VLA Test Memorandum 101

INITIAL TEST PLAN FOR THE VLA

C. M. Wade
11 February 1974

I. Purpose and Scope

This memorandum describes a general plan for evaluating the performance of the first components of the VLA. It is concerned with the tests which must be performed before the two prototype antennas, with their electronics, comprise an astronomically functional interferometer.

The test program outlined here is preliminary. It will evolve somewhat as planning and construction proceed, but it nevertheless should be a serviceable guide to the general course of the work. In preparing it, I have made no serious effort to estimate the time required for the various tests, since it would be premature to do so now. However, it should be kept in mind that the first two antennas will be complete and ready for testing on or about 20 April 1975 and 22 June 1975, respectively. NRAO will perform about two months of single-dish tests on each antenna, in addition to NRAO participation in the many tests performed by the manufacturer during fabrication and assembly. The first tests in interferometer mode should begin by early September 1975. The interferometer tests will probably require four to six months, so the work covered by this memorandum will extend into the early part of 1976.

As far as the electronics and the computer programming are concerned, the testing considered here begins with their arrival and installation at the VLA site. In the case of the antennas, on the other hand, we are dealing with an outside vendor whose test and alignment procedures must be approved by NRAO, and whose application of these procedures will be observed and checked by NRAO engineers. Therefore it is logical to regard the antenna portion of the test program as beginning with the NRAO review of the manufacturer's procedures. This will be done during the spring of 1974.

The test program falls naturally into three logical stages. These will be discussed in detail in the later sections of this memorandum. They are:

A. Preliminary Work (§II): This includes everything which must be done before the antennas are released to NRAO for testing on the Plains of San Augustin. Work in this category can be regarded as starting with the present memorandum. It will be finished by April 1975.

B. Single Antenna Tests (§§III-V): This will include, but will not be limited to, the final acceptance tests of the antennas. Optical and mechanical tests will be made and evaluated. Subsequent measurements will be made with a receiver installed. After these are finished, the antenna will be moved around on the transporter and replaced on the same observing station. Certain of the earlier measurements then will be repeated in order to see how stable the antennas are against the stress of being hauled around. This phase will begin with the completion of the first antenna in April 1975, and it should be finished by the end of August 1975.

C. Interferometer Tests (§§VI-VII): Here is where everything comes together. The tests will cover the electronics, the computer software, control and monitor functions, data reduction methods, and atmospheric effects. They will continue until we have a fully operational two-element interferometer on the Plains of San Augustin. This stage should begin by September 1975, and it ought to be completed by the spring of 1976.

II. Preliminary Work

This phase includes everything which must be done before the first antenna is released to NRAO in April 1975. The following are among the major items:

A. Evaluation of the Test and Alignment Methods Proposed by the Antenna Manufacturer: E-Systems will submit an Assembly and Alignment Plan by 22 March 1974, and a Test and Acceptance Plan by 5 April 1974. These documents will describe in detail the means they propose to use to ensure that the contract specifications are met. They require NRAO approval, and must be evaluated thoroughly in order to make certain that they are fully adequate. Our contract with the manufacturer provides for NRAO personnel to observe and approve all tests when they are made. Here is a partial list of the tests and alignments to be considered:

1. Verticality of the azimuth axis and procedures for leveling the antennas on the base pads;
2. Perpendicularity of (a) the azimuth and elevation axes and (b) the elevation and collimation axes;
3. Intersection of the azimuth, elevation, and collimation axes;
4. Alignment and centering of the azimuth and elevation encoders;
5. Backlash errors in the drive train;
6. Drive rates and the performance of the antenna pointing servo system;
7. Control of the surface panel shapes during manufacture;
8. Adjustment of the panels to the correct surface figure during antenna assembly; and
9. Location and alignment of the subreflector.

Many of these items will be checked independently by NRAO during the single antenna tests.

B. <u>NRAO Preparation for the Tests</u>: Orderly testing should proceed as soon as the first antenna has been released to us, and the measurements should be analyzed promptly and correctly. This can be accomplished only if our people, procedures, and equipment are ready when they are needed. Attention will have to be given to the following fairly soon:

1. Decide what test equipment will be needed, and acquire it. This will include a suitable theodolite, a precise level, etc., plus whatever auxiliary electronics are needed for the single-dish measurements.
2. Certain key personnel should be designated well in advance of the actual testing, and trained as required. In addition to the engineers who will take part in the mechanical and electronic measurements, this includes the core of the operations group since telescope operators will be useful during the single-dish tests and necessary when we go into the interferometer mode.

3. Measurement procedures should be thought out, and written up with their mathematics, in advance of their application so that members of the VLA group can comment on them. This is a form of insurance. In cases where computer programs are required to analyze the results, they should be debugged fully before they are needed. It may be desirable to try out some of the measurement procedures on existing telescopes before using them for the VLA.

