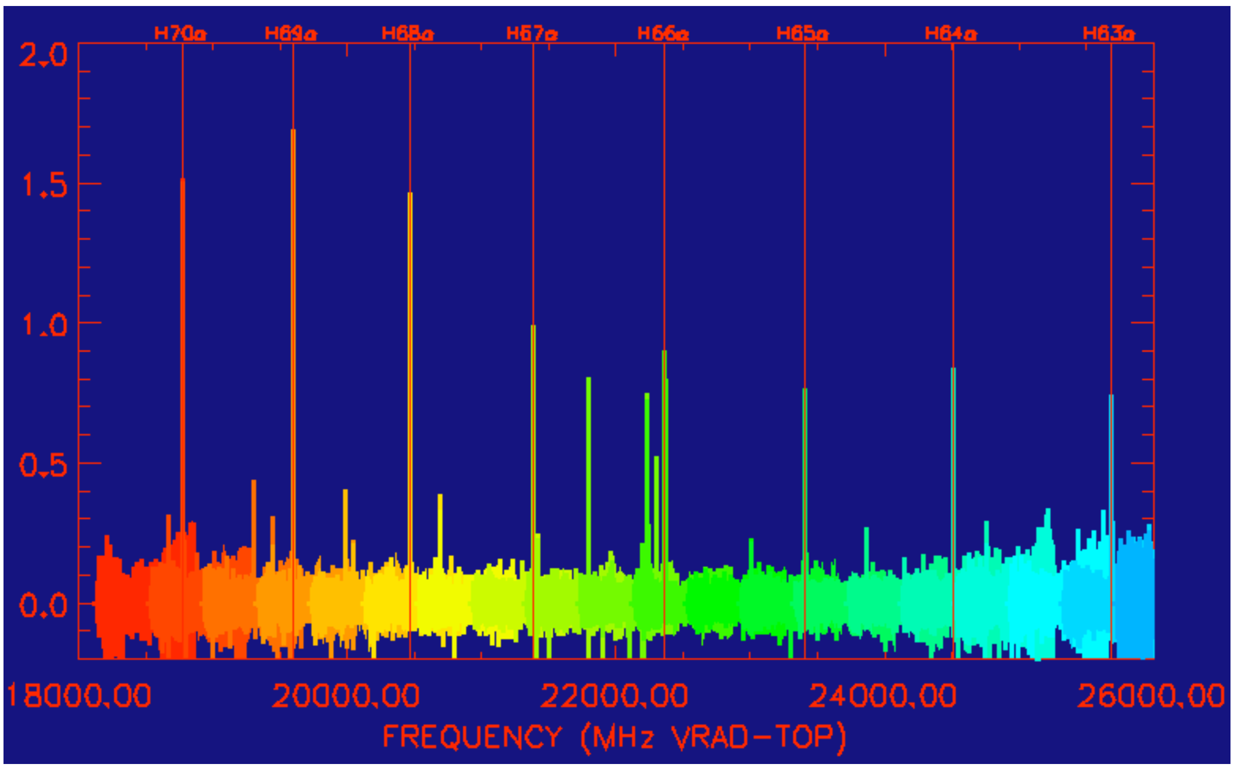
The weather was overcast, but the system temperature were reasonable, ranging between 50 and 100 K, in agreement with the CLEO weather forecast for this date.
The initial peak and focus observations went nearly flawlessly.   Even though there were no calibration noise diode values accessible from Astrid, we were able to
perform the peak and focus tests rapidly by creating custom Astrid scripts.



First Peak and Focus observations with K1 towards source 3C123

The spectral line observations also went well, although the LO up/down conversion equation was not implemented in Astrid. We were able to quickly recognise features in the band pass spectrum indicating the system was performing in a reasonable manner. Previously, lab tests had shown strong IF spurs were being generated by the first down conversion unit. Our astronomical tests confirmed these IF spurs. After making a number of observations with different LO settings, we were able to isolate the origin of the IF spurs. This topic is discussed in more detail in other documents.

By crafting scripts for data reduction in IDL, we could suppress the IF spurs, for plotting purposes.



Band Scan of Orion A with K1, showing a series of Hydrogen and Helium recombination lines as well as the water line and some residual IF spurs.

