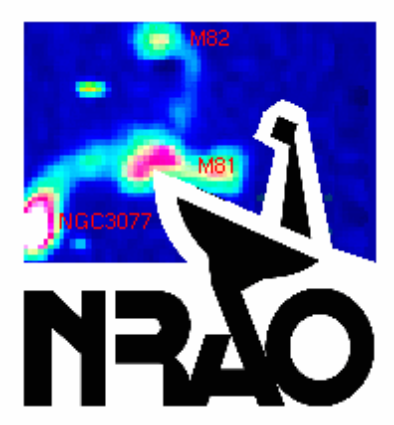

GBT Memo #274

GBTIDL Calibration using On/Off Moon Scans

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Abstract

This memo describes GBTIDL scripts developed to facilitate data reduction of calibration observations, based on On/Off scans of the Moon. The scripts were developed for recent K band Focal Plane Array (KFPA) observations of the Moon, made in order to calibrate the receiver gain and noise diode values. We summarizes the observing steps, data reduction scripts and application of the measurements to the KFPA pipeline.

Spectral line On/Off observations of the Moon are easily obtained and now may be easily reduced to check the Noise Diode values. Observers are encouraged to include Moon On/Off observations during their observing session.

Change Record

Revision	Date	Author	Sections/Pages Affected
	Remarks		
1.0	2011-Apr-1	G. Langston	All
	Initial version		
2.0	2011-Apr-5	G. Langston	All
	Use recent values from the scripts		
2.1	2011-Apr-7	G. Langston	All
	Add Plot of Table of values		

1. Introduction

This memo describes GBTIDL scripts developed to facilitate data reduction of calibration observations, based on On/Off scans of the Moon. The scripts were developed for recent K band Focal Plane Array (KFPA) observations of the Moon, made in order to calibrate the receiver gain and noise diode values. We summarizes the observing steps, data reduction scripts and application of the measurements to the KFPA pipeline.

The KFPA has been used to observe a large number of galactic star forming regions, using the 7 beam, 50 MHz mode. An important aspect of these observations is accurate calibration of the measured intensities. We present a series of measurements of the antenna temperature of the moon, and use a moon brightness temperature model to deduce gain factors appropriate for each observing session. Moon observations and data reduction are described by GBT Memo 273, by Glen Langston (GBT Memo 273).

As previously noted, calibration using the Moon has a number of advantages, including that all beams may be calibrated simultaneously so observing time is minimized. The On-Off moon scans only require 30 seconds observation each. Also the relative gain factor estimates are weather independent. Pointing focus accuracy is not critical for calibration. The On-Off moon observations can be scheduled immediately after a mapping observation and before repointing and focusing.

We summarize the observations in §2 and discuss the scripts for presenting the raw and processed spectra in §3. In §4 the results are presented.

For more information on the KFPA development project, see links from the page:
https://safe.nrao.edu/wiki/bin/view/Kbandfpa/WebHome

2. Observations

We analyze a number of GBT observations in the interval 2010 Sept 6 through 2011 March 31. Of particular interest are observations carried out with the GBT on 2011 March 1, as a part of KFPA commissioning tests (project TKFPA_51). The telescope was configured in the standard manner for galactic NH_3 (1,1) and (2,2) transitions, using Astrid. The weather was clear. The observations were carried out using the 7 beam+1, 50 MHz bandwidth observing mode. The observations were made when the Moon was at 25^o elevation. The median off-Moon system temperature for all beams was approximately 48 K.

The spectral line observations consisted of several components and were carried out using three astrid Scripts, `configMap50MHzNH3`, `OnOffMoon` and `petalMoon`. These scripts are kept in the KFPA directory:

