# Subject: K7 System Checkout and First Use Case

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This document summarizes the requirements for three fundamental KFPA use cases for the first system tests of the KFPA 7 pixel receiver (K7). We assume that the single pixel observing modes will be preserved during the initial checkout, and that we are primarily concerned here with modes that use 7 pixel configuration.

The three primary use cases are:

1. Pointing and focus continuum check of antenna pointing and comparison of beam gains. Data will be obtained with the DCR and reduced using ASTRID.
2. On-Off spectral line check, using two (observer selected) beams. Data will be obtained with the spectrometer in the 50 MHz bandwidth, 7 beam mode.
3. Mapping, spectral line using all 7 beams. Data will be obtained with the spectrometer in the 50 MHz bandwidth mode.

We discuss features of these use cases below. These use cases are based on experience with GBT mapping observations and the types of observing modes described by Lockman and Prestage (April 2007) and Pisano (August 2008). We describe in detail the first spectrometer mapping mode.

The first two cases are important for checkout, but will not be processed by the mapping pipeline. The third case is the first use case to be processed by the data pipeline. Additional use cases will be described in separate documents.

**Background**

The single pixel (K1) tests were successful using the existing ASTRID observing modes. We expect that these modes will also be valuable for initial tests of the seven pixel array (K7). The significant additions required for the first K7 tests are:

1. Support for the K7 LO chain, allowing convenient setting of the frequency of observation.
2. Support for selecting individual beams of the K7 system for individual peak and focus tests.

The very first tests of the 7 beam system will be carried out in “single pixel” mode, using the existing ASTRID capabilities, with the required capability for accurately setting the KFPA IF/RF frequencies. We assume that the single pixel mapping modes will be preserved for use with the K7 system and that the observer will be able to select the single pixel that will be used in these mapping observations.

Different observers will want different K7 mapping modes. For the initial checkout observations, we will want to use a relatively simple observing mode. We assume the initial observing mode will position switched (not frequency switched), however frequency switched modes will be required for later observations. These use cases are described elsewhere.

## Pointing

The important first additions for the K7 checkout are pointing methods that provide quick and efficient estimates of the GBT pointing offsets and also show the proper operation of all seven beams. The existing ASTRID pointing scripts have space allocated for showing 4 scans, the first two back and forth in the cross-elevation direction, followed by scans in elevation.

With many beams, many possible pointing sequences are possible. For the sake of minimum changes (and also to keep the pointing time approximately the same), we suggest keeping 4 scans per pointing observation. Also we suggest keeping the same backwards and forwards motion for cross-elevation direction. After the first two scans, then the cross-elevation offset will be calculated and applied. The next two scans are diagonal, crossing the expected location of the other 4 beams, plus re-crossing the center pixel twice. This pointing mode is shown in Figure 1. During the observations, the observer will select the signal beam (usually the center beam) and the reference beam. The pointing offsets will be computed for the difference between the signal and reference beam data. The observer will have the option of selecting both the signal and reference beams.

If the initial pointing offsets are large, we expect that repeated pointing observations will allow convergence to a good pointing offset, as is generally the case for GBT observations at 18 to 26 GHz. We do not consider the various options required if a pixel has failed.

The pointing observations could be made quicker and more efficient by combining the four motions into a single daisy motion, and using the pointing offsets computed from the different beams (as well as the signal and reference beams). These improvements are not needed for initial checkout.

