NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY

VLA OBSERVATIONAL STATUS REPORT
December 15, 1988

This report summarizes the current observational parameters of the VLA. It contains the essential information needed to prepare an observing program with the VLA. More technical information is also available from the following general books and publications:

a) Course notes from the NRAO Summer School on "Synthesis Imaging" (August 5-9, 1985) are available from C. Ziegler at NRAO/Green Bank or S. Montoya at NRAO/AOC. The cost is $10.00 per copy. A new, expanded volume, from the 1988 Synthesis Imaging Summer School, will be available in 1989. This volume will be published by the ASP Conference Proceedings.

b) An Introduction to the NRAO, Very Large Array (Green Book). Many sections are out of date. (NOTE: Extra copies are no longer available.)

c) The Very Large Array: Design and Performance of a Modern Synthesis Radio Telescope, Napier, P.J., Thompson, A.R., and Ekers, R.D., Proc. IEEE, 71, 1295, 1983 (available from S. Montoya, VLA).

d) Other specific manuals and documentation available at the VLA are listed in Section 5.0.

1.0 HARDWARE CONFIGURATIONS

Continuum and spectral line observations are supported at six separate wavelength bands centered near 1.3 cm, 2 cm, 3.6 cm, 6 cm, 18-20 cm and 90 cm, known as K, U, X, C, L and P bands respectively. Continuum observations always provide full polarization information at each of two separately tunable frequencies within the same band. (See the next paragraph for an exception.) These frequencies can be separated by no more than approximately 450 MHz. Spectral line observing provides only Stokes' parameters I and V at this time. Full spectral line polarization capability should be available sometime in 1989.

There are now 25 antennas outfitted with 90 cm receivers, with all antennas to be outfitted by January, 1989. This frequency can be tuned in one IF pair and a frequency in any other band can be tuned separately and simultaneously in the other IF pair. At the moment we support only the 20/90 cm combination principally because the focus and pointing at the other bands is significantly different from 90 cm.

There are currently 26 antennas outfitted with 3.6 cm receivers. All antennas will be outfitted at this band by mid-January, 1989. Twenty-two antennas have the new 1.3 cm HEMT or FET receivers. All antennas will be retrofitted by April, 1989.

Observations at seven different bandwidths (50 MHz/2^n, where n = 0,1,2...6) are possible in each of the two separate IF pairs. It is possible, in continuum mode, to have different bandwidths on the different IF pairs.

The array is cycled through its four main configurations (A,B,C, D) during a 15 month period. The reconfiguration schedule for the next year, and the approximate long-term schedule are outlined in Table I. Updates to this table are published in the NRAO and AAS Newsletters. See Section 6 for the scheduling scheme.

2.0 OBSERVATIONAL LIMITATIONS

Tables IIa and III summarize the sensitivity and resolution of the VLA. Note that the sensitivities in Table IIa and Section 2.1 refer to naturally weighted data (which gives maximum sensitivity), whereas the resolutions quoted in Table III refer to uniformly weighted data.

2.1 Sensitivities

The sensitivity parameters listed in Table IIa are based on theoretical estimates using the quoted system temperatures. The sensitivities are confirmed from observations. The rms noise on an image can be calculated approximately using the formulae (for natural weighting):

$$S_{rms} \simeq \frac{K}{\sqrt{N(N-1)\ T\ n\Delta f}} \quad \text{mJy / beam area}$$

where:

N = number of antennas
T = integration time on source, in hours
Δf = bandwidth in MHz
n = number of IF pairs
K = 31, 10, 7.4, 5.2, 19, 33 for bands 90, 20, 6, 3.6, 2, 1.3 cm

The constant K can be expressed in terms of system temperature and efficiency as: $K = .082\ T_{sys}/\eta$ where T_{sys} = system temperature and η = system efficiency.

Use of uniform weighting will decrease the sensitivity by a factor of 1.5 - 2.5 depending on the image and cell sizes.

The brightness temperature (for the uniformly weighted case) is given approximately by

$$T_b \sim FS\ {}^{o}K$$

where S is flux density in mJy and F = 300, 30, 3, 0.3 for configurations A, B, C, D respectively. The F values depend on u,v coverage and source structure and should be used with caution. A rough estimate of the minimum detectable brightness temperature can be obtained by substituting 3 S for S in this expression. However, this applies for the case of an object whose size is equal to the synthesized beam. A more detailed description of flux and surface brightness sensitivity, including the effects of uniform weighting and tapering, is given in Chapter 7 of the 1988 "Synthesis Imaging Summer School".

The sensitivity degrades near the band edges. Table IIb shows the frequency ranges, for each band, at which the sensitivity degrades by 10% and by a factor of 2, and the full tuning range. Note that at X, U, and K bands, the number of antennas which will lock up drops, typically by half, between the frequencies listed in the second and third columns. The system sensitivity of these bands at the extreme tuning range is typically 10 to 100 times worse than nominal. Dynamic range, interference and confusion (particularly at 20 and 90 cm) may prevent one from reaching the sensitivity limits quoted in Table IIa.

The sensitivity parameter given at 1.3 cm is applicable under dry observation conditions, with dew points near or below freezing. In summer the sensitivity will be degraded by up to perhaps 20%.

2.2 Large Scale Structures

Imaging of large sources is restricted by the smallest spacings of the array. Table III indicates approximately the largest scale structure "visible" to the VLA at the six standard bands and the four standard configurations. Sources with extended regions larger than these limits will be missing major fractions of flux density and images may seriously misrepresent the large-scale structures.