`/home/astro-util/projects/TKFPA`

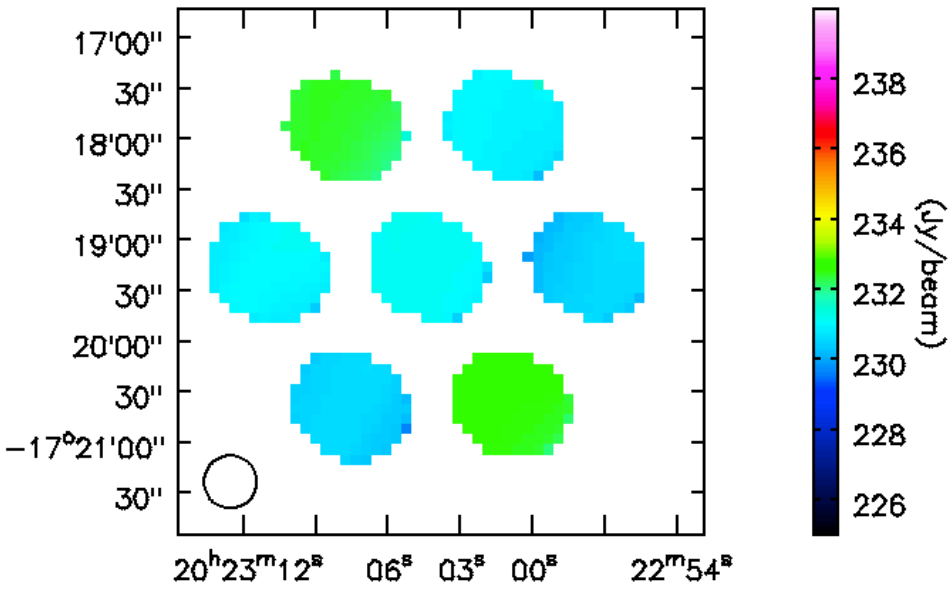

Fig. 1.— KFPA map of the On/Off observation. The gain factors from the `mooncalget.pro` script have been applied in the gbtpipeline. On this date, 2011 March 1, the model center Moon brightness temperature was 232.5±9.5 K. The image is produced directly from the archive data. The good agreement between intensities of the beams is due to application of measured gain correction factors.

The configuration scripts setup the IF path and Spectrometer for observations, with 1 second integration times. During the observations the noise diode signals were toggled on and off in at a 1 Hz rate (ie. noise diode on for 0.5s and off for 0.5s).

3. Example Execution of a GBTIDL script to extract Gain Factors

The observations were reduced using a contributed set of GBTIDL scripts. The scripts were placed in directory:

/home/astro-util/gbtidl/contrib

These scripts are available for general use. Others are encouraged to place useful data reduction scripts in this location as well. Below is a listing of an execution of these scripts. The observer needs only execute two commands inside GBTIDL, a setup command and a command to extract the data from the archive and compute the gain factors:

```
@/home/astro-util/gbtidl/contrib/mooncalsetup.pro
mooncalget,'TKFPA_51',29,30
```

The script finds the data in the archive, in this case for project TKFPA_51, and converts two scan numbers for On and Off Moon observatons (29,30) to the required format. After execution of this script, the observer should copy the gain factor values into their gbtpipeline input parameter file.

A log file is updated with the latest calibration values. The file is named `MoonTemp.log`.

