AIPS Procedures for Initial VLBA Data Reduction
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Abstract

This memo provides a guide to procedures currently available in *AIPS* (some in 31DEC00, all in 31DEC01) to do the initial processing steps of VLBA data reduction. These procedures are designed for VLBA-only observations, and make a number of assumptions that may not be appropriate for other types of VLBI experiments. Therefore, they should be used only with extreme caution for observations including non-VLBA antennas. The present memo discusses the key defaults that are used in the VLBA procedures, as well as the times when these procedures may not be appropriate. For more details regarding the procedures in the full context of VLBI data reduction, see Chapter 9 and Appendix C of the *AIPS CookBook*.

1. Summary of VLBA Procedures

The procedures needed to simplify many of the initial VLBI data reduction steps in *AIPS* are available to users after they enter the command RUN VLBAUTIL C_R. After this, the following procedures will be available:

- VLBALOAD: loads VLBA data with simplified inputs
- VLBASUBS: finds subarrays in VLBA data
- VLBAMCAL: removes redundant calibration data from tables
- VLBAFQS: copies different frequency IDs to separate files
- VLBAFPOL: fixes polarization labelling for common cases
- VLBASUMM: makes summary listings of your data set
- VLBACALA: determines *a-priori* amplitude calibrations
- VLBAPANG: determines phase corrections for parallactic angles
- VLBACPOL: calibrates cross polarization delays
- VLBAPCOR: determines instrumental phase corrections
- VLBAFRNG: does global fringe fit using FRING
- VLBAKRNG: does global fringe fit using KRING
- VLBAFRGP: does global fringe fit for phase referenced experiments using FRING
- VLBAKRGP: does global fringe fit for phase referenced experiments using KRING
- VLBASNPL: plots the SN or CL tables versus time
- VLBACRPL: plots the cross-correlation spectrum

There are two additional procedures that can make life easier, called `ANTNUM` and `SCANTIME`. `ANTNUM` will return the antenna number of the antenna corresponding to a certain character string, for a data set containing an `AN` table. For example, in most data sets, typing REFANT = ANTNUM ('BR') CR will be the equivalent of typing REFANT = 1 CR. `SCANTIME` will return the time range of a given scan number, for use in various programs. Typing TIMERANG = SCANTIME(4) CR will fill the eight-element array `TIMERANG` with the start and stop times of the 4^{th} scan of a given data set. (There must be an `NX` table for this to work.)

Note that all of the `VLBAUTIL` procedures have `HELP` files with good discussions about when to use the simple procedures and when to use the tasks directly. Also, note that the procedures do not include data editing, which should be performed at appropriate points in the calibration process. You only need to `RUN VLBAUTIL` once to access all of the procedures. If you run it again for any reason, it is a good idea to enter COMPRESS CR immediately afterwards to avoid overflowing `AIPS`' symbol memory.

2. VLBALOAD

The procedure `VLBALOAD` can be used in place of the task `FITLD` to load your VLBI data on disk. Enter

> RUN VLBAUTIL CR	to acquire the procedures; this need be done only once since they will be remembered.
> INTAPE *n* CR	to specify the input tape number.
> NFILES 0 CR	to start loading from the current tape position.
> NCOUNT 20 CR	to load 20 tape files.
> OUTNAME 'TEST' ; OUTDI 1 CR	to specify the name and disk of the output file.
> DOUVCOMP 1 CR	to save disk space by writing compressed data.
> CLINT $\triangle t$ CR	to set the `CL` table interval to $\triangle t$ minutes (see discussion below).
> INP VLBALOAD CR	to review the inputs.
> VLBALOAD CR	to run the procedure.

Typically, the user will set DOUVCOMP=1 CR to write compressed data. `CLINT` should be set so that there are several `CL` table entries for each self-calibration or fringe-fitting interval anticipated; this will minimize interpolation error during the calibration process. However, setting `CLINT` too short will result in a needlessly large table. (See further discussion in the *AIPS CookBook*.) For the VLBA correlator, `VLBALOAD` automatically does the appropriate digital and delay decorrelation corrections. The other key `FITLD` parameter that is set automatically is WTTHRESH = 0.7, which results in irrevocable discarding of all data with playback weight less than 0.7.

