VLBA Scientific Memo #39

VLBA+Y1 Calibration

AIPS and CASA

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Abstract

Adding a single VLA antenna (Y1) to a VLBA observation provides a single very short baseline (PT–Y1, $\sim$ 50km) and slightly improves the *uv* coverage. Prior to 2022 July 06, VLBA+Y1 FITS-IDI files were missing some crucial data. In most cases, no gain curve values were included for the Y1 antenna. In some cases, the Y1 system temperature (T_{sys}) values were also missing. Without both system temperature and gain curve values, the Y1 data cannot be calibrated. Therefore, there are additional steps that need to be taken during calibration to ensure the Y1 data are handled properly. This memo guides users through the necessary steps to prepare their VLBA+Y1 data with missing system temperatures and/or gain curve values for calibration in both AIPS and CASA.

1 Introduction

The VLBA requires a combination of recorded system temperature (T_{sys}) measurements and a gain curve (the gain of an antenna vs elevation) in order to calibrate the amplitudes (convert measured voltage levels into Jy). This is because there is no such thing as a simple, well-modeled calibrator source when observing with very long baselines. All sources are resolved with the VLBA, and most sources are variable on short timescales. The effort to maintain calibration models for standard flux density calibrators would be enormous and require daily observations.

The ability to add a single VLA antenna to a VLBA observation was first offered as a General Observing (GO) capability in the NRAO 2020B semester (2020 August 01 to 2021 January 31). During the first several months of the GO observations with Y1, no T_{sys} or gain curve values were included for Y1 in the FITS-IDI files. Later, Y1 T_{sys} values were provided, but the gain curve values were not (except for 2cm observations). As of 2022 July 06, all VLBA+Y1 observations should include both T_{sys} and gain curve values in the FITS-IDI file. Users who have a VLBA+Y1 dataset from 2022 July or later that is missing T_{sys} or gain curve values should contact VLBA staff via the NRAO helpdesk (https://help.nrao.edu) as soon as possible to have the data re-correlated with the appropriate values included.

In order to calibrate the Y1 data with missing T_{sys} and/or gain curve information, users must alter their files to add the necessary values. This memo documents the processes needed to add the T_{sys} and/or gain curve values to a Y1 observation for both AIPS and CASA. Throughout this memo, AIPS and CASA tasks will be shown in `typewriter font`. AIPS tasks and adverbs will always be capitalized (e.g., `FITLD` and `OUTTEXT`), and CASA tasks and parameters will be in all lower case (e.g., `importfitsidi` and `caltype`).

Users who need additional assistance are encouraged to contact NRAO staff via the helpdesk: https://help.nrao.edu

2 AIPS Processes

The following sections detail the steps needed to add the T_{sys} and/or gain curve values to a Y1 observation being calibrated in AIPS. There are two possible methods: TBOUT/TBIN and IANTB/ANTAB. If only the gain curve is missing for Y1, the TBOUT/TBIN method is significantly easier. If the Y1 T_{sys} values are missing, the IANTB/ANTAB method is easier.

2.1 Load the data into AIPS

The first step for either method is to load the data into AIPS as normal with either FITLD or VLBALOAD.

2.2 TBOUT/TBIN Method

Altering the gain curve (GC) table is very easy to do by writing out the table to a text file with TBOUT, editing it with a text editor, and reading it back into AIPS with TBIN.

2.2.1 Write out the GC table

To write the GC table to a text file, use the TBOUT task. Set INEXT 'gc' and INVER 1. Set OUTTEXT to the desired filename for the text version of the gain curve table.

2.2.2 Edit the gain curve table text file

Locate the new text file on disk and open it with a text editor. Inspect the file to see what is included for each antenna. If the Y1 gain curve values are missing, copy the values for the Pie Town (PT) antenna and past them at the end of the file. Make sure to update the row number (first column) and antenna number (second column) for the Y1 values. It is recommended to save the edited gain curve text file with a new filename.

2.2.3 Read in the edited gain curve

To read the edited gain curve text file into AIPS, use the TBIN task. Set OUTNAME to the name of the file created when the data were loaded into AIPS in §2.1. Set OUTCL to the data type for the file creates when the data were loaded (usually 'UVDATA'). Set INTEXT to the edited gain curve text file. Once TBIN has completed running, a new GC table should be created (usually version 2).

At this point, the data should be ready to continue with the calibration steps as normal.