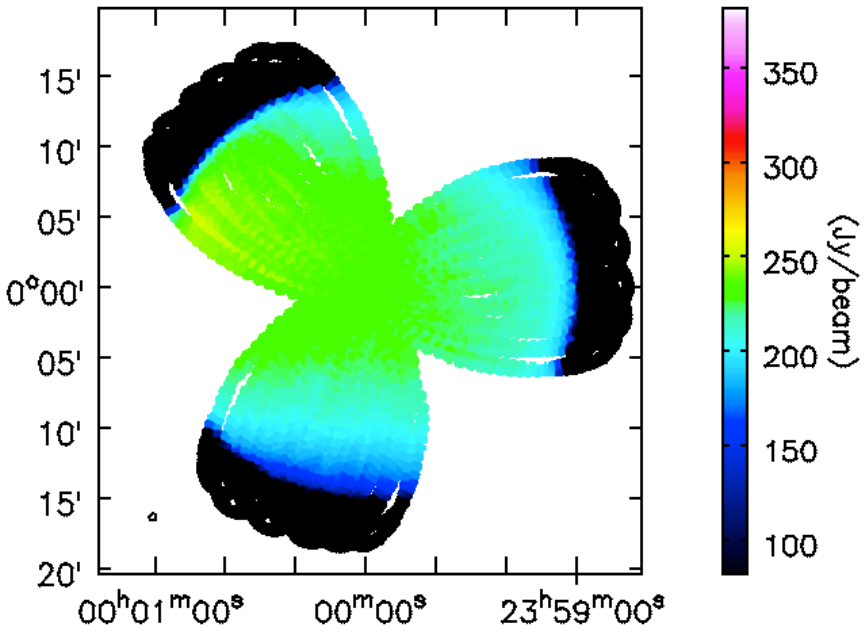

Fig. 2.— Partial Daisy Map of the Moon showing the relatively uniform temperature of the center of the Moon. The sub-solar point (upper left) on the Moon is warmest and the poles of the Moon are coolest. The coordinates have been corrected for the motion of the Moon (significant) during the observations. The map has Moon-centered coordinates, however it has not been rotated.

Log of a GBTIDL session for computing gain factors:

```
GBTIDL -> @/home/astro-util/gbtidl/contrib/mooncalsetup.pro
% Compiled module: GAINEL.
% Compiled module: TAUDATE.
% Compiled module: DATETOMJD.
% Compiled module: ENDFIX.
% Compiled module: OPACITY.
% Compiled module: NATM.
% Compiled module: TATM.
% Compiled module: TSYSTAU.
% Compiled module: GETTAU.
% Compiled module: ETAGBT.
% Compiled module: SHOWTSYS.
% Compiled module: AVG.
% Compiled module: SHOWSIGREF.
GBTIDL -> mooncalget,'TKFPA_51',29,30,factors
% Compiled module: MOONCALGET.
```

```
% Compiled module: MOONCAL.
Scan:    29   Tsys: 193.23
Scan:    30   Tsys:  47.10
2011_03_01_12:51:41 ->        55621.536
zenithOpacity    :   0.027 +/-   0.002
Opacity Factor(M):   1.064+/-  0.004
Opacity Factor(R):   1.064+/-  0.004
Model Number of Atmospheres:        2.2937212 at elevation        25.773423
Freq, etaA, etaB :        23708.530      0.64375975      0.82465625
Gain Factor (m,r):       0.97341559      0.97373389
% Compiled module: MOONMODEL.
% Compiled module: MPHASE.
% Compiled module: MOONPOS.
% Compiled module: MCYCLE.
Moon Illumination:      0.10012500 (fraction) for MJD        55621.536
Moon Phase Angle :       323.42796 (degrees)  for Date
Moon Phase Offset:      40.0000 (degrees)
Moon Model: tAve :       239.18626 tVariation:        28.724946 K
Moon Temp (K)    :        232.51568 +/-        9.5438231
Opacity factor :        0.93994823
All Corrections:        0.74698243
Predicted On-Off Moon Temp K:        171.58906
Predicted On Moon Temp(-Trx):        173.68513
Predicted Off Moon CMB Temp :        2.0917443
Predicted Elevation Change K:    -0.0043302484
#IF 1L    1R    2L    2R    3L    3R    4L    4R    5L    5R    6L    6R    7L    7R        MHz     Az(
 0 180.5 173.8 182.0 177.8 198.4 194.3 193.5 195.2 165.0 170.8 198.0 197.6 182.3 171.8   23708.537  143
 1 181.6 179.1                                                                           23872.371  143
SigScan:    29  RefScan:    30  units: Ta (K)  Tsys:  46.55
SigScan:    29  RefScan:    30  units: Ta (K)  Tsys:  47.10
Calibration Factors
--gain-factors-left  0.951,0.943,0.865,0.887,1.040,0.867,0.941
--gain-factors-right 0.987,0.965,0.883,0.879,1.004,0.868,0.999
```

After computing the gain factors, these should be applied using the KFPA pipeline input file. Below is an example input parameter file `tkfpa51.par`:

```
#KFPA pipeline arguments for KFPA observations; RR Polarizations, no beam 4
--clobber
-v 4
-a 20
# make a map of an On/Off moon observation
-m 29
```