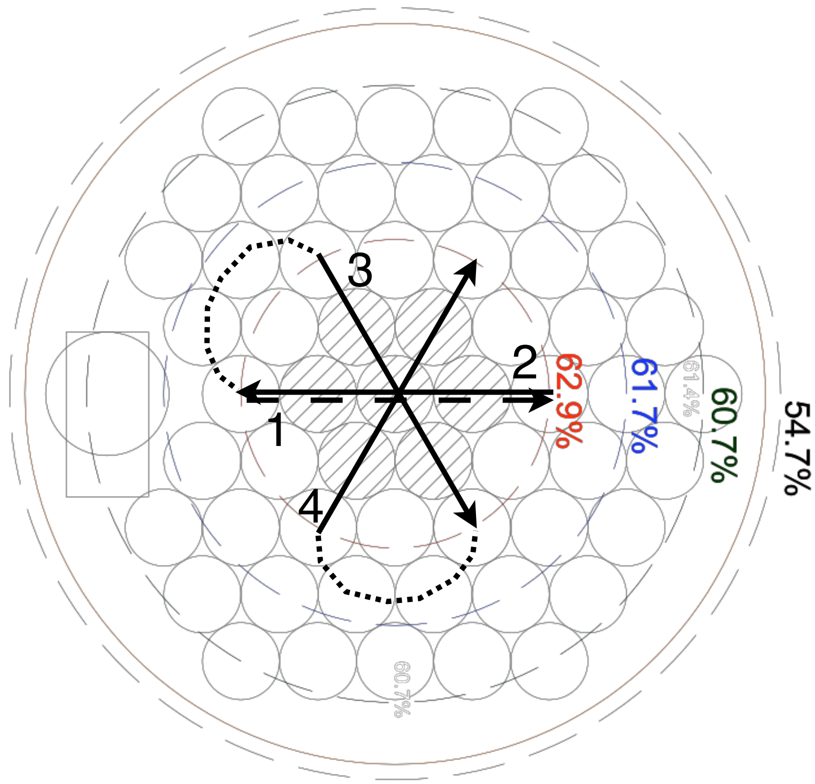


*Figure 1: Schematic of the sequence of 4 pointing motions making up a pointing scan.*

After the pointing observation, the same reference beam will be used for the focus observations. The focus observation will be carried out in the same manner as is done for the dual beam receivers.

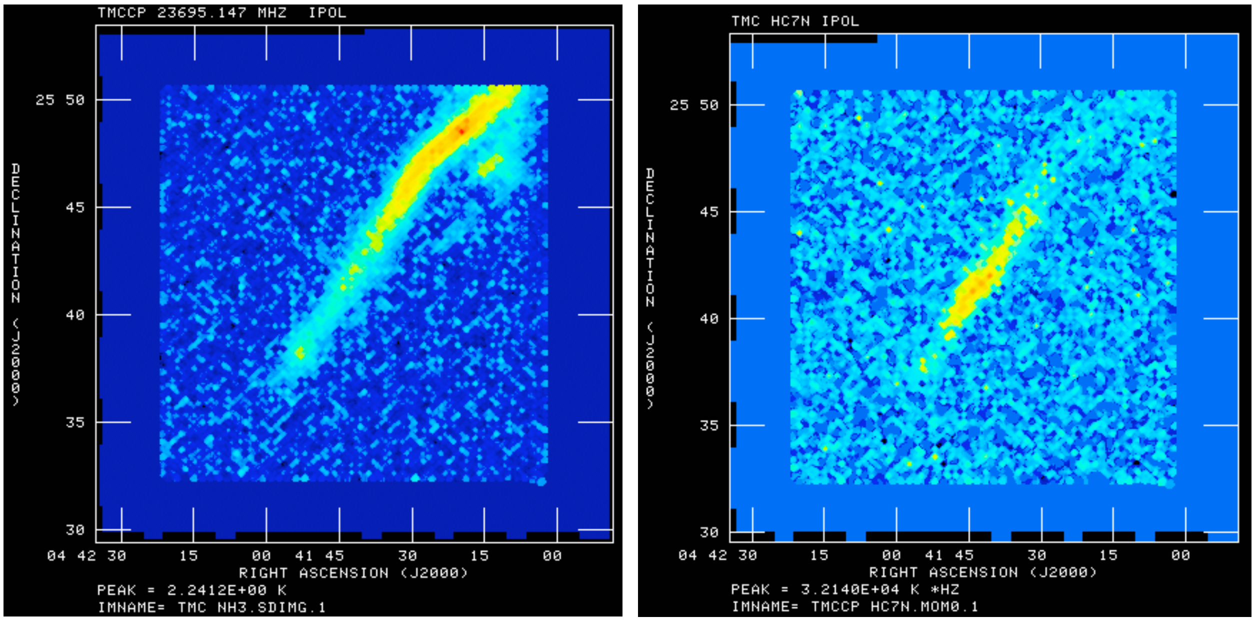


*Figure 2: K1 images produced with 1 second per integration dump times and 1/3 of a beam separation of the integrations.*

**On-Off Spectral Line Verification**

Before commencing a spectral line map, the observer will need to confirm proper operations of the spectrometer, usually by observation of a bright spectral line source, with known spectral features. We expect the observer will have the same ASTRID capabilities for single beam observations, that are currently available. In addition the observer will be able to perform a dual beam observation using the existing ONOFF, OFFON or NOD options. The observer will be able to select the signal and reference beams.

This observing mode will also be valuable for selected observations of compact radio sources. All the existing spectral line capabilities for dual beam observations (e.g. several spectral bands, frequency switching) should be preserved for the dual beam use of the K7 system.