2.2.4 Summary of the AIPS TBOUT/TBIN method

1. Load the data into AIPS (FITLD or VLBALOAD)
2. Write out the GC table to a text file (TBOUT)
3. Edit the gain curve text file (text editor)

4. Read in the new gain curve file, creating a new GC table in your original UV data file in AIPS (TBIN)
5. Continue with the calibration as normal

2.3 IANTB/ANTAB Method

The structure of the TY table is much more complicated than the GC table. Adding T_{sys} values is easier to do with an antab file. An "antab" file is a text file containing the gain curve and T_{sys} information for each antenna. These files can be read into AIPS with the ANTAB task.

2.3.1 Create an antab file

Once the data is loaded into AIPS, the user should write out an antab file using IANTB. Set GCVER 0 and TYVER 0, and set the output antab filename using OUTTEXT.

2.3.2 Edit the antab file

Locate the new antab file and open it with a text editor. Inspect the file to see what is included for each antenna. Older versions of AIPS may write out bad values in the antab file, so it is a good idea to carefully inspect the file (see Appendix A for details). If Y1 T_{sys} values were recorded, they will likely be the last values in the file. There may also be a value for the Y1 gain curve, even if there is not one in the GC table in AIPS (this is most likely for observations at 2cm).

If any values are missing for Y1, copy the needed values from the Pie Town (PT) antenna and paste them into the Y1 section. If the Y1 section is completely missing, simply copy and paste the entire PT section and edit the Y1 header section to look something like:

```
! For antenna: Y
GAIN Y ALTAZ DPFU= 0.11, 0.11 FREQ=12412.,12796.
POLY=1.00000,-1.604E-04 /
TSYS Y FT=1.0 TIMEOFF=0
INDEX= 'R1','R2','R3','R4','L1','L2','L3','L4' /
```

Note that this example is for a 2cm dual-polarization observation. The exact values for each entry in the header will be different depending on the observing band and setup.

2.3.3 Update the TY and GC tables using the edited antab file

Use the ANTAB task to read the edited antab file and update the TY and GC tables. Set GCVER and TYVER to the current GC and TY version numbers (both will most likely be 1). Set CALIN to the edited antab filename. Running ANTAB should create new TY and GC tables with values for Y1.

At this point, the data should be ready for the normal calibration steps.

2.3.4 Summary of the AIPS IANTB/ANTAB steps

1. Load the data into AIPS (FITLD or VLBALOAD)
2. Create an antab file (IANTB)
3. Edit the antab file (text editor)
4. Update the TY and GC tables of your UV data file using the edited antab file (ANTAB)
5. Continue with the calibration as normal

3 CASA Process

This section details the steps needed to add the gain curve and/or T_{sys} values to a Y1 observation being calibrated in CASA. Adding the necessary values for use in CASA requires creating an antab file and using some external scripts.

3.1 Obtain the JIVE CASA VLBI scripts

The CASA process requires users to obtain the JIVE CASA VLBI scripts, which are available at:
https://github.com/jive-vlbi/casa-vlbi
Users can obtain the scripts using the standard git commands, or they can go to the link above and use the "Code" drop-down menu to download all the scripts in a ZIP file.

3.2 Create and edit an antab file

Users will need to create an antab file with the necessary information to add the T_{sys} and/or gain curve information to calibrate Y1 observations in CASA. The easiest way to create an antab file from VLBA data is to use the AIPS IANTB task. This requires loading the data into AIPS (see §2.1) and writing out the antab file (see §2.3.1). Once the antab file is created, use a text editor to inspect and edit it (see §2.3.2).

3.3 Ensure that CASA has access to astropy.io.fits

The JIVE CASA VLBI scripts "append_gc.py" and "append_ty.py" require the use of astropy.io.fits in order to create a valid FITS-IDI file. If CASA uses the PyFITS module instead, it may result in a corrupted FITS-IDI file that will not work in CASA or AIPS.

For those who are using CASA on an NRAO machine, either locally or via remote connection, it is best to use the pipeline versions of CASA which have access to astropy. To see which versions of CASA are available, simply type "casa -ls" in a terminal command line. This will list all versions of CASA that can be used. Look for the most recent "-pipeline" version (at the time of writing, the most recent pipeline version was 6.2.1-7-pipeline-2021.2.0.128).

For users relying on their personal installations of CASA, it is recommended to install astropy in the local CASA environment. Instructions for installing astropy into CASA can be found on the astropy installation website:
https://docs.astropy.org/en/stable/install.html

3.4 Alter the FITS-IDI file

Once a valid antab file is created, users must use the JIVE CASA VLBI script "append_gc.py" with the "--replace" flag set to overwrite the gain curve included in the original FITS-IDI file.