3. VLBASUBS

VLBA data may require some repair after `VLBALOAD` has been run. They may need to be sorted, have the subarray nomenclature corrected, and/or have the index (`NX`) table and calibration (`CL`) version 1 table rebuilt. If both of these tables are missing, then a subarray condition is likely to exist. Generally speaking, `VLBALOAD` or `FITLD` will have given a message stating that a subarray condition appears to exist. In this case, there is a simplified procedure to combine the three repair operations:

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> CLINT $\triangle t$ CR	to set the `CL` table interval to $\triangle t$ minutes.
> INP VLBASUBS CR	to review the inputs.
> VLBASUBS CR	to run the procedure.

The only user-controllable input is the `CL` table interval; see discussion above.

4. VLBAMCAL

The information processed by the VLBA correlator is somewhat redundant so that the calibration tables, the GC table in particular, must be merged using TAMRG, a very general and hence complicated task. For the VLBA correlator, there is typically a new set of entries made in the GC table for each correlator job loaded with VLBALOAD or FITLD, and calibration programs such as APCAL and VLBACALA will fail if multiple GC entries exist for a single antenna. To fix this,

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> INP VLBAMCAL C_R	to review the inputs.
> VLBAMCAL C_R	to run the procedure.

You should use VLBAMCAL after you have finished loading the data from tape, but before you either change the polarization structure of the data with FXPOL (or VLBAFPOL), load any calibration data for non-VLBA telescopes, or apply the calibration data. Another procedure called MERGECAL will carry out activities similar to VLBAMCAL; see the *AIPS CookBook* for further details.

5. VLBAFQS

If you have multiple frequency IDs in your data, it is strongly recommended that you separate the data for different FREQIDs at this point, before performing any calibration. The procedure VLBAFQS will run UVCOP to separate the different FREQIDs, deleting the data flagged by the correlator with FLAGVER=1, and then re-index the data set to generate new CL and NX tables. Enter the following:

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> CLINT $\triangle t$ C_R	to set the CL table interval to $\triangle t$ minutes.
> INP VLBAFQS C_R	to review the inputs.
> VLBAFQS C_R	to run the procedure.

VLBAFQS will normally be run after searching for subarrays (VLBASUBS) and before fixing polarization labels (VLBAFPOL). Note that the subarray condition can be due to overlapping frequency IDs rather than different sources. In that case, using VLBAFQS before VLBASUBS may be advantageous.

6. VLBAFPOL

The VLBA correlator does not preserve polarization information unless it is operating in full polarization mode. This results in polarizations not being labelled correctly when both RR and LL polarizations are observed without RL and LR, either within the same band or in different bands. Each VLBA correlator band is loaded into *AIPS* as a separate IF and is assigned the same polarization. FXPOL takes a data set from the VLBA correlator and produces a new data set that has the correct IF and polarization assignments. *Note that* FXPOL *makes a new copy of the data set in order to re-label the polarizations, so you must have plenty of disk space available in order to run* FXPOL. For the simplest cases for VLBA-only data, there is a procedure that attempts to determine which polarization case applies and then runs FXPOL for you:

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> INP VLBAFPOL C_R	to review the inputs.
> VLBAFPOL C_R	to run the procedure.

Use VLBAFPOL to check whether you need to relabel the polarizations in your data after loading the data, looking for subarrays, and merging redundant calibration data, but before reading any calibration data from non-VLBA stations. VLBAFPOL assumes that all of your FREQIDs have similar polarization setups. For this reason, you should normally run VLBAFPOL after copying each frequency ID to a separate file using VLBAFQS. This strategy also reduces the amount of disk space needed for VLBAFPOL.

7. VLBASUMM

In order to keep track of your experiment it is a good idea to get a listing of the antennas and scans in your experiment. VLBASUMM does this, writing the information to a file, to the screen or directly to the printer. The last is likely to be the most useful. This procedure runs PRTAN and LISTR (OPTYPE='SCAN').

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> DOCRT -1 C_R	to print to a file or printer; 1 to go the the CRT screen.
> OUTPRI '*env*:*name*'	to print to a file in area *env* called *name*.
> VLBASUMM C_R	to generate the listings.

This should be done after the data has been "fixed" (VLBAMCAL, VLBASUBS, VLBAFPOL and/or VLBAFQS) and before calibration is started (VLBACALA).