C. Observing Stations: The relative locations of the observing stations to be used during the test program should be determined accurately by NRAO survey so that good initial baseline constants will be available for the interferometer measurements. It should also be verified that the base pads at each station have the correct level bias to make the azimuth axes of the antennas parallel within acceptable tolerances.

III. Single Antenna Measurements Prior to Receiver Installation

When the antennas are released to NRAO by the manufacturer, they will already have undergone thorough tests in the presence of NRAO engineers. It is reasonable to expect that the antenna surfaces will be accurately adjusted to the design figure, that the axis alignments will be within specifications, and that the drives will function properly. There are a number of items that we ought to re-measure independently, however, in order to verify the accuracy of the manufacturer's tests. There are also some measurements which are not included in the manufacturer's program which can be made at the same time. The NRAO measurements will include the following:

A. Measurements Referred to Stars Observed with a Theodolite Rigidly Mounted in the Reflector Structure:

1. Deviation of the azimuth axis from the vertical;
2. Perpendicularity of the azimuth and elevation axes;
3. Indexing of the azimuth and elevation encoders;
4. Pointing and tracking accuracy over the whole sky. This will include a search for servo problems, periodic errors, response to steady and gusty wind loads, etc.

B. Non-Astronomical Measurements:

1. Thermal effects on axis alignments, including uneven solar heating of the structure and alignment stability during rapid ambient temperature changes at sunrise and sunset;
2. Subreflector deflection as a function of elevation;
3. Subreflector movement under changing thermal conditions;
4. Lateral displacement of the subreflector under wind loads.

These tests will be conducted at the master station where the antenna assembly is done. Weather permitting, this program will run around the clock, the "A" measurements being done through the night while those under "B" are done during the day. When these tests are finished, the antenna will be transferred to Station CW3. Then items A.1, A.2, and A.3 will be repeated, while the days will be devoted to receiver installation.

These operations should require one to two weeks for completion.

IV. Single Antenna Measurements with Receiver Installed

The measurements under this heading are pretty standard, since they are mostly of the kind that are made when any new radio telescope is brought into operation.

A. Preliminary Adjustments:

1. Focus the system. This will be repeated at intervals during the test program to determine the thermal stability of the focus;
2. Verify that the feeds are correctly positioned.

B. Pointing:

1. Determine the initial set of pointing constants by observing strong sources. Verify that they are the same at all wavelengths (this is a check on the correct placement of the feeds) and for both polarizations;
2. Analyze the measured pointing constants for consistency with the earlier theodolite measurements;
3. Analyze the pointing residuals to verify that they are not excessive. This will show whether the pointing equations adequately describe the actual behavior of the antenna;

4. Check to see that the pointing reproducibility is within the specifications.

C. Primary Beam Pattern:

1. Measure the size and shape of the radiation pattern, including the near-in sidelobes, at each operating wavelength and in both polarizations;
2. Verify that the predicted and observed radiation patterns are in reasonable agreement;
3. Measure the system noise temperature as a function of elevation angle.

D. Aperture Efficiency:

1. Measure the aperture efficiency at each operating wavelength, and see whether the results are consistent with the measured rms surface error and the feed horn patterns;
2. Determine the change of aperture efficiency with elevation angle at two different wavelengths.

The above tests should require four to six weeks for completion and analysis.

V. Stability of the Antenna Against the Stresses of Movement on the Transporter

After the above measurements have been completed and the antenna is in satisfactory adjustment, it will be placed on the transporter and moved up and down the track a few times. It will then be returned to the observing station, and the following measurements repeated:

1. Alignment of the azimuth axis;
2. Focus;
3. Pointing constants;
4. Aperture efficiency at the shortest operating wavelength.

Changes should be nil. If they are appreciable in any respect, the causes must be found and corrected in cooperation with the manufacturer.

Unless serious changes occur during antenna movement, this stage of the testing should require no more than a week.

When all of the tests described in §§III-V are satisfactorily completed, NRAO can formally accept the antenna from the manufacturer.

VI. Tests in Interferometer Mode: Initial Phase

The first step is to achieve an interferometer with working electronics and software which can be counted on to give reproducible fringes. Most of the tests in this section will be in the hands of the electronics people, and it is assumed that most of the basic testing of the computer system will be made more or less concurrently. The initial interferometer work, which will not necessarily be done in the order stated, will include the following:

A. First Steps:

1. Get the first fringes from a radio source, in each of the four frequency bands. This may require a fair bit of fiddling with the electronics and the software.
2. Adjust the lobe rotators and delays so that they are doing their job.
3. Check that the phases and amplitudes are reasonably stable.
4. Refine the baseline constants in order to minimize the phase drifts of geometrical origin.
5. While tracking cold sky, look for spurious responses in the output with the lobe rotator rates set equal to the difference in phase switching sequences.