It is strongly recommended that users create a new copy of their FITS-IDI file before continuing with the next steps! There is a risk that overwriting the FITS-IDI file can result in a corrupted file that cannot be used in CASA or AIPS. Having an untouched version of the FITS-IDI file will reduce the number of times the file needs to be downloaded from the NRAO Archive.

Before running the scripts, it is necessary to define some paths to the directory containing the JIVE CASA VLBI scripts:

```
export PYCAPATH=/full/path/to/script/directory/
export PYTHONPATH=/full/path/to/script/directory/:$PYTHONPATH
```

Once the paths are properly defined, run the "append_gc.py" script.

If the script is being run on an NRAO computer, execute the script in a terminal by typing:

casa -r *casa-version* --nogui -c $PYCAPATH/append_gc.py --replace *antab-filename FITS-IDI-filename*

where *casa-version* is the version of CASA to use, *antab-filename* is the filename for the altered antab file, and *FITS-IDI-filename* is the filename of the FITS-IDI file to update.

If the script is being run on a user's own computer, execute the script in a terminal by typing:

casa --nogui -c $PYCAPATH/append_gc.py --replace *antab-filename FITS-IDI-filename*

where *antab-filename* is the filename for the altered antab file, and *FITS-IDI-filename* is the filename of the FITS-IDI file to update.

Example: Executing the "append_gc.py" script on an NRAO machine using an antab file named "TL016B.ANTAB" and a FITS-IDI file named "TL016B.idifits":

```
casa -r 6.2.1-7-pipeline-2021.2.0.128 --nogui -c $PYCAPATH/append_gc.py --replace TL016B.ANTAB
TL016B.idifits
```

Watch the terminal for messages that say something like "PyFITS is deprecated, please use astropy.io.fits". This is an indication that the PyFITS module was used and the resulting FITS-IDI file is likely corrupted and unusable (hopefully, a copy was made before attempting to update it).

Once the "append_gc.py" script finishes successfully, the FITS-IDI file should include the Y1 gain curve values.

If the original FITS-IDI file did not contain any T_{sys} measurements for Y1, it will be necessary to update the FITS-IDI T_{sys} values with the values from the antab file. This is done by using the "append_tsys.py" script in the same way that the "append_gc.py" script overwrites the gain curve values.

Example: Executing the "append_tsys.py" script on an NRAO machine using an antab file named "TL016B.ANTAB" and a FITS-IDI file named "TL016B.idifits":

```
casa -r 6.2.1-7-pipeline-2021.2.0.128 --nogui -c $PYCAPATH/append_tsys.py --replace TL016B.ANTAB
TL016B.idifits
```

3.5 Import the data, create the calibration tables, and inspect

Import the altered FITS-IDI file into a CASA Measurement Set (MS) using the `importfitsidi` task. Be sure to set `scanreindexgap_s` to a reasonable number (usually something between 5 and 15) in order to ensure that the resulting MS separates the scans correctly [1].

Once the new MS is created, create the system temperature and gain curve calibration tables using the `gencal` task.

System temperature:
`gencal(vis='`*MS-filename*`', caltable='`*tsys-table-name*`', caltype='tsys', uniform=False)`
where *MS-filename* is the name of the MS, and *tsys-table-name* is the desired name of the table with the T_{sys} values.

Gain curve:
`gencal(vis='`*MS-filename*`', caltable='`*gain-curve-table-name*`', caltype='gc')`
where *MS-filename* is the name of the MS, and *gain-curve-table-name* is the desired name of the table with the gain curve values.

Inspect the tables with `plotms` to make sure there are valid T_{sys} and gain curve values for the Y1 antenna.

Inspecting the T_{sys} table:
`plotms(vis='`*tsys-table-name*`', xaxis='time', yaxis='tsys', antenna='*&&&', coloraxis='spw', iteraxis='antenna')`
Use the GUI controls to step through the antennas and look for the Y1 antenna (usually the last antenna, and often just labeled "Y").

Inspecting the gain curve table:
`plotms(vis='`*gain-curve-table-name*`', xaxis='time', yaxis='amp', antenna='*&&&', coloraxis='spw', iteraxis='antenna')`
Use the GUI controls to step through the antennas and look for the Y1 antenna (usually the last antenna, and often just labeled "Y").

If the plots of T_{sys} and gain curve tables both show valid data, appending the antab data to the FITS-IDI file worked properly.

3.6 Correct the Y1 antenna diameter

Before continuing with the calibration, it is important to verify that the Y1 antenna has the proper diameter.