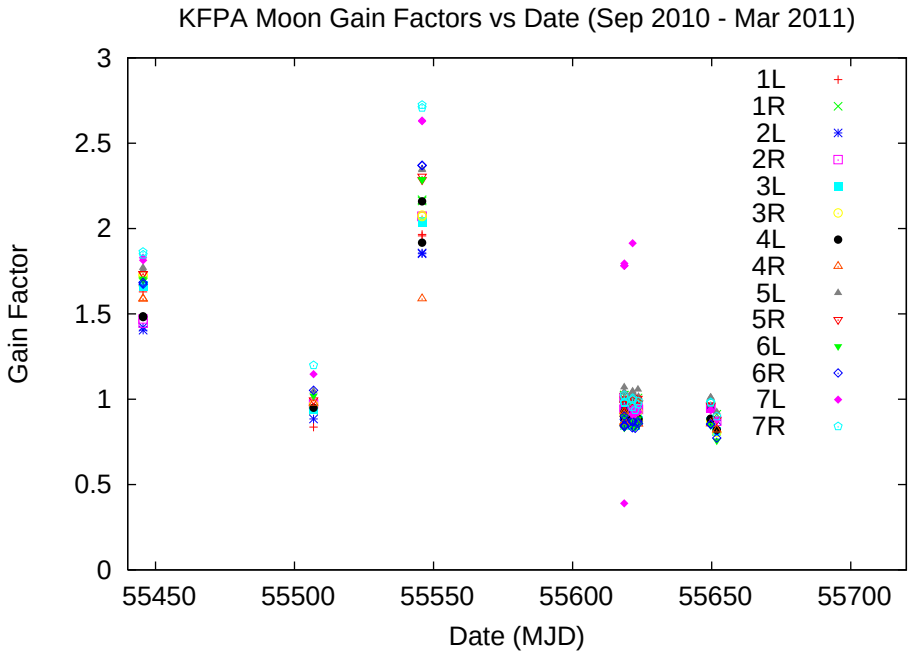

Fig. 3.— Plot of KFPA Gain Factors versus MJD Date for the 7 dual polarization beams, for observations at 23.7 GHz. The earliest data are from Sept 6, 2010 and latest from Mar 31, 2011. Observations at MJD 55506 are from project AGBT10C_045_02 on Nov 6, 2010 and the high points at 55545 are from project TKFPA_40 on Dec 15, 2010. Observations of other calibrators confirm the anomalous Cal Noise Diode values on Dec 15, 2010.

```
--refscan1 30
#--refscan2 35
# factors for scans 29,30
# values if etaB = 1.32 * etaA
#--gain-factors-left  0.980,0.972,0.891,0.914,1.072,0.893,0.970
#--gain-factors-right 1.017,0.994,0.910,0.906,1.035,0.895,1.029
# values if etaB = 1.28 * etaA
--gain-factors-left  0.951,0.943,0.865,0.887,1.040,0.867,0.941
--gain-factors-right 0.987,0.965,0.884,0.879,1.004,0.868,0.999
#potentially turn off automatic mapping
#--imaging-off
#--allmaps
#-m 31:33
#Limit noise range to 4 K RMS
-n 4.0
#The following allows selecting all beams, but 4
#-f 1,2,3,5,6,7
#-f -4
#-f -1
#Potentially select only RR or LL polarization
#-p LL
#Select the maximum number of processors
#--max-processors 14
#--no-map-scans-for-scale
-i ./TKFPA_51.raw.acs.fits
-u Tmb
```

4. Results

After correcting for the gain factors associated with each beam and polarization, the image of the moon center, Figure 1, shows good agreement between the temperatures measured by each of the beams. All temperatures agree, with temperature of 232±2 K, in the center of the frequency band. Beam 3 has a gain slope (of unknown origin), so that only the central region of the band matches the intensities measured by the other beams.

Figure 2 show the application of the gain factors to a Moon Daisy map, resulting in an image with consistent calibration of the relative gain of the beams. Before application of the calibration factors, the dominate structure in the image of the center of the Moon was striping due to the gain differences in the intensities of the different beams.

Figure 3 shows all KFPA On/Off Moon observations at 23.7 GHz. A number of features are seen in the plot. The most recent gain factors indicate the laboratory based noise diode measurements are reasonably accurate. There is some scatter in the Beam 7, L polarization values, due to a hardware problem with the analog filter rack at the time of these observations. At that time the switch had failed which commanded 50 MHz observations failed to switch from 12.5 MHz. This has since been fixed.

