VLB ARRAY MEMO No. 153

VLBA Software Requirements

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This is a first attempt to specify the software requirements of the VLBA at a level close to that of individual programs. It is based on VLBA Memos 126, 127, 128, and 133 which outline the requirements of specific aspects of the system and on experience with current VLB and VLA data analysis. The software outlined here is intended to serve the needs of all users of the VLBA. Any deficiencies should be pointed out as soon as possible so that they will not appear in the final system. A block diagram of the most important aspects of the data reduction system specific to the VLBA is given in Figure I.

I. GENERAL POINTS:

There are some general philosophical points that should be made before discussing details of the software.

A. The observer will establish the needs of a project and, perhaps, a specific schedule based on siderial time well before the observations are made. The operations staff will choose when to run the project based on the condition of the array and on the weather. This will minimize the impact of equipment problems and poor weather.

B. Correlation of the data will be carried out by the operations staff in a manner consistent with the needs specified by the observer. The observer will not have access to the data until after correlation is complete.

C. Much of the science that can be done with the VLBA will concern changes in source and/or baseline parameters over long periods of time. Therefore the data archive system must preserve all of the information needed to reconstruct any amplitude, phase, and delay modifications made to the data and must preserve all information needed for full geodetic and astrometric analysis of the data. Such a reconstruction should not require reference to the original software since that software will probably change with time.

D. The various types of observations to be made on the VLBA should use the same software to the greatest extent possible. Specifically, the data format should be flexible enough to handle continuum, spectral line, and astrometric/geodetic data. This insures that, for example, source maps can be made from astrometric data or that astrometric source positions can be found from mapping data (within the limitions imposed by observing style).

E. We should take advantage of the massive software efforts that have already been made. The image formation and analysis should be done using the VLA AIPS system or its successor (AIPS is already used for VLBI) and the NASA-NGS software should be used or adapted for astrometric/geodetic analysis. If data format conversions are needed to use any such software, it should be done as late as possible in the analysis so that use of one package does not preclude use of another.

F. Most routines whose net effect is to alter the data should actually only alter gain tables. This is most efficient in use of disk space and does the least damage to the data if errors are made. Clearly, averaging routines and format conversion routines must actually modify the data and any display routines must be capable of applying the gain information. This style is much like that used in the DEC 10 at the VLA.

G. The software should be exportable so that users that have the necessary hardware (which may be inexpensive by the end of the decade) can take their data home at early stages of the processing. AIPS sets a good example here.

II. FORMATS.

There are three basic types of data that will be stored: visibility data, history information, and gain tables. The great majority of storage space will be consumed by visibility data so the format used for that type should be as efficient as possible without loss of accuracy. The other types of data can be stored in formats that are designed more with ease of access than with space requirements in mind. The data formats should be flexible so that all types of data can be understood by the same software and so that parameters or data types that are not envisioned at the time the format is designed can be added easily. An example of what might be used is FITS (which is very close to the AIPS internal format) in which header parameters are given along with identifying keys and the meaning of the data arrays is variable and is described in the header. The history information and gain tables should also be in very general formats for ease of use. Current VLB routines use standard ASCII text files which can be accessed easily with editors, system utilities and simple routines.

III. SCHEDULING.

Pearson (VLBA Memo 133) gives a good discussion of the needs of the VLBA for scheduling and bookkeeping. The basic programs that will be needed are:

A. Scheduler - A 'friendly' program to help an observer prepare a schedule and check that it is reasonable.

B. Program selection - The operations staff probably could use a routine that helps select an observing project for a given time based on such parameters as array condition, weather, priority, project needs, 'seniority' of project and any other factors that can be found.

C. Schedule distribution - get the schedule to the telescopes.

IV. OBSERVING.

The following software will be needed during observations:

A. Telescope control.
1. Receive instructions from control center.
2. Point telescope.
3. Control receivers, subreflecter, frequencies etc.
4. Control data recording process.
5. Monitor weather information.
   a. Temperature, dew point, pressure.
   b. Water vapor radiometer data.
   c. Cloud cover (how?), storms etc.
6. Monitor condition of all systems.
7. Inform control center of status.