2.3 Dynamic Range

The dynamic range, which is the ratio of the maximum image brightness to the rms in the blank part of the image, is limited mainly by tropospheric and ionospheric phase stability. Many of the synthesized images generated from VLA observations are limited by dynamic range (typically 100:1) and not by noise. Self-calibration can improve the dynamic ranges to values up to 100,000:1, depending upon source structure, u,v coverage, sensitivity and data quality. Self-calibration of VLA data is done within the AIPS image processing system. To obtain the highest dynamic range it is necessary to use the spectral line correlator. Details on self-calibration procedures are in the AIPS Cookbook and the 1988 Synthesis Imaging Proceedings.

Spectral line dynamic range is commonly defined as the ratio between the weakest believable feature in a spectrum and the total flux density of the continuum in that spectrum. This ratio is generally limited by instrumental effects, which must be calibrated out. The spectral line dynamic range depends on bandwidth in a poorly understood way. Applying the on-line autocorrelation only can result in about 50:1 dynamic range. Better than 3000:1 is possible when careful bandpass calibration is used.

2.4 Pointing

Large daytime antenna pointing errors of 1 arcminute or more occur occasionally when the sun shines upon the yoke and pedestal under calm conditions (dawn to dusk period). At 1.3 cm this could affect the sensitivity by as much as 50 percent.

All antennas have been thermally insulated with the result that such large pointing errors are very rare. The rms pointing error is 10 arc seconds for all antennas during the night. Daytime pointing will be worse by a factor of up to perhaps 1.5, depending on weather and details of the observing. These errors will lower the sensitivity of half the antennas at 1.3 cm by 20% or more. Pointing errors due to wind are also a problem. Noticeable degradation at 1.3 cm occurs at wind velocities above three meters per second (7 mph).

Observations within 1.5 degrees of the zenith should be avoided due to both pointing errors and hardware limits.

2.5 Interference

The bands within the frequency range of the VLA that are allocated exclusively to radio astronomy are the following: 1400-1427 MHz, 4990-5000 MHz, 15.35-15.4 GHz, and 23.6-24.0 GHz. There should be no interference within these bands. Some interference (White Sands radar, meteorological balloons, airborne drones, satellites, etc.) can be expected outside of these bands, particularly at 20 cm (1340-1730 MHz) amd 90 cm (305-340 MHz). The results of an interference study in the 20 cm band from 1350 to 1730 MHz are available in VLA Test Memorandum No. 139; the results of a continuing program monitoring the frequency range 1330 to 1750 MHz are posted in the Control Room and Visitor's offices. In summary:

(1) There are birdies every 50 MHz at frequencies of 1300+ n50 (n=1,...) MHz over the whole tuneable range. These are of moderate strength, could interfere with narrow-band continuum observations, and should be avoided. It is most important to avoid the 1600 MHz birdie as it is exceptionally strong. Also note that the 3rd harmonic of this frequency (4800 MHz) must be avoided.

(2) Located within the range 1670 to 1700 MHz are the frequencies used by meteorologists to receive weather data from balloons. These are released from nearby South Baldy during thunderstorm season (July - September). Thus, one is "probably" safe during the winter, spring and fall in this frequency range -- but summer observations, especially in the daytime, are likely to be affected.

(3) The band from 1610 MHz to 1660 MHz, formerly devoid of any measurable interference, is now quite unsuitable for broadband observations. In particular, the frequencies between 1603 and 1620.2 MHz now commonly harbor very strong interference. Between 1620.2 and 1669.2 MHz, the band remains rather good for continuum observations.

Two standard bands have been set up at 20 cm to help avoid interference. The HH code places the observing frequency within the protected band and may be used with observing bandwidths of 25 MHz or less. The LL code should be used with 50 MHz bandwidths.

2.6 Bandwidth and Time Averaging Smearing

A. Effects Due to Bandwidth (Chromatic Aberration)

Observing with a finite bandwidth causes a radial smearing of the image which increases with separation from the phase center. There is a corresponding reduction in the peak response and hence point source sensitivity.

The loss is parameterized by the product of the fractional bandwidth ($\Delta\nu/\nu$) with the offset in synthesized beams (θ_o/θ_{FWHP}). Table IV(a) shows the loss of central intensity as a function of this parameter. In addition to a loss of peak response, the image of a point source becomes radially smeared. The amount of smearing (apparent broadening) is inversely proportional to the loss of intensity so their product (the total flux) remains constant.

More details are in the 1988 Synthesis Imaging Proceedings.

B. Effects Due to Time Averaging

Time averaging over intervals during which the visibility changes significantly causes loss of amplitude similar to that due to the bandwidth effect. However, the analysis of the time effects is more complicated. A simple case exists for the North Pole, where the losses are equivalent to bandwidth losses except that the smearing is in the azimuthal, rather than the radial direction. The functional dependence is the same as in bandwidth smearing with $\Delta\nu/\nu$ replaced by $\omega\Delta t$, where ω is the angular rotation rate of the Earth, and Δt is the integration time. A guideline for keeping time averaging losses small in broadband continuum observations is to keep them less than the corresponding bandwidth losses. Table IV(b) gives the averaging times for which time averaging broadening equals bandwidth broadening at $\delta = 90^o$.

2.7 Confusion

As indicated in Table IIa, the presence of sources in the primary antenna beam, but outside the useful or practical imaging area, can limit image quality. These sources produce unwanted sidelobes in the images and can lead to aliasing problems. Although bandwidth and time smearing in the larger configurations will suppress some of the effects from confusing sources in the primary beam, they are a major concern, especially at 20 and 90 cm, and for observations near the galactic plane using the compact configurations. The brightest source expected in the primary antenna beam (away from the galactic plane) is listed in Table IIa for each of the observing bands.