The On-Off spectral line observing mode is constructed from two TRACK observations, while taking data from all 7 beams of the KFPA. We anticipate that the observers will normally use the 50 MHz observing mode. The use case for 12.5 MHz mapping is described in a separate use case document.

**K7 50 MHz Mapping Use Case**

The primary observing initial mode for the K7 array will be On-The-Fly (OTF) raster scanning of a rectangular region with all seven beams. We first discuss qualitatively the type of observation envisioned, followed by a more detailed discussion of the individual observing steps and the process for calibration and mapping.

The observer will observe a reference location at the beginning and end of each region or observing session. In the initial tests, the observer will be sampling the sky once per second and recording data for both polarizations of all beams. The prototypical observation is an observation will be carried out in the 50 MHz mode, allowing simultaneous observation of the $NH_3$ 1-1 (23,694.506 MHz) and 2-2 lines (23,722.634 MHz). The RF system would be configured for observation in a 50 MHz band centered on the average frequency, 23,708.57 MHz.

The minimum spacing between sky samples is half a beam width, and a more reasonable separation is a third of a beam width, in order to assure of minimal smearing during on the fly mapping. Initially we will image small regions, on order of 10x10 arc-minutes, and will observe the central regions with all 7 beams (the outer edge regions will only be observed with a small number of beams). For the sake of round numbers, we assume 30" FWHM beam size and 10" sampling. The slew rate during mapping is 10"/second (10'/minute or $10^o$/hour or $0.17^o$/minute). At this rate, a 10'x10' square region could be mapped in 3600 seconds, plus stopping and starting time of approximately 10%. The total observing time for a 10'x10' region would be 90 minutes, with an integration time of 7 beams x 9 samples per beam x 1 second = 63 seconds per beam. Figure 2 shows an example of this type of observation, done with the K1 system.

Assuming the same observing parameters, the time to observe one square degree is 54 hours. To cover larger angular areas, we must move faster, so we should target at least a 0.25 second dump time for all spectra. That could reduce the one square degree time to 14 hours. Note the time to map the whole northern sky with the K7 system is large, 290,000 hours or 12,000 days.

Calibration will be done by performing (Signal - Reference)/Reference calibration of each 1 second integration, for each beam independently of the others. The Reference spectra will be computed from the average of 1 minute observes of a reference location before and after each 10x10 region. Between 10x10 region observations, the pointing and focus observations will be repeated.

After calibration, the data will be converted to a format compatible with the image gridding software. Data from each beam will be independently imaged and inspected. After completing the images produced from each beam, the 7 independent images will be averaged.

This type of calibration, using the same reference for each pixel of the image has the advantage that the reference spectra add little to the final noise in the spectra for each pixel, but has the disadvantage that images for each region will have common features, due to sharing the reference spectrum. It will be important to check that the reference spectrum does not have significant emission in the frequency ranges of interest. This is usually possible for molecular line observations (but very difficult for neutral hydrogen observations). Using the same reference spectrum for the entire map is not just from emission in the reference or even from RFI in the reference, but any artifacts that change between the mapping and reference scans (such as the baseline ripples seen in Ka-band observations, or even the apparent weak spectral line seen by Wagg et al. using the Ka-band receiver). We must plan on performing detailed baseline stability tests during instrument checkout, to determine the optimum switching algorithm.

We take the experience with the process of GBT mapping as the starting point for definition of the first K7-Mapping use case. Upon consideration of the mapping process, we felt that it would be good for the observer to declare the start and end of a pipeline mapping session. Later observing system revisions could infer the start and end of pipeline map sessions.

**Observing Steps in Spectral Line mapping**

In order to fully define the mapping pipeline steps, we need to first define the observing and calibration steps. The steps for use Map Case 1 are given in Table 1. In this observing case, the first 3 steps are for system configuration and checkout. After this phase, the observer declares the start of a pipeline observation (4). Then begins an absolute calibration observation (5); there are a number of options for absolute calibration. The most common is a spectral line calibration observation of some source with documented spectral properties (e.g. 3C48, 3C286, a reference location or a planet). The most common spectral line absolute calibration techniques must be documented. These will be reported separately, and the output will consisted of vectors of gain versus frequency that are applied to later observations.

After begins the observation of the map reference location, that will be used to calibrate all the map spectra. One requirement is that the calibration observation should not contribute significantly to the noise of the individual integrations. In this case, the calibration observation (a TRACK) would have 100 times the integration of an individual integration. For a one second image samples, a two minute reference observation would be sufficient. Next comes the first mapping session, using the appropriate ASTRID MAP procedure. During the observation, ASTRID would occasionally display calibrated integrations Intensity_Calibration*(signal-reference)/reference spectra for each beam and polarization. Finally, we observe the reference location again, and record spectrum of the reference location. It is not necessary to display every integration.