Feed Gain at 3 locations of the array - October 6, 2008

On October 6, 2008 from midnight to 8:00 AM, Steve White, Bob Simon and Glen Langston ran tests of the first pixel of the K band Focal Plane Array. We measured the system performance by peak and focus observations of 3C48 at 19 and 25 GHz with the feed located in the nominal center position and also offset in the cross elevation and elevation positions. The test report describes the measured intensity as a function of feed offset location.[3]

To summarize the report, we did measure the gain as a function of offset position. For these tests the offset was 3.8 arc minutes, relative to the center position. At 19 GHz, we found a 5 +/-2 % drop in gain from the center position to the offset positions. At 25 GHz, we found a drop of 5 +/- 5 % drop in the gain. The signal was weaker at 25 GHz, and the measurements were probably effected by the IF spurs in down conversion during the measurement.

Comparison of the GBT K0 and Single Pixel performance

Observations were made with the current 4 beam K band receiver (K0) and with the single pixel receiver (K1) in order to directly compare the performance of the two systems. The "High" K-band system was used, so the performance was only compared above 22.5 GHz.

The observations consisted of Peak and Focus observations of 3C48 and by spectral line observations of the Taurus Molecular Cloud.

The first 36 scans were performed using the 4 Beam receiver and the remaining scans used the single pixel receiver. All observations were performed without Doppler tracking. The test report compares the single pixel and K band 4 beam receiver system temperature as a function of observing frequency.[4]

Summarizing the results: the system temperature of the single pixel receiver was higher than the current GBT 4 beam receiver. There were two causes of the increased system temperature. The first was due to the strong IF spurs in the down conversion unit and insufficient gain at the higher frequencies. This issues are being addressed by the down converter redesign work. The second cause of the higher system temperature was due to noise contribution due to out-of-band noise generated by post-amplifiers and the integrated down-converter module (IDM). After the IDM there were no band pass filters. In the first tests, we used the all-pass filter in the IF rack, when measuring the total power.

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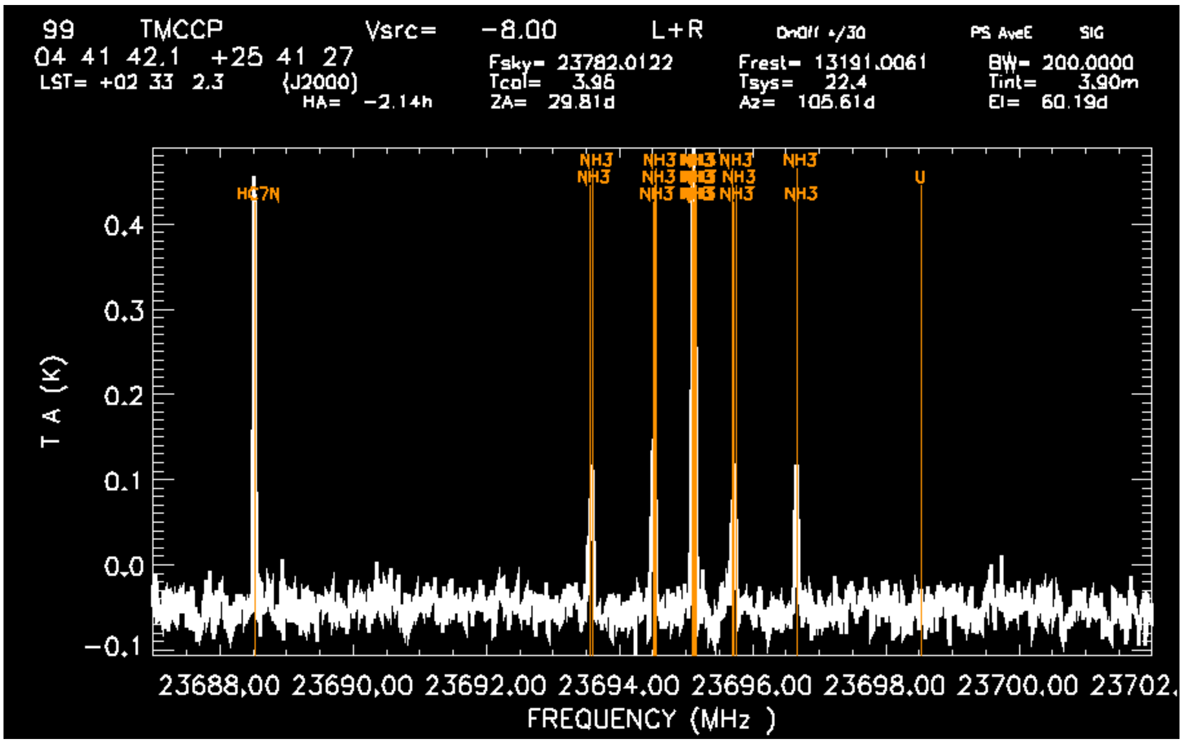
[3] At: https://safe.nrao.edu/wiki/pub/Kbandfpa/TKfpa08Oct06/observingLog08Oct06-II.txt

[4] At:https://safe.nrao.edu/wiki/pub/Kbandfpa/KbandTests08Oct12/observingLog08Oct12-II.txt

After the amplitude comparisons, we configured the GBT for a single 200 MHz wide band, centered on the ammonia (NH_3) 1-1 and 2-2 lines. In addition, the molecule HC_7N was coincidentally in this same frequency range. The plot below shows these lines.