2.8 Strong Source Interference

The presence of very strong sources in the sky may lead to interference problems. For example, the sun is such a strong source that the far sidelobes of the antenna are not able to suppress its signal entirely. For broad continuum bandwidths the correlated signal from the sun is bandwidth smeared down to negligibly low levels. However, this is not true for the narrow bandwidth spectral-line observations of weak sources in the more compact configuration during the daytime which may be degraded even when the sun is far away from the source. The problems are especially severe at 90 cm, where observations of weak sources within several degrees of Cyg A, Cas A, Tau A, and Virgo A are also not possible.

2.9 Positions

The typical positional accuracy obtained is generally about 0.1 arcsec in the A configuration (at 20 cm and 90 cm wavelengths, careful correction for ionospheric effects are necessary to attain this accuracy). The main limitations are the phase errors caused by the ionosphere and the troposphere. Positional accuracy of 0.03 arcseconds can be obtained in good weather by using only the class A or B calibrators and checking antenna baseline parameters. Position errors in declination are about a factor of 2 worse for sources at -20 degrees declination and will further deteriorate at more southern declinations.

The VLA supports the J2000 epoch ephemeris, preferred for accurate astrometric work, as well as the 1950.0 epoch.

2.10 Flux Density Scale

The VLA staff has compiled a list of sources which are sufficiently unresolved and unconfused to permit gain calibration at all bands to a few percent. This list currently contains about 700 sources and is available at the VLA site. Although the primary flux density calibrator is 3C286, 3C48 and 3C147 are also used. 3C48 and 3C147 are known to be slowly variable. The flux densities of these sources will now be accurately bootstrapped to the Baars' value for 3C295 at P, L, C, and X bands when the VLA is in the 'D' configuration. At U and K bands, NGC 7027 will be the primary reference. Table V contains the results of this program for 1987.

There is now an established list of about 130 P-band calibrators. Contact Theresa McBride for a copy.

2.11 Polarization

Circular polarization measurements are limited by large circularly polarized sidelobes and are restricted to sources with very large degrees (>10%) of circular polarization or to point sources located at the center of the primary beam. This limitation is due to the offset of the two oppositely polarized beams.

Linear polarization observations are possible at all bands. The on-axis instrumental polarization can usually be determined to an accuracy of much better than 0.5 percent at 6 and 20 cm. At 2 and 1.3 cm the accuracies are usually about a factor of 2 worse. The limit of this accuracy is partly a result of pointing errors. Imaging the polarization of sources more than 10 percent of the half-power beam width away from the beam center may be subject to uncertainties greater than one percent because of the linearly polarized sidelobes.

Polarization observations in the 20 cm band and in the 90 cm band are always hampered by ionospheric Faraday rotation. The amount of Faraday rotation has been occasionally larger than 35 degrees at 20 cm during solar maximum and will probably continue to be a factor in observations at 20 cm even during the minimum of the solar cycle. More information can be obtained from the Linear Polarization Measurements document in the VLA COOKBOOK and a general discussion is available in the proceedings of the 1988 Summer School on Synthesis Imaging.

The instrumental polarization can be calculated from observations of the calibrator normally used to obtain the amplitude and phase of the instrument, provided that there are enough observations to ensure both a high signal-to-noise ratio in the cross hand correlators (i.e., the RL and LR) and a change in parallactic angle exceeding 90°. The number of observations must not be less than 3, and should exceed 5. Absolute position angles are determined by observing a strong, linearily polarized source whose polarization is known. The two calibrators used are 1328+307 (3C286) and 0518+165 (3C138).

2.12 Spectral-Line Capabilities

The VLA correlator can support a wide range of spectral line observing modes. Those which are, or soon will be supported are four single IF modes: 1A, 1B (Right Circular polarization) and 1C, 1D (Left Circular polarization); six 2-IF modes; giving a pair of polarizations; and three 4-IF modes, two of which give full polarization information (see Table VI).

In general, a channel-to-channel stability of about 30:1 can be achieved easily, but achieving 100:1 at wide bandwidths is very hard. Stabilities better than 100:1 require special treatment and cannot be guaranteed (discussed in greater detail in Chapter 18 of the Proceedings of the 1988 Synthesis Imaging Summer School.

The allowed numbers of spectral line channels are listed in Table VI. See "A Short Guide for VLA Spectral Line Observers" for more information.

UVFITS tapes may now be written on SORTER or from the DEC-10. Use of the DEC-10 version for spectral-line data is more convenient than the SORTER version because of the 8 channel grouping limitations on SORTER, especially when dealing with large data bases. However UVFITS on the DEC-10 is very slow and should be avoided if possible. These make it possible to use the full 3-D structure in AIPS.

For spectral line mapping where self-calibration is not needed we encourage the use of the PIPELINE (GRIDER) or ISIS on the CONVEX. Mapping is quite fast and there is no need for uv data to be written to tape. The maps can be looked at using the PIPELINE display system on OUTBAX, which includes the Image Storage Unit (ISU). A second ISU is attached to the CONVEX.

2.13 VLBI Observations

VLBI observations using the VLA and the Mark II or Mark III backend are possible either using phased array mode or a single antenna. There is a VLBI cookbook available (in the COOKBOOK manual). See comments under 3.0 (VLA REMOTE OBSERVING PROGRAM) for the support available for in-absentia VLBI observing.

2.14 Snapshot Mode

Short duration observations of bright and fairly small sources ("snapshots") can be very effectively done with the VLA. However, because of the effects of confusion, this mode is not recommended at 90 cm (P-band).