B. Array monitor and control. (At control center)
1. Implement any schedule changes.
2. Monitor status of all telescopes.
3. Monitor weather at all sites.
4. Warn if current conditions are incompatible with current project.

C. Fringe verification. Real time check of most systems.
1. Control aquisition of fringe check data.
2. Transmit data to control center.
3. Correlate and fringe search.

D. Bookkeeping.
1. Log weather and system status at all telescopes.
2. Log all necessary calibration information.
   a. System temperatures.
   b. Weather information.
   c. Water vapor radiometry data.
3. Gather schedule and all log information to begin data base history file.

V. PROCESSING.

A. Bookkeeping.
1. Read log files for information needed by processor.
2. Monitor processor operation.
3. Tape inventory.
4. Add necessary information to history file.

B. Processor control. This program will be one of the major software efforts for the VLBA. It should be designed to provide the greatest possible flexibility in observing parameters and should leave all of the information needed to reproduce its calculations in the history records. The use of a high level language in a reasonably powerful computer is attractive here. If enough intelligence is built into the processor, the burden on a general purpose computer for the primary geometric calculations and control instructions should not be great.

1. Calculate geometry for delays and rates.
2. Synchronize tapes.
3. Set up data path in processor.
4. Control any on-line data processing. Possibilities are:
   a. Transform to spectra.
   b. Correct for fractional bit shifts in the delays.
   c. Apply system temperature and gain corrections.
   d. Edit for known system problems.
   e. Average data.
   f. Shift spectra to a desired center velocity.
   g. Pass a restricted range of delays or frequencies to help reduce data volume.
   h. Fringe fit on strong sources.
5. Write data to an archive medium and to post-processing computers. The output of the correlator should be in the format used by the VLBA reduction programs. Let's avoid the need for programs such as DECODE and FILLER.

VI. EDITING AND CALIBRATION.

A. Interactive editing. Most editing should be automatic, but an editing capability will always be needed and should be available at all stages of the data reduction including after mapping has begun.

B. Calibration. The following functions are needed. The functions in each group could be combined in a single program.

1. Gain calibration (from log and system information).
   a. System Temperatures.
   b. Gain curves or antenna temperatures.
2. Spectral calibration.
   a. Bandpass - amplitude and phase.
   b. Gain based on autocorrelation data.
   c. Phase slope (delay).
   d. Shift to common center velocity.
3. Geodetic calibration (eg correct for subtle effects)
   a. High accuracy geometry (good precession, earth tides, relativity etc.).
   b. Water vapor radiometry.
   c. Ionosphere.
4. Phase referencing.
   a. Spectral channel.
   b. Reference source (like linked interferrometer calibrator).
5. Polarization calibration.
   (Polarization calibration methods and possible useful hardware devices should be considered soon. For example, should the array have linearily polarized reference signals at each telescope to calibrate the relative phases of the left and right circular

polarizations?)

The calibration routines should primarily generate gain tables to help protect the data and to reduce number of data sets that are generated. Time consuming operations such as velocity shifts in spectral data (double FFT) might actually be done to a copy of the data set to avoid excessive calculation in display and mapping routines.

C. Averaging.
1. Average in time to reduce bulk of data set.
2. Average across frequency channels.

VII. DISPLAY.

It should be easy to examine data in any way desired in order to determine its quality and to compare with any models. Much of the needed display will presumably be provided in the AIPS system but some capability is needed before entering AIPS (Assuming AIPS or equivalent is not used for all processing - a possible option). Possible displays are:

A. Amplitude (all stokes parameters), phase, delay, fringe rate, closure phase, closure amplitude vs. time (UT, UT folded on 24 hr., IHA, GST), u, v, uv distance, angle and any other desired parameters. It should be possible to display several baselines at once and to compare the data with a model.

B. Graphics and printer displays of data from the history and monitor data files. For example, displays of system temperature or weather parameters as a function of time.