K1 spectrum of Taurus Molecular Cloud Cyanopolyyene peak.   The Ammonia and HC7N lines are clearly visible in a 4 minute observation.

Molecule Mapping Tests

As a tests of the stability of the receiver system and to test mapping software, we performed a mapping test with the K1 receiver.   We configured the K1 receiver (without doppler tracking) for observations of the lines shown in the previous figure. We then used Astrid to command a 20 arc-minute square map of the region. The two images produced from the spectra are shown below.

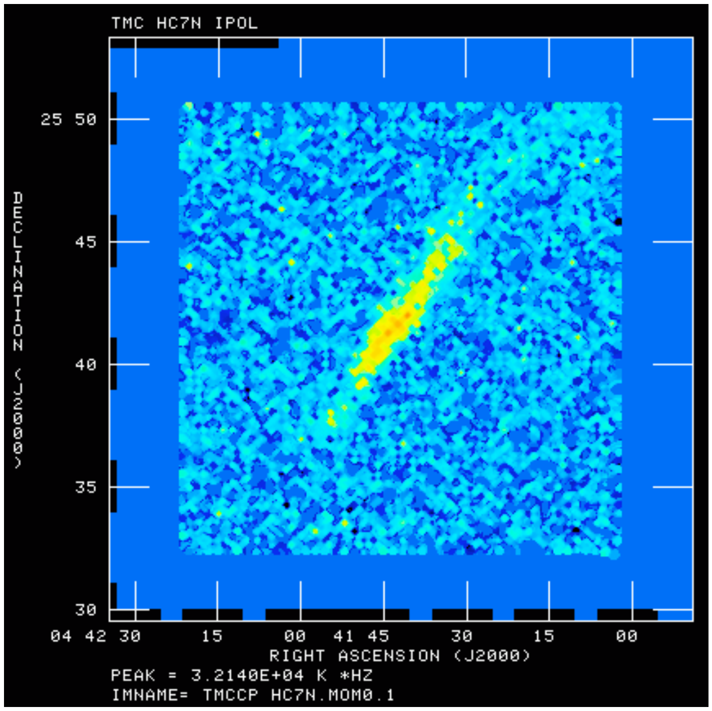


Image of the HC7N molecule distribution in the region surrounding the Taurus Molecular Cloud.The image region is 0.5 degrees square. The integration time for each pixel is 1 second.

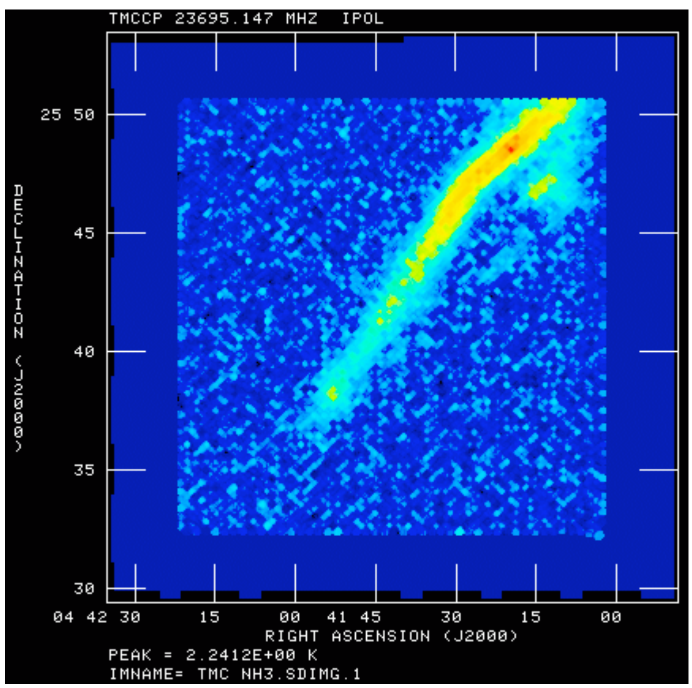


Image of the NH3 molecule distribution. Same mapping parameters as before.