Single snapshots with good phase stability should give dynamic ranges of up to 500 to 1 for sources whose angular size does not exceed the numbers listed in Table III for "Largest Scale Structure Visible". Snapshots do not give as good protection against the sidelobes of distant confusing sources as full imaging. This is especially true at 20 cm in the C and D configurations. A single snapshot of less than 5 minutes duration at 20 cm will give an rms noise of approximately 1 mJy due to confusing sidelobes. This level can be reduced either by making multiple snapshots, with at least 1 hour separating the observations, or by imaging and cleaning the entire primary beam with the AIPS program MX, or by doing both.

2.15 Shadowing

Observations at low elevations taken in the C and D arrays may be affected by antenna shadowing (see VLA Scientific Memorandum No. 134). The OBSERV program will indicate when shadowing will occur and on what antennas. It is generally recommended that the data from shadowed antennas be flagged, especially for observations of extended sources. After the observations, the program SHADOW or GTBCOR (with FLAGER) can be used to find out what antennas have been shadowed and to flag shadowed antennas. There are no automatic on-line shadowing corrections applied to the data. Observations using a hybrid array with a longer north arm (see Section 6.0) are preferable for sources with declinations $<-15^{o}$.

2.16 Combining Configurations

It is useful to combine data from different configurations when there is a large range of structure scales in the source. This can be done by using software in AIPS. Note that it is not necessary to keep the same frequencies and bandwidths in multi-configuration studies, provided the changes are small. Further, spectral studies using data from adjacent bands do not require identical u-v coverages, so use of the standard VLA frequencies is fine.

2.17 Weak Source Detections

Offsets in the correlators can lead to artifacts in the center of the field. Although it is believed that this effect should no longer be seen, it is advisable to offset the source positions a few beamwidths from the field center in weak source detection experiments.

2.18 Imaging Large Objects

Imaging of objects larger than a VLA primary beam is now possible using AIPS software developed by Tim Cornwell and Robert Braun. To image a large object one must obtain the VLA observations at a number of pointing centers spanning the object, with separations of one-half the FWHP of the antenna primary beam and optionally, single dish observations of the same object, spanning the same region.

At 90 cm, full use of VLA u,v data requires the use of 3-dimensional Fourier transforms. Software to do this is available on the CONVEX, and will handle data from the "C" and "D" configurations.

For further details and advice, those interested should contact either Tim Cornwell or Robert Braun.

3.0 VLA REMOTE OBSERVING

3.1 Absentee Observing

Observers may be absent during the observations provided that advance notice (at least two weeks) has been given. For standard VLA continuum or spectral-line programs and all standard Mark II VLBI programs which need very little operator interaction, the observer is generally not required to be present at the VLA site. However, for any complicated or unusual Mark II or III VLBI programs (or for Mark III programs exceeding 12 hours) the presence of an observer on-site may be required.

3.2 Observing File Preparation

The observing file can be prepared for standard VLA observing programs. The observer is required to specify the detailed source list, sequences and observing options at least two weeks in advance. The observing files for any complicated programs generally must be completed by the observer himself. In particular, the observer must take responsibility for setting frequencies for line programs. The preparation of VLBI observing files is the responsibility of the observer. If the VLBI observer is unable to prepare his source file he should contact Pat Crane at least two weeks before the start of the Network run.

3.3 Editing and Calibration of VLA Data and Related Tasks

(a) Any standard VLA continuum observing program can be edited and calibrated. Complicated calibration of continuum data or calibration of spectral-line data may be possible but must be checked out well in advance.
(b) Calibrated visibility tapes (Export or UVFITS tapes), backup tapes and copies of archive tapes can be prepared.
(c) In general, images will not be produced.
(d) Data from VLBI observing runs will not be calibrated.

3.4 DEC-10 Dial-Up Line

The DEC-10 has four dial-up lines which may be used for preparing observing files or the calibration of a DEC-10 database. One telephone number, (505) 772-4346, will access all lines. Modem protocols allowed include Bell 103j (300 baud), Bell 212A (1200 baud) and Racal-Vadic (1200 baud). Eight bits and no parity are the usual settings.

All requests for remote calibration MUST be made through the Data Analysts (see Section 3.6(b) below) at least 10 days in advance in order to obtain disk space. Data will be filled on a first-come, first-served basis. In general, a five day limit will be imposed on disk space usage for a given project.

NRAO will pay for the call. Dial (505) 772-4011 and request to be called back and transferred to the computer (DEC-10).

3.5 On-Site Help

The Data Analysts who normally carry out the tasks listed under 3.2 and 3.3 will be available on weekdays to on-site observers for direct assistance.

3.6 How to Make Use of Remote Observing Services

(a) Check the appropriate box on the observing cover sheet for your proposal.
(b) Contact either Dave Wunker (505-772-4359) or Peggy Perley (505-772-4239) and pass on the details well in advance (>2 weeks). The advance notice is required to enable us to schedule all the requests efficiently. Or, use their E-mail address: ANALYSTS@NRAO (on BITNET), NRAO::ANALYSTS (on SPAN).

(c) For VLBI observations, contact Pat Crane (505-835-7227) at least 2 weeks before the start of the VLBI Network session. Complicated observing files must be prepared by the observer.

4.0 SOFTWARE

The current on-site VLA software capabilities for converting raw visibility data into well-calibrated images are best summarized by briefly listing the various tasks presently implemented at the different stages of data processing. No attempt is made to list the complete set of either the software options or its limitations.