Run `listobs` to get the observation summary:
`listobs(vis='`*MS-filename*`')`

Look for the antenna section at the bottom of the `listobs` output. The VLBA antennas should all have diameters of "25.0 m". The Y1 antenna may have a diameter of "0.0 m", in which case it needs to be corrected to be "25.0 m".

[1] For more information on `scanreindexgap_s` and the other input parameters of `importfivtsidi`, see the documentation at https://casadocs.readthedocs.io/en/stable/api/tt/casatasks.data.importfitsidi.html

If the Y1 antenna diameter needs to be corrected, do so using the following commands:

```
ants = ['BR', 'FD', 'HN', 'KP', 'LA', 'MK', 'NL', 'OV', 'PT', 'SC', 'Y']
diams = [25.0, 25.0, 25.0, 25.0, 25.0, 25.0, 25.0, 25.0, 25.0, 25.0, 25.0]
tb.open('MS-filename/ANTENNA', nomodify=False)
tb.putcol('DISH_DIAMETER', diams)
tb.close()
```

Notice that the above commands are for an observation that contains all 10 VLBA stations plus Y1. If one of more antennas are missing from an observation, the `ants` and `diams` variables will need to be adjusted accordingly.

Once the commands have run successfully, check that the Y1 antenna diameter was corrected by running `listobs` again. If all antenna diameters are listed as "25.0 m", the data are now ready to calibrate following the standard procedures.

3.7 Summary of CASA steps

1. Obtain the JIVE CASA VLBI scripts (https://github.com/jive-vlbi/casa-vlbi)
2. Load the data into AIPS (`FITLD` or `VLBALOAD`)
3. Create an antab file with AIPS (`IANTB`)
4. Edit the antab file (text editor)
5. Export the paths to JIVE CASA VLBI scripts

6a. Execute the "append_gc.py" script with the "--replace" flag
6b. If necessary, execute the "append_tsys.py" script with the "--replace" flag

7. Import the FITS-IDI file into CASA (`importfitsidi`)
8. Create the T_{sys} and gain curve calibration tables (`gencal`)
9. Plot the T_{sys} and gain curve calibration tables and verify that values are present for Y1 (`plotms`)
10. Correct the Y1 dish diameter, if necessary (`tb.open, tb.putcol, tb.close`)
11. Continue with the calibration as normal

4 A note on self-calibration

Because the T_{sys} and gain curve information for Y1 is often "faked" (values from other antennas are used), it is very important to be able to self-calibrate the data. Self-calibration, especially amplitude self-calibration, will help correct for any major errors in the Y1 T_{sys} and gain curves by scaling Y1 to the other antennas. As always, users are encouraged to be extremely careful when doing amplitude self-calibration.

IMPORTANT: WHEN DOING SELF-CALIBRATION, DO NOT USE Y1 AS THE REFERENCE ANTENNA!

5 Additional Resources

Websites

AIPS Homeapge: http://www.aips.nrao.edu/index.shtml
CASA Documentation: https://casadocs.readthedocs.io/en/v6.5.1/index.html
CASA Download page: https://casa.nrao.edu/casa_obtaining.shtml
CASA Homepage: https://casa.nrao.edu

VLBI CASA Guides: https://casaguides.nrao.edu/index.php?title=VLBI_Tutorials

Publications

The AIPS Cookbook: html version, linked pdf version
VLBA Scientific Memo 38: VLBA Data Calibration with CASA

A Some IANTB issues in older versions of AIPS

Older versions of AIPS had a few problems writing out a valid antab file with IANTB.

The antab file may be missing single quotes (') around the INDEX values for each antenna. The entries for the INDEX should look something like:

INDEX= 'R1','R2','R3','R4','L1','L2','L3','L4' /

Older versions of AIPS sometimes write out invalid timestamps that look like "01:08:-0.0". To determine if this is an issue in the antab file, it is very easy to use a "find" function of the text editor to look for bad values in the timestamps. Search for "-0" and replace any dashes in the timestamps with zeros (i.e., change "01:08:-0.0" to "01:08:00.0").

Finally, older versions of AIPS sometimes write out bad entries in the POLY row for the gain curve. These bad values will look something like:

POLY=1.00000,********** /.

The long strings of asterisks need to be replaced with actual values. The appropriate values can be found in the vlba_gains.key file, which can be found at:
http://www.vlba.nrao.edu/astro/VOBS/astronomy/vlba_gains.key
Look for the values for the appropriate band on each antenna and use them to replace the "**********" entries in the antab file.

Version Tracking

Here are summaries of the changes made for each version after 1.0.

Version 1.1

- Fixed missing section links.
- Minor changse in formatting for improved readability.

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