8. VLBACALA

The procedure VLBACALA will apply all *a-priori* amplitude calibrations to your data, writing a CL table with the appropriate calibrations included. This procedure runs ACCOR to use the autocorrelation results in order to correct cross-correlation values; SNSMO to clip discrepant values output by ACCOR and make a solution (SN) table; APCAL to merge GC (gain) and TY (system temperature) tables into another SN table; and CLCAL (twice) to apply these SN tables and create new CL tables. VLBACALA *should be run only for data from the VLBA correlator, since the* ACCOR *correction is not necessary for other correlators.* To run this procedure, enter

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> FREQID *ff* ; SUBAR *ss* C_R	to select the frequency ID and subarray numbers — only one of each per execution.
> REFANT 0 C_R	to default the reference antenna appropriately.
> INP VLBACALA C_R	to review the inputs.
> VLBACALA C_R	to run the procedure.

VLBACALA will normally be run after correcting the polarization labels with VLBAFPOL (if needed) and loading any gain curves or system temperature data for non-VLBA antennas using ANTAB (see *AIPS CookBook*). Usually, VLBACALA will be run before doing any phase solutions, in which case the value of REFANT does not matter. However setting REFANT=0 C_R may be the safest thing to do. The VLBACALA procedure defaults to 2-minute solution intervals for the computation of the autocorrelation correction, then uses a 30-minute median-weight filter to clip all autocorrelation solutions that are more than 0.02 (in gain) from the running mean. In applying the measured gain and system temperature calibrations, the underlying task CLCAL uses INTERPOL='SELF' in order to avoid interpolation between sources at different elevations. No atmospheric opacity corrections are applied to the nominal amplitude calibration values for the antennas.

9. VLBAPANG

The RCP and LCP feeds on each antenna will rotate in position angle with respect to the source during the course of the observation for alt-az antennas (which probably constitute a majority of the antennas in your observation). Since this rotation is a simple geometric effect, it can be corrected by adjusting the phases without looking at the data. This correction must be performed before executing any phase calibration that actually examines the data. It is important for polarization observations, and also can be important for some phase referencing observations, depending upon the distribution of calibrators and targets on the sky. The procedure VLBAPANG assists you in running CLCOR together with doing the subsidiary table copying (TACOP) needed to correct phases for parallactic angle:

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> SUBAR *ss* CR	to select the subarray number — only one per execution.
> INP VLBAPANG CR	to review the inputs.
> VLBAPANG CR	to run the procedure.

VLBAPANG will normally be run after applying *a-priori* amplitude corrections with VLBACALA, but before applying any other phase corrections.

10. VLBAPCOR

Each IF has its own phase offset and gradient with frequency. These offsets and "instrumental single-band delays" are caused by the passage of the signal through the electronics of the VLBA baseband converters or MkIII/MkIV video converter units. If pulsed, narrow-band signals ("phase-cals") are sent through the electronics, the IF channel phase offsets and instrumental single-band delays can be determined. If this pulse-cal information is not available, then the offsets and single-band delays can be determined "manually" by running FRING (or KRING) on a short scan on a calibrator source.

The procedure VLBAPCOR runs PCCOR to take the information out of the PC table, create an SN table, and run CLCAL to apply the corrections to a CL table. A TIMERANGE for a strong calibrator must be given. This is to solve 2π ambiguities after which the phase corrections are solved for all times. If there are antennas missing from the PC table or the data for some antennas in the PC table are bad, VLBAPCOR will run FRING and then CLCAL to incorporate them into the output CL table. To invoke this option, set OPCODE='CALP' and set ANTENNAS to the missing (or bad) antennas. For this to work, the TIMERANGE that is chosen *must* have strong fringes for these antennas. EXPLAIN VLBAPCOR lays out the steps to solve for the instrumental phase solutions outside of VLBAPCOR.

Note that VLBAPCOR assumes that the highest PC and FG tables are the correct ones to use.