The on-line computers, the Modcomps, automatically (a) change the LO phase to compensate for differential atmospheric refraction; and (b) correct the visibility phases for variations in the effective electrical length of the waveguide and some of the antenna LO paths. (This latter correction is often termed the "round-trip phase correction"). In addition, gain variations caused by changes in the system temperature are corrected by using real-time measured system temperatures. (This correction is applied to both continuum and spectral line data.) The latter correction may be turned on or off at the astronomer's option and by default is turned on at all bands. The on-line system, both hardware and software, has been upgraded.

Processing required to take the initially corrected visibility data from the Modcomps through calibration can be done using the DEC-10 general-purpose computer. The software is quite extensive and employs an antenna-based calibration technique. For the calibration of data, there exist programs to (a) flag data good or bad, (b) correct phases for known source position errors, antenna position errors and time errors, and (c) correct amplitudes for general, zenith angle, dependent effects such as atmospheric absorption. The antenna gain, phase and polarization characteristics are calculated from calibrator source observations, interpolated in time, and stored with the visibility data. The data may then be written on an UVFITS or EXPORT tape. A full suite of calibration and editing functions, including antenna-based and baseline-based calibration, polarization and bandpass corrections, and interactive TV-based data editing, is now included in the AIPS software package, which is available on all VAXes and CONVEXes at the VLA and in Charlottesville.

Conversion of calibrated u,v data to images can be done by using (a) PIPELINE, (b) AIPS (Astronomical Image Processing System), or (c) ISIS (Interactive Spectral-line Imaging System). AIPS runs on all of the NRAO VAXes and CONVEXes. ISIS is available on the VLA CONVEX. The tasks for conversion of calibrated data to images include sorting, gridding, fast Fourier transform, source subtraction in the u,v plane, and the clean algorithm. Both u,v plane convolution (to aid in reducing the aliasing problems) and tapering are supported. Self-calibration is only available in AIPS.

The PIPELINE system (and ISIS on the CONVEX) handle a large volume of data efficiently and, in particular, accommodate a substantial increase in spectral-line processing. SORTER can write UVFITS tapes that can be read on the VAX for transfer of visibility data (continuum or spectral-line). Images made in the PIPELINE can be displayed on OUTBAX (VAX 11/750) after transfer to that system.

Image display formats include: character display on computer terminals, line printer output (DEC-10), Laser printer (VAXes and CONVEX); contours with or without polarization on a Selanar terminal (DEC-10), ZETA pen plotter (VAX), the laser printer or Selanar (on the VAX and CONVEX); gray scale and color images in two dimensions (2-D) on the IIS video terminals (VAX and CONVEX); and Dicomed film recorder. The image storage unit (ISU) attached to OUTBAX and CONVEX allows the storage of multiple images and replay of these images in a "movie" mode. This is most used for spectral line observations.

The AIPS post-processing system includes options to edit, calibrate and display u,v data, to make and deconvolve images using a variety of algorithms including CLEAN and MEM, self-calibration, display 2-D images on a TV monitor, contour images on the QMS laser printers, source fitting, polarization, optical depth, etc. Input is images (FITS) or u,v data (EXPVIS or UVFITS). Spectral-line capabilities are available. This system is currently running on the two VAX 11/780s, one VAX 11/750 and one CONVEX at the VLA and on a VAX 11/780 and a CONVEX in Charlottesville. Visibility data can be displayed in baseline time format on OUTBAX at the VLA using the PIPELINE or with ISIS on the CONVEX at the VLA. Time-baseline u,v data can also be displayed in AIPS with the new task TVFLG; this also allows interactive editing of data. Spectral line data may be processed on OUTBAX using GIPSY. One AIPS system at the VLA has dismountable disk packs for temporary use by observers (these packs are available from the Computer Operations Group). The Charlottesville CONVEX now has about 700k blocks of disk space that can be signed up for in advance on request to Jim Condon (this is not a demountable disk, but functions like one, in that the signed-up user can be guaranteed that part of the total space). It also supports an IVAS 1024 by 1024 TV that is particularly useful when displaying large images, or when editing large data sets with TVFLG.

All computers support image data exchange using the FITS and UVFITS format.

One return visit to Charlottesville or the VLA for further VLA reduction is supported by NRAO. Contact Jim Condon in Charlottesville (804-296-0322) or Carl Bignell at the VLA (505-835-7242).

5.0 DOCUMENTATION

Documentation for VLA data reduction, image making, observing preparation, etc., can be found in various manuals. Some, but not all, of these manuals can be mailed out. Manuals which can be mailed are marked with an asterisk (*). Direct your requests to S. Montoya at the VLA.

INTRODUCTION TO THE NRAO VERY LARGE ARRAY (Green Book): This manual has general introductory information on the VLA. Topics include theory of interferometry, hardware descriptions, observing preparation, data reduction, image making and display. Parts of the 1983 manual are now out of date. Copies of this are found at the VLA, but no new copies are available.

*NRAO-VLA WORKSHOP: Synthesis theory and technical information and observing strategies can be found in: "Synthesis Imaging -- Course Notes from an NRAO Summer School Held in Socorro, New

Mexico" (June, 1988). These proceedings are scheduled to be published by the ASP in 1989.

THE OBSERVERS REFERENCE MANUAL: This is a reference manual which contains all the information on individual computer programs and utilities run from the DEC-10. There is a separate volume for the PIPELINE system (ORM Vol. II). This manual is available for use on-site only.

VLA COOKBOOK: The Cookbook contains some observing strategies and recipes on the initial data reduction of continuum, polarization, spectral line, solar observations, and guides to self-calibration. This manual is available on-site only.