After an interval, the GBT must be re-pointed and refocused (steps 9 and 10). Currently the GBT is also usually re-balanced, that is the RF/IF gains are changed. This prevents convenient use of the reference spectra for use in calibration of non-adjacent mapping observations. (A system of recording and accounting for gain differences between pointing observations would allow for using more reference observations for the calibration process.)

The reference observations, and mapping observations are repeated until the observation is complete (steps 11, 12, 13). The final step is flagging the pipeline observation is complete, step 14.

| | Observing Step | Procedure | Reduction Responsibility |
|---|---|---|---|
| 1 | Point | K7-Point | ASTRID |
| 2 | Focus | K7-Focus | ASTRID |
| 3 | Spectral Band Check Source with known spectral features. | ONOFF | ASTRID, display spectral band |
| 4 | Start Pipeline | STARTPIPE | PIPELINE, initiate data grouping |
| 5 | Intensity Calibration: Observe Astronomical Source with known Spectrum | ONOFF | PIPELINE, compute model spectrum for selected frequency range. Compute gain as a function of frequency channel. |
| 6 | Reference Spectrum | TRACK | ASTRID, display band pass PIPELINE, sum all integrations |
| 7 | Map Region | K7-Map-1 | ASTRID, display latest (sig-ref)/ref |
| 8 | Reference Spectrum | TRACK | ASTRID, display band pass PIPELINE, sum all integrations |
| 9 | Point | K7-Point | ASTRID |
| 10 | Focus | K7-Focus | ASTRID |
| 11 | Reference Spectrum | TRACK | ASTRID, display band pass PIPELINE, sum all integrations |
| 12 | Map Region | K7-Map-1 | ASTRID, display latest (sig-ref)/ref |
| 13 | Reference Spectrum | TRACK | ASTRID, display band pass PIPELINE, sum all integrations |
| 14 | Stop Pipeline | STOPPIPE | PIPELINE, finish |

*Table 1: Observing Steps for the first mapping pipeline process.*

The procedure names in Table 1, do not exist, and are provided as an example of the types of procedures we will need for pipeline processing.

**Steps in Pipeline Reduction**

We assume that the calibration process can proceed with one absolute calibration observation. The absolute calibration process will calibrate the T-cal intensities measured while normal observations continue. The absolute calibrated T-cal vector can be applied at the end of the pipeline process, scaling the image results.

The data processing pipeline will be able to separately calibrate sub-sections of the mapping process, for which reference spectra can be identified with mapping observations (e.g. steps 6,7 and 8 can be calibrated, while still obtaining later observations). However no useful pipeline processing can be completed until sets of mapping observations are complete. During the observations, ASTRID will provide diagnostic displays, but these will not be used in the pipeline processing.

We assume the pipeline will do all scaling for GBT beam efficiency and correct for atmospheric attenuation based on the elevation of the telescope when the data were obtained. The atmospheric attenuation will be computed assuming the GB weather models, developed by Ron Maddalena. These attenuation estimates are sufficient for observations in good weather. In poor weather, the absolute calibration will be difficult in any case. The mapping software will linearly interpolate the pair of reference spectra so as to compensate for the change in elevation during the observation. The output of calibration of each section of the mapping process (i.e. steps 6, 7 and 8 and, independently, steps 11, 12 and 13) will be an image cube and a weight cube. The weight cube will be proportional to the square root of integration time and inversely with the system temperature during the observations.

After the mapping session is complete, the observer (or scheduler) must declare a complete session (step 14), so that the images can be merged and absolutely calibrated. The individual map sections will be weighted before combination, so as to yield an optimum resultant image.

**Summary**

The first observing modes for the K7 system checkout have been outlined. It is likely that many of the spectral line observations with the K7 system will be carried out in this way. The calibration techniques already developed in the reduction packages should be applied to the calibration of pipeline data.

A number of other use cases will have similar properties to the mapping use case described above. For example the 12.5 MHz bandwidth, higher spectra resolution, mode will be processed in a manner identical to the process described above. We will document additional use cases for frequency switched observations and for observations using the 8th pair of spectrometer bands.

The details of calibration using weather models, spectral baseline subtraction and data flagging must also be addressed. These topics will be addressed in a separate document. Further topics to be discussed include the selection of channels for mapping and other observer inputs to the pipeline.

New GBT observing modes are being developed, such as sub-reflector nodding and pointing, may be employed in later use cases.