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* CR	to specify a short scan on a calibrator. There is no default.
> REFANT *m* CR	to select a particular reference antenna.
> SUBARRAY 0	to do all subarrays.
> CALSOUR '*cal1*', ' '	to specify the calibrator source name.
> GAINUSE *CLin* CR	to indicate the CL table with all calibration up to this point.
> OPCODE 'CALP' CR	to indicate that there are antennas with no usable pulse cals; use OPCODE ' ' if all antennas have pulse cals.
> ANTENNAS *a1 a2 a3* CR	to solve for antennas *a1, a2, a3* "manually" (using FRING).
> VLBAPCOR CR	to run the procedure.

This should be done after the *a-priori* amplitude calibration (VLBACALA) and, for polarization experiments, the paralactic angle correction (VLBAPANG), but before any global fringe fitting (VLBAFRNG, VLBAKRNG, VLBAFRGP, or VLBAKRGP). The corrections should be examined with VLBACRPL.

11. VLBACPOL

For polarization experiments, the instrumental delays must also be removed from the cross-hand correlators. This is done in a procedure called VLBACPOL (formerly known as CROSSPOL). Like the other utility procedures, this procedure will produce new (highest numbered) `CL` and `SN` tables.

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> OUTDI 1 CR	to use disk 1 for temporary files.
> FLAGVER 0 CR	to use the highest numbered flag table.
> GAINUSE *CLin* CR	to use the `CL` table with all calibration up to this point; *no default*.
> SUBARRAY 0 CR	to do all subarrays.
> BASELINE 0 CR	to use all antennas.
> REFANT 1 CR	to select the reference antenna; it must be the highest or lowest antenna number.
> CALSOUR '*cal1*' , ' ' CR	to specify the calibrator source to use.
> TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* CR	to specify a time range with high SNR for RL and LR.
> SOLINT 0 CR	to set the `FRING` solution interval in minutes; 0 is taken as 10.
> DPARM(4) = *x* CR	to tell `FRING` the minimum integration time in the data set in seconds; other `DPARM` parameters are also used by `FRING`.
> OPCODE ' ' CR	to solve for delays in each IF separately.
> VLBACPOL CR	to run the procedure.

`VLBACPOL` should be done after parallel-hand instrumental delays are removed (`VLBAPCOR`) but before fringe fitting (`VLBAFRNG`, `VLBAKRNG`, `VLBAFRGP`, or `VLBAKRGP`). The corrections should be checked with `VLBACRPL`, by setting `STOKES` to `'RL'` and/or `'LR'`.

12. VLBAFRNG, VLBAKRNG, VLBAFRGP, VLBAKRGP

Now one must remove global frequency- and time-dependent phase errors. To do this, `FRING` or `KRING` is run along with `CLCAL` on the output `SN` table. The procedures `VLBAFRNG`, `VLBAKRNG`, `VLBAFRGP` and `VLBAKRGP` do this. These procedures assume a simple experiment, *i.e.*, one frequency etc. `VLBAFRNG` and `VLBAFRGP` use `FRING` and `VLBAFRGP` is specifically for phase referencing. Similarly, `VLBAKRNG` and `VLBAKRGP` use `KRING`, with `VLBAKRGP` specifically for phase referencing.

For all these procedures, if the `SOURCES` adverb is set, then `CLCAL` is run once for each source in `SOURCES`. For the phase-referencing procedures (`VLBAFRGP` and `VLBAKRGP`), any source that is in the `SOURCES` list that is *not* in the `CALSOUR` list will be phase referenced to the *first* source in the `CALSOUR` list. Note that, if every source in the `SOURCES` list occurs in the `CALSOUR` list, `VLBAFRNG` and `VLBAKRNG` will run identically to `VLBAFRGP` and `VLBAKRGP`, respectively. If the `SOURCES` list is empty, `VLBAFRNG` and `VLBAKRNG` will run `CLCAL` once over all sources, while `VLBAFRGP` and `VLBAKRGP` will run `CLCAL` once referencing all the sources to the first source in `CALSOUR`. These procedures will produce new (highest numbered) `SN` and `CL` tables.

Procedure `VLBAKRNG`

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> TIMERANGE 0	to include all times.
> BCHAN 0 ; ECHAN 0 CR	to use all frequency channels.
> GAINUSE *CLin* CR	to use the `CL` table with all the calibration up to this point.
> REFANT *n* CR	to specify an antenna that is present most of the time as the reference antenna.
> SUBARRAY 0 CR	to use all subarrays.