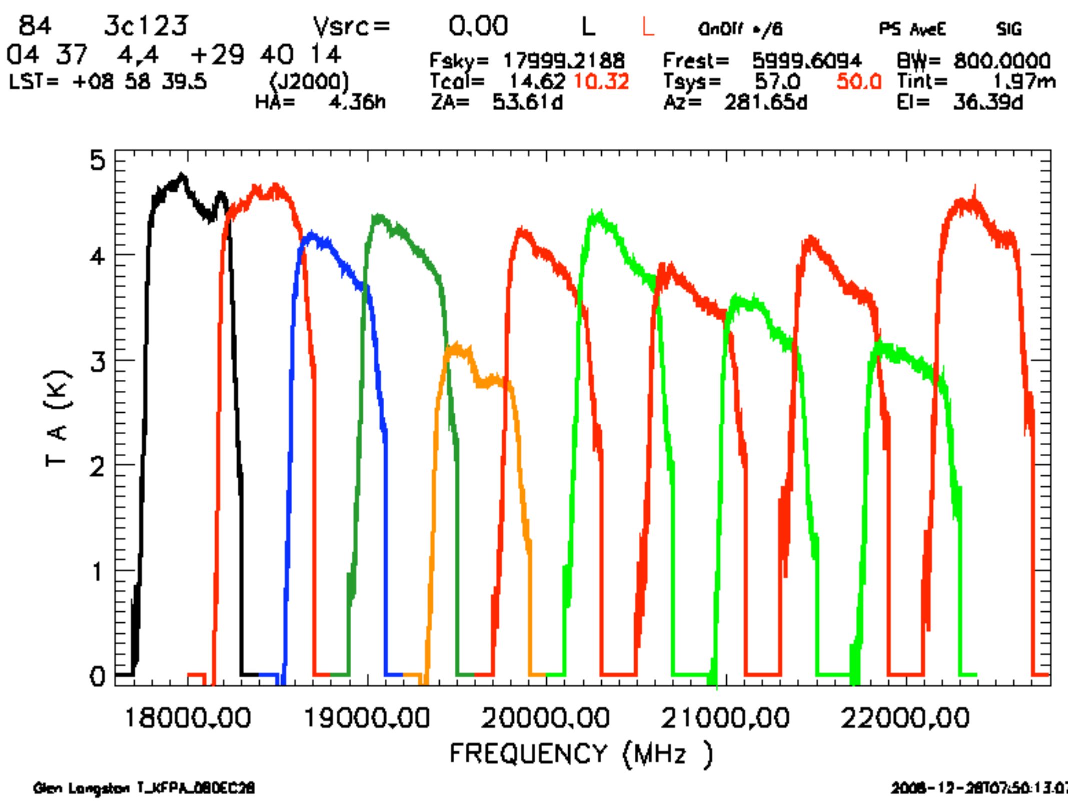
K-band FPGA Single Pixel Test Report for 2008 December 28

These single pixel tests compared the K1 performance with the current GBT K-band receiver (K0). The observations were made under reasonably good weather conditions, but there was some humidity, which makes the direct comparison more difficult. We also searched IF spurs that might have been generated by the second type of down converter unit.   In these tests, the IF-rack 320 MHz wide band pass filter was used to limit the out-of-band contribution to the measured system temperature.

The summary of our findings are:

* The system temperature performance of the K0 and K1 systems are similar.
* No IF spurs were found in the K1 spectra obtained. Due to a lack of time, only part of the band was scanned for IF spurs.

We observed source 3C123 with the K0 feed at 19, 23, 25 and 21 GHz (in that order), to get representative measures of the system temperature across the band. We also observed the same source at 25, 19, 21 and 23 GHz with the K1 feed.[5]   The observations showed sum differences in the intensities measured for the two polarizations.   This may be due to errors in the calibration process. We are in the process of reviewing the calibration data.



[5] At:https://safe.nrao.edu/wiki/bin/view/Kbandfpa/KbandTests08Dec28

The second part of our test was a search for IF spurs that could have been generated by the down conversion units. The check was made by stepping across the spectral band from 18 to 22.4 GHz, performing 2 minute signal-position, reference-position observations. The results of these observations are shown in the figure above. There data are calibrated using the laboratory measurements of the noise source values.

Summary

Tests of the single Pixel prototype of the KFPA have yielded encouraging results.   The first spectral line tests showed some IF spurs in the spectra that are now understood. Our tests of second down converter unit did not find any IF spurs in the frequency range studied.

The system temperature performance of the K1 feed is similar to that for the K0 feed.

The science priorities for the KFPA are more important than ever, and we should move forward with construction of the full array.