These measurements of the Gain Factors should be confirmed by comparison with values obtained by other methods, including point source measurements of 3C48, 3C123 and 3C286. In GBT Memo 272, we showed that the Moon gain factor measurements were consistent with values from selected point source observations. We also plan comparison with factors deduced from observations of Venus and the other planets.

These observations and data reduction show that the gain factors are now consistently being applied to the calibrated output pipeline data. Note that before this date (2011 April 5) errors in the software were preventing transfer of the calibration values to the images.

We encourage observers to include On/Off Moon observations in there observing session to track any changes in gain calibration.

A. GBTIDL Scripts for Moon-based Calibration

The KFPA gain stability studies were facilitated by new plotting scripts for comparison of spectral intensities versus time and frequency.

These scripts have been placed in the directory

`/home/astro-util/projects/contrib`

These scripts are described below:

`mooncalsetup.pro` Run this script once with to setup for Moon calibration. This script adds the path `/home/astro-util/projects/contrib` To your GBTIDL search path.

`mooncal.pro` Takes a pair of On-Moon, Off Moon spectral line scans and computes the calibration factors required to scale the measured intensities to achieve accurate intensities. The script assumes the GBTIDL `filein` command has already been run so that the input scans are already available.

`mooncalget.pro` Script runs `sdfits` to retrieve the required scans and inputs these scans to the GBTIDL environment. The script then calls `mooncal.pro` to calibrate the observations.

Example GBTIDL script for retrieving the GBT archive data and calculating the gain-factors.

```
;+
;  Compute gain correction factors based on OnMoon, OffMoon
;  Observations
; usage:
;    moonCalGet, <projectId>,<onMoonScan>, <offMoonScan>, <factors>, /remove
;      <projectId>    GBT project to process for moon gain factors
;      <onMoonScan>   On center of the moon observation
;      <offMoonScan>  Off center of the moon observation
;      <factors>      Scale factors to multiply data for
;                     acurate calibration
;      /remove        Optionally remove any previously filled data
;      /doOnOff       Calibrate using On-Off, not (sig-ref)/ref
;Example:
; projectID ='AGBT11A_031_03'
; pair of Moon scans
; onMoonScan  = 14 & offMoonScan = 15
; mooncalget,projectID,onMoonScan,OffMoonScan,/remove
;-
;IDL procedure for KFPA computing Moon Calibration factors
;HISTORY
;11APR07 GIL add doOnOff parameter, fix comments
;11MAR27 GIL new function to find data for processing

pro moonCalGet, projectId, onMoonScan, offMoonScan, factors,$\
                remove=remove,doOnOff=doOnOff

  if (not keyword_set( offMoonScan)) then begin
      usage,'moonCalGet',/verbose
      return
  endif

  ; if no output factor array, create
  if (not keyword_set( factors)) then   factors = dindgen(16)
  if (not keyword_set( remove)) then remove=0
  if (not keyword_set( doOnOff)) then doOnOff=0

  extension = '.raw.acs.fits'
  datadir = './'
  dataFileName = datadir+projectId+extension
  fileIsReadable = file_test(dataFileName,/read)
  scansString=strtrim(string(onMoonScan),2)+','+strtrim(string(offMoonScan),2)
  ; if removing old files before filling
  if (fileIsReadable and remove) then begin
    indexFileName = datadir+projectId+'.raw.acs.index'
    rmCmd = 'rm -f '+dataFileName+' '+indexFileName
    print,rmCmd
    spawn,rmCmd
  endif
  fileIsReadable = file_test(dataFileName,/read)
  ; if data file is not present, then get it from the archive
  if (not fileIsReadable) then begin
    getCmd = '/users/glangsto/bin/SDFITS '+scansString+' '+projectId
    print,getCmd
    spawn,getCmd
  endif
  fileIsReadable = file_test(dataFileName,/read)
  ; if we're able to retrieve the file, then process it
  if (fileIsReadable) then begin
      filein, dataFileName
      moonCal, onMoonScan, offMoonScan, factors, doOnOff=doOnOff
  endif

  if (not fileIsReadable) then $\
      print,'Can not read project ',projectId,' Scans ',scansString

  return
end
```