> SEARCH 0 CR	to try all antennas as a reference antenna if fringes cannot be found using `REFANT`. *This is different from* `FRING`*; in* `FRING` *this must be set to try other reference antennas.*
> OPCODE ' ' CR	to leave all solutions in the output `SN` table.
> CPARM 0 CR	to use defaults for `KRING` steering parameters; this is okay for strong sources.
> CPARM(1) *x* CR	to specify the minimum integration time in seconds.
> CPARM(8) 1 CR	to avoid re-referencing solutions; do this *only* for polarization experiments.
> CALSOUR '*src1*', '*src2*' CR	to specify the sources to fringe fit using `KRING`.
> SOURCES '*src1*', '*src2*' CR	to have `CLCAL` run for each source using the interpolation method given below.
> INTERPOL 'AMBG' CR	to use the "`AMBG`" interpolation method (linear phase connection using rates to resolve phase ambiguities).
> BADDISK 0 CR	to use all disks for scratch files.
> VLBAKRNG CR	to run the procedure.

Procedure `VLBAKRGP` sets the same adverbs as `VLBAKRNG` *except*

> SOURCES '*src1*', '*src2*', '*src3*' CR	to have `CLCAL` run for each source using the interpolation method given by `INTERPOL`. Any source here that is not in the `CALSOUR` list will be phase referenced to the first source in the `CALSOUR` list. In this example, *src3* is phase referenced to *src1*.
> VLBAKRGP CR	to run the procedure.

`VLBAFRNG` and `VLBAFRGP` are identical except there is no `OPCODE` (it is equivalent to `DPARM(8)`) and `DPARM(4)` and `DPARM(7)` in `FRING` are the same as `CPARM(1)` and `CPARM(8)` in `KRING`, respectively. Also note the different use of `SEARCH` in `FRING` and `KRING`.

These procedures should be run after the instrumental phase calibration (`VLBAPCOR`). For polarization data, they should be run after `VLBACPOL`. After the global fringe fit, the solutions should be checked in `VLBACRPL` setting `GAINUSE` to the CL table produced by the procedure chosen.

13. VLBASNPL

`VLBASNPL` is a utility procedure to check the calibrations by plotting the `SN` and/or `CL` table versus time. It runs `SNPLT` with simplified inputs. The example below might be run after `VLBACALA`.

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> INEXT 'CL' CR	to plot a `CL` table.
> INVERS 0 CR	to plot the highest version.
> SOURCES ' ' CR	to plot all sources.
> TIMERANGE 0 CR	to plot all times.
> STOKES ' ' CR	to plot both R and L solutions.
> SUBARRAY 0 CR	to plot all subarrays.
> OPTYPE 'AMP' CR	to look at amplitudes; `'PHAS'`, `'DELA'`, and `'RATE'` are other useful choices.
> DOTV 1 CR	to plot the data on the TV; -1 to make a plot file.
> VLBASNPL CR	to plot the data.

14. VLBACRPL

This procedure plots the amplitude and phase of the cross-power spectrum for a data set, applying the given `CL` table. This is useful after `VLBAPCOR`, `VLBACPOL`, or `VLBAFRNG` and friends. It is a simplified `POSSM`.

> RUN VLBAUTIL CR	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> SOURCES ' ' CR	to plot all sources.
> TIMERANGE 0 CR	to plot all times.
> SUBARRAY 0 CR	to plot all subarrays.
> REFANT *n* CR	to plot the cross-power spectrum for baselines with antenna *n*.
> STOKES ' ' CR	to plot Stokes I.
> GAINUSE *CLin* CR	to apply `CL` table *CLin* to the data before plotting.
> DOTV 1 CR	to plot the data on the TV; -1 to make a plot file.
> VLBACRPL CR	to plot the data.

15. Concluding Remarks

At this stage, you are ready to apply the calibration to your data and begin imaging. Tasks `SPLIT` and `SPLAT` are used to apply the calibration. Both can do spectral averaging (after calibration but before writing the output); `SPLAT` can do time averaging and can keep the data in the multi-source format. Details of these actions, and of later imaging and self-calibration processes can be found in the *AIPS CookBook*.

Chris Flatters and Amy Mioduszewski developed these procedures. The original `VLBACPOL` called `CROSSPOL` was developed by Bill Cotton.