*A SHORT GUIDE FOR VLA SPECTRAL-LINE OBSERVERS: This is an important document for those wishing to carry out spectral-line observations at the VLA. This guide can also be found in the VLA Cookbook.

*AIPS COOKBOOK: The "Cookbook" description for the AIPS image processing system can be found in the AIPS terminal room in the VAX building. You may obtain your own copy from S. Montoya at the VLA, or by writing to E. Allen at NRAO, Edgemont Road, Charlottesville. The latest version has expanded descriptions of imaging, cleaning, self- calibration, spectral line reduction, VLBI reductions and a section for CONVEX users. The AIPS COOKBOOK is now produced in a ring binder format for greater ease of updating. Custom binders are available from S. Montoya at the VLA or E. Allen in Charlottesville for $5.00.

*GOING AIPS: This is a two-volume programmers manual for those wishing to write programs to interface with AIPS.

VLA CALIBRATOR BOOK: This manual contains the list of VLA Calibrators in both 1950 and J2000 epoch and a discussion of gain and phase calibration. This is available on-site only. There exists an IBM PC computer program which can be used to search the calibrator list. The program and data files can be ordered from S. Montoya at the VLA.

*GUIDE TO VLBI AT THE VLA: This manual describes VLBI observing procedures and requirements when the VLA is one of the NUG stations.

PIPELINE REFERENCE AND USER'S MANUAL (OBSERVER'S REFERENCE MANUAL VOL.II): The detailed descriptions of, and "how to use", the PIPELINE system is described in this manual. The USER'S MANUAL part may be requested separately.

*A STEP BY STEP GUIDE TO VLA DATA CALIBRATION: This is a guide (found in the VLA COOKBOOK) to facilitate calibration of visibility data on the DEC-10. Familiarity with the DEC-10 programs is assumed.

*<u>The Very Large Array: Design and Performance of a Modern Synthesis Radio Telescope</u>, Napier, Thompson, and Ekers, Proc. of IEEE, <u>71</u>, 295, 1983.

6.0 VLA OBSERVING REQUESTS

Observing requests should be sent to the NRAO Director:

Dr. Paul A. Vanden Bout
Director
NRAO
Edgemont Road
Charlottesville, VA 22903-2475

Requests should be concise (less than 1000 words) and emphasize the scientific justification. Sufficient thought should be given to instrumental capabilities to enable filling out the attached observing application form, which should be submitted with the proposal.

Closing dates for receipt of observing requests are listed in Table I(a). Prospective users are advised to submit their proposals well in advance of the change to the required configuration and certainly no later than the appropriate deadlines listed in the Table. Beginning in the last half of 1988, the VLA will be scheduled on a trimester basis instead of the previous quarterly system. The change will have the desirable effects of synchronizing the trimesters with the duration of any given telescope configuration and minimizing the administrative burden that the scheduling process for approximately 600 annual proposals entails. Additionally, the scheduling committee will be able to provide more uniform treatment of all proposals for a given configuration since their review will no longer artificially straddle two quarters.

IMPORTANT NOTE: Once rejected, single configuration proposals will not be retained for future consideration on the same configuration when it recycles 16 months later. Proposals will still be refereed as they are received, regardless of configuration, however. Proposers who submit their requests one configuration early may still get referee feedback in time to modify their requests.

Proposal due dates will fall at four month intervals with occasional shifts to keep in step with the VLA configuration changes. The proposed long-term schedule is given in Table I(b), but it may be subject to changes.

The duration of each configuration can be varied in response to proposal pressure. We will support observations during the reconfiguration. Suitable observations are point-source monitoring and detection programs for which the configuration is not critical. During reconfiguration we will pause in the hybrid configuration with the north arm in the next larger configuration. For declinations $<-15^{o}$ the longer north arm hybrid gives a more circular beam and reduces shadowing.

VLA observers are also urged to arrange their travel as soon as possible after scheduling and no later than two weeks before you are scheduled to arrive at the site. Both rooms and vehicle reservations (Albuquerque to VLA site) can be made by dialing (505) 835-7357.

7.0 VLA ARCHIVE DATA

A directory of the VLA archive data back to September, 1981 is available in seven reports, covering the six years 1981 (09/81-12/81), 1982, 1983, 1984, 1985, 1986 and 1987. There is also available a cumulative report covering all years (09/81-12/87), but only containing observations longer than one hour on source (ACCUM.SRT). Users with access to the VLA DEC-10 can find computer readable versions (1981.SRT[13,542], etc.) of these reports and of all completed quarters in the current year in user area [13,542]. Hardcopy versions are available from S. Montoya and in all NRAO libraries. There is now an IBM PC program (VLASORS) that can be used to search the archive source list (it also searches the calibrator list as well). Currently it only handles the ACCUM.SRT file. The data and program are available from A. Patrick.

NRAO has the following policy on the extent to which an observing team has exclusive use of the raw data obtained as part of their VLA observations. This policy is:

> Eighteen months after the end of a VLA observaion the raw (uncalibrated visibility) data will be made available to other users on request. The end of an observation is defined to be after the last VLA configuration requested, either in the original proposal or in a direct extension of the proposal. VLA correlator data taken for VLBI observations are immediately available.

8.0 PUBLICATION GUIDELINES

Any papers using observational material taken with NRAO instruments (VLA or otherwise) or papers where a significant portionof the work was done at NRAO, should include the following acknowledgement to NRAO and NSF:

> "The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation."