C. Graphics and printer displays of the contents of gain files.

D. Indexing of the contents of disks or tapes for bookkeeping.

VIII. FRINGE FITTING.

Fitting the data from continuum sources for amplitude, delay, rate, and phase is projected to be one of the major time consuming operations of the VLBA computer system. This can currently be done inside AIPS but it is likely that, unless all processing is done in AIPS, a program that uses the standard VLBA data bases should be provided. The program should be as efficient as possible, should be capable of a global (station-based using all baselines) fit and should be capable of dealing with multiple-band data such as will be typical from geodetic experiments. It should also be capable of using a source model if necessary.

IX. IMAGE FORMATION AND ANALYSIS.

The image formation and analysis needs of the VLA and of the VLBA are so similar that it would not be reasonable to use separate programs, especially considering how much effort is involved in writing a good system. Therefore, the VLBA should rely on AIPS or its successor. AIPS can be used for both continuum and spectral line observations. Unique capabilities needed for VLBI are:

A. Fringe rate mapping - especially for spectral line.

B. Display of data vs model (not traditional but would be useful for VLA).

C. Ability to give different weights and timescales for different stations in Self-Cal. Also the ability to do something reasonable in Self-Cal with data when only a few stations (eg. 2 or 3) are on source.

X. GEODESY AND ASTROMETRY.

For geodesy and astrometry, the VLBA could either adapt its data for analysis in the NASA/NGS software or that software could be adapted for use on the VLBA data. It might be best to adapt the software so that any VLBA data could be corrected for all known effects, an operation that will be needed for experiments that attempt to use reference sources to map weak sources or to measure proper motions. The main functions that will be needed are:

A. Grand geodetic and astrometric fit. Fit data for all unknown parameters such as station locations, polar motion, Earth rotation, source positions, clock parameters etc.

B. Correct data for all a-priori known effects. This will be useful for many astronomy projects.

C. Ability to analyze old data for monitoring of tectonic plate motions, source motions etc. This is the reason for having extensive information in the history files.

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              Block Diagram of VLBA Software for Data Analysis
                (Observing and array control not included)


      |                              |
      |                              |
 Observing logs             Wide Band Tapes from Telescopes
      |                              |
      V                              |
---------------      - - - - - - - -V- - - - - - - - - - -
| Bookkeeping |      |        ---------------           |- Intelligent
| data set    |<------------>| Correlator  |               processor.
| (history)   |      |       |             |            |
---------------              ---------------
      |              |             ||||                 |
      |                            VVVV
      |              |    -------------------------------- |
      |                  | On-line Analysis             |
      |              |   | eg: Some calibration         |  |
      |                  |     Narrow rate-delay window |
      |              |   |     Finge fit                |  |
      |                 --------------------------------
      |              |              |||                 |
      |              - - - - - - - -|||- - - - - - - - - -
      |                             |||---------------
      |                             VVV            | bandpasses
      |                      ----------------      | calibrators
------------------------->| VLBA          |      | autocorrelations
   ------------           |  data base    |      V
   | Display  |<---------|               |     -----------------
   ------------           | incl:         |     | Calibration:   |
   ------------           |     visiblity |     |   Gains        |
   |  Edit    |<---------|       data    |----->|   Bandpasses   |
   |          |--------->|     history   |<-----|   Phase Ref.   |
   ------------           |     gains     |     |   Polarization |
   -------------          |               |     |   Geodetic     |
   |  Fringe   |<--------|               |     -----------------
   |   Fit     |-------->|               |     -------------
   -------------          |               |----->| Average   |
                          |               |<-----|           |
                          -----------------     -------------
          ____________________||_____________________
          |--------------------||--------------------|
          ||                   ||                   ||
          VV                   ||                   VV
   -------------------         VV             ------------------------
   |     Image       |   ----------------     | Astrometric-Geodetic |
   |   Processing    |   |  Archive     |     |     Processing       |
   |    (AIPS?)      |   ----------------     |                      |
   -------------------                        ------------------------
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