Preprints

NRAO requests that you submit four copies of all papers which include observations taken with any NRAO instrument or have NRAO author(s) to Ellen Bouton in the Charlottesville Library. NRAO authors may request that their papers be included in the official NRAO preprint series. Multiple author papers will not be included in the series if they are being distributed by another institution. All preprints for distribution should have a title page that conforms to the window format of the NRAO red preprint covers. Note that preprints will be distributed ONLY when the NRAO author so requests; inclusion in the series is not automatic. This action will also cause the paper to be included in NRAO's publication lists.

Reprints

NRAO no longer purchases reprints from the major astronomical journals for distribution. However, NRAO will purchase and distribute reprints in the following cases:

1. The paper is in a publication less likely to be readily available to other astronomers (i.e., IAU symposia/colloquia, IEEE and SPIE proceedings, commercial journals).
2. The paper is likely to be in great demand (i.e., comprehensive catalogs, detection of ETI, etc.).

In such cases, please send copies of the order forms supplied by the publisher to Ellen Bouton in the Charlottesville Library.

NRAO will also order 50 reprints for the personal use of the NRAO author(s) if reprints are requested at the time of submission of page charge information. Orders at a later date should be avoided in order to minimize administrative hassle. Normally, the first author should be responsible for reprint orders and share reprints as appropriate with collaborators. Do not ask NRAO to order reprints in those cases where reprints will be received from a non-NRAO first author.

TABLE I(a)

VLA CONFIGURATIONS FOR 1988/89

Period+	Configuration	Antennas Available* 327 MHz	8.4 GHz	23 GHz*	Proposal Deadline
1988 O,N,D,J	D-A, A	24	26	21	June 15, 1988
1989 F,M,A,M	A/B,B,B/C	27	27	24	October 15, 1988
1989 J,J,A,S	C, C/D	27	27	27	February 15, 1989
1989 O,N,D	D	27	27	27	June 15, 1989

Maximum antenna separation for the four VLA configurations are: A-36km, B-11km, C-3km, D-1km.

* All 27 antennas are available at 1.4, 5, 15 GHz. At 23 GHz the number given is the number of antennas with new receivers, approximately three times more sensitive than current ones.

\+ Note change to configuration based scheduling. See NRAO Newsletter No. 34, dated January 1, 1988 for details.

TABLE I(b)

APPROXIMATE LONG TERM VLA CONFIGURATION SCHEDULE

	Q1	Q2	Q3	Q4
1988	B	C	D	A
1989	A+#	B	C*	D
1990	D	A	B	C
1991	C	D	A	B

\# All antennas equipped for 327 MHz operation.
\+ All antennas equipped for 8.4 GHz operation.
* Voyager-Neptune encounter August 24, 1989. Modified C array to minimize shadowing. All antennas equipped for 23 GHz operation.

TABLE IIa

VLA SENSITIVITY

Frequency (GHz)	0.3 - 0.34	1.34 - 1.73	4.5 - 5.0	8.0 - 8.8	14.4 - 15.4	22.0 - 24.0
Band Name (approx. wavelength)	90 cm	20 cm	6 cm	3.6 cm	2 cm	1.3 cm
System Temperature (^{o}Kelvins)	150 - 180	60	60	40	120	160 - 210
Antenna Effeciency (%)	40	51	65	63	52	43
RMS Sensitivity (mJy) in 10 minutes (50 MHz bandwidth - 27 antennas, 1 IF pair)	1.6 (3 MHz bw)[1,2]	.13	.095	.067	.24	.42
RMS Sensitivity (mJy) in 12 hours (50 MHz bandwidth - 27 antennas, 1 IF pair)	0.19 (3 MHz bw)[1]	.015	.011	.0079	.028	.050
Untapered brightness (mKelvins) temperature (D configuration, 50 MHz bandwidth, 27 antennas, 1 IF pair)	57 (3 MHz bw)[1]	4.5	3.3	2.4	8.4	15
Antenna Primary Beam Size (FWHP)	156'	30'	9'	5'.4	3'	2'
Peak Confusing Source (mJy) Expected in Antenna Primary Beam	10 Jy	195 mJy	18	4.4	0.9	0.3

[1] Needs 3-D imaging to reach this level.

[2] Snapshot observations will not usually reach this level, even with 3-D imaging, as the confusion problem is insoluble with only snapshot u,v coverage.

TABLE IIb

SENSITIVITY RANGES AT VLA BANDS

Band	1.1 x Nominal	2 x Nominal	Extreme Range
90 cm	300 MHz 340 MHz	298 MHz 345 MHz	295 MHz 350 MHz
20 cm	1320 1700	1250 1800	1225 1875
6 cm	4500 5000	4250 5100	4200 5100
3.6 cm	8080 8750	7550 9050	6800 9600
2 cm	14650 15325	14250 15700	13500 16300
1.3 cm	22000 24000	21700 24500	20800 25800

TABLE III

CONFIGURATION SUMMARY

	A	B	C	D
Maximum Antenna				
Pair Separation (km)	36.4	11.4	3.4	1.03
(ns)	121,250	36,740	11,431	3,429
Minimum Antenna				
Pair Separation (km)	.68	.21	.073	.033
on meridian at (ns)	2,267	700	243	110
zero degrees declination				
Approximate Synthesized Half-Power Beamwidth* (arcseconds):				
90 cm	6	17	56	200
20 cm	1.4	3.9	12.5	44
6 cm	.4	1.2	3.9	14
3.6 cm	.24	.7	2.3	8.4
2 cm	.14	.4	1.2	3.9
1.3 cm	.08	.3	.9	2.8
Approximate Largest Scale Structure "Visible" to VLA **				
90 cm	170"	9'	30'	70'
20 cm	38"	2'	7'	15'
6 cm	10"	36"	2'	5'
3.6 cm	7"	20"	1'	3'
2 cm	4"	12"	40"	90"
1.3 cm	2"	7"	25"	60"

* These numbers are estimates for a uniformly weighted and untapered map produced from full synthesis observations of a high declination source which passes near the zenith.

North-South resolution degrades for southern sources. Sources below -15 degrees declination observed with the long north arm hybrid configuration will have resolutions similar to those of the smaller configurations.

The approximate resolution for natural weighted map is about 1.5 times these numbers.

The approximate resolution of snapshots is about 1.3 times the above values.

**These numbers are the largest source size (anywhere in the image) which can be reasonably well imaged in full synthesis observations. For single snapshot observations these numbers should be divided by 2.

TABLE IV(a)

LOSS OF PEAK RESPONSE DUE TO BANDWIDTH SMEARING
(CHROMATIC ABERRATION)

$\frac{\Delta\nu}{\nu} \cdot \frac{\theta_o}{\theta_{FWHP}}$	Peak Response
0	1.0
0.50	0.95
0.75	0.90
1.0	0.80
2.0	0.50

$\frac{\Delta\nu}{\nu}$ = fractional bandwidth

$\frac{\theta_o}{\theta_{FWHP}}$ = source offset from delay center in synthesized beams

TABLE IV(b)

AVERAGING TIMES (in seconds) AT WHICH TIME LOSSES EQUAL BANDWIDTH LOSSES, FOR = 90^o

Bandwidth (MHz)		50	25	12.5	6.25	3.125
Observing Frequency (MHz)	1460	415	210	105	55	25
	4885	140	70	35	18	9*
	15000	45	22	10	5*	3*
	23000	30	15	7*	3*	2*

* Default minimum integration time is 10^s. It is possible to obtain integration times as low as 1 2/3 seconds.

TABLE V

FLUX DENSITIES OF STANDARD CALIBRATORS FOR MAY 1987

	327.5 MHz	1425 MHz	4866 MHz	8434 MHz	14984 MHz
3C48	42.4±.2	16.00±.05	5.58±.01	3.32±.01	1.85±.02
3C147	53.2±.3	21.55±.08	7.80±.01	4.68±.01	2.65±.02
3C286	25.6±.3	14.71±.09	7.43±.01	5.19±.02	3.45±.03
3C295	60.2	22.0	6.56	3.42	--------
NGC 7027	-------	1.39±.01	5.53±.02	6.10±.05	6.03±0.1

TABLE VI(a)
AVAILABLE BANDWIDTHS AND NUMBER OF FREQUENCY CHANNELS

Normal Mode

BW Code	Bandwidth MHz	Single IF Mode(1) No. Channels(4)	Single IF Mode(1) Freq. Separ. kHz	Two IF Mode(2) No. Channels(4) per IF	Two IF Mode(2) Freq. Separ. kHz	Four IF Mode(3) No. Channels(4) per IF	Four IF Mode(3) Freq. Separ. kHz
0	50	16	3125	8	6250	4	12500
1	25	32	781.25	16	1562.5	8	3125
2	12.5	64	195.313	32	390.625	16	781.25
3	6.25	128	48.828	64	97.656	32	195.313
4	3.125	256	12.207	128	24.414	64	48.828
5	1.5625	512	3.052	256	6.104	128	12.207
6	0.78125	512	1.526	256	3.052	128	6.104
8	0.1953125	256	0.763	128	1.526	64	3.052
9	0.1953125	512	0.381	256	0.763	128	1.526

Notes:
(1) Observing Modes 1A, 1B, 1C, 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, 2CD.
(3) Observing Modes 4, 4PA, 4PB.
The observing mode determines how the hardware combination of the correlator and the four IFs are to be used to handle the data. It is possible to use the output from one, two or four IFs in such a way as to obtain different combinations of number of frequency channels and channel separation. The minimum and maximum number of channels is 8 and 512 respectively.
(4) These are the numbers of frequency channels produced in the AP. Any number of channels that is a power of 2, that is less than or equal to the number in the table and that is greater than or equal to 8 may be selected using the data selection parameters on the DS card.

TABLE VI(b)
AVAILABLE BANDWIDTHS AND NUMBER OF FREQUENCY CHANNELS

On-Line Hanning Smoothing Option(5)

BW Code	Bandwidth MHz	Single IF Mode(1) No. Channels(4)	Single IF Mode(1) Freq. Separ. kHz	Two IF Mode(2) No. Channels(4) per IF	Two IF Mode(2) Freq. Separ. kHz	Four IF Mode(3) No. Channels(4) per IF	Four IF Mode(3) Freq. Separ. kHz
0	50	8	6250	4	12500	2	25000
1	25	16	1562.5	8	3125	4	6250
2	12.5	32	390.625	16	781.25	8	1562.5
3	6.25	64	97.656	32	195.313	16	390.625
4	3.125	128	24.414	64	48.828	32	97.656
5	1.5625	256	6.104	128	12.207	64	24.414
6	0.78125	256	3.052	128	6.104	64	12.207
8	0.1953125	128	1.526	64	3.052	32	6.104
9	0.1953125	256	0.763	128	1.526	64	3.052

Notes:
(1) Observing Modes 1A, 1B, 1C, 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, 2CD.
(3) Observing Modes 4, 4PA, 4PB.
(4) These are the numbers of frequency channels produced in the AP. Any number of channels that is a power of 2, that is less than or equal to the number in the table, and that is greater than or equal to 8 may be selected using the data selection parameters on the DS card.
(5) This option MUST be specified on the DS (Data Selection) card.