B. Waveguide Tests:

1. While observing a radio source, determine the effects of varying the waveguide temperature up the antenna.
2. Using narrow IF filters, vary the LO frequency to move the reception band across the waveguide characteristic. The purpose is to look for phase and amplitude ripples which would cause trouble in the spectral line system. If possible, alter the frequency of the microwave carrier and repeat the test.
3. Deliberately introduce reflections at the waveguide terminations and examine their effect on frequency response.
4. Look for hour angle effects while tracking a source (possible effects of rotating joints).
5. Look for crosstalk between IF bands.

C. Local Oscillator Phase Compensation:

1. Determine how well the servo-controlled line stretcher compensates for diurnal temperature effects and for heating of the waveguide run up the antenna.
2. Examine phase stability when the automatic system is not operating.

D. Interference:

1. Vary the frequency of the observing passband in the vicinity of interfering signals in order to determine how close to them we can operate.
2. Find out whether special filtering at the front ends is needed in the 1.35 - 1.7 GHz band.

E. Sensitivity:

1. Determine the "counts per jansky" at each frequency and in both polarizations.
2. Compare the results with the theoretical sensitivity.
3. Track "cold sky" fields to determine the internal noise level of the system at each frequency and in both polarizations. Make sure that the results are at about the theoretical level.
4. Integrate observations to determine where the signal to noise ratio ceases to improve in proportion to the square root of the observation time.

F. Delay-Amplitude Effects:

1. Find how the fringe amplitude for point sources at different declinations varies with hour angle, at all operating frequencies and in both polarizations.
2. While tracking a source, vary the delays in the paths from the two antennas while maintaining the correct delay difference, and see if there is any effect on the output.

G. Miscellaneous Tests:

1. Repeat the determination of the delay centers at regular intervals. If changes are found, try to locate the causes and correct them.
2. Test the functioning of the ALC loop.

3. Introduce deliberate malfunctions in order to test the efficacy of the monitoring system. Experiment with diagnosing failures from the control building.
4. Thoroughly evaluate the performance of the master clock.

This list is undoubtedly incomplete. At the conclusion of this phase of the testing, which will probably take two or three months, there should be a thorough review of everything which has been done to this point. Everyone involved will probably have some doubts and worries which should be brought out and discussed. Any modifications to the electronic system or the computer software which seem desirable should be made and tested. It is likely that some hardware failures will have occurred by this time; they should be analyzed to see if changes to the system are warranted.

VII. Tests in Interferometer Mode: Operational Phase

The operational phase of the test program will consist mainly of astronomical measurements. The instrument should be functioning reasonably well by the time this stage is reached. While the purpose of the programs described below is to evaluate the performance of the instrument as an integrated system, they are also representative of the kind of observations the VLA was designed to make. They will test its performance as a working radio telescope.

The following list of programs is not meant to be complete, but it is representative of the work that will be done:

A. Preparatory Tasks: During this phase of the test program, the antennas will be moved a number of times. After each move, we shall have to:
   1. Refine the pointing constants in interferometer mode.
   2. Re-determine the delay centers.
   3. Measure the baseline constants at each operating frequency.

B. Astrometric Program: Approximately ten days of observations of 10 to 15 unresolved sources, in all of the frequency bands, with the identical sequence of observations being repeated each day. The analysis will include the following:

1. Repeatability of the phases and amplitudes. Try to distinguish between atmospheric and instrumental effects. Particular attention should be given to the stability of the instrumental phase constant. Delay-amplitude effects will be analyzed in detail. The stability of the amplitude calibrations will be determined.
2. Adjustment of the coefficients of the equations used to make atmospheric corrections to phase and amplitude.
3. Adequacy of the on-line phase corrections.
4. Possible diurnal variations in the system phase.
5. Determination of the baseline constants with the highest attainable accuracy.

Only one baseline will be used for this program.

C. Polarization Program: Approximately five days of observations of point sources whose polarization properties are known, at each wavelength. Analyze the instrumental polarization; determine the values of the instrumental constants and their stability. Find out how the instrumental polarization varies with elevation angle. Only one baseline will be used for this program.

D. Weak Source Program: Spend approximately one week on observations of very faint unresolved sources, especially radio stars, in order to make a realistic evaluation of the sensitivity limit of the system. Only one baseline will be needed.

E. Mapping Programs: Several strong sources whose structures are well known will be mapped at each wavelength. This will require the occupation of a number of observing stations. Concurrent observations of fields containing weak sources, and of fields free of known sources, will also be made. It would be desirable to repeat some of these observations with a considerably reduced bandwidth. In the case of the strong sources, polarization maps should be made also.

By the time the above programs have been completed, we will have a pretty good idea of the quality of the basic VLA system. The results should be reviewed thoroughly and critically in order to identify the factors which most seriously limit its performance (hardware and software), and to make improvements where we can.

The first four programs above should require about two months. The mapping programs will take the order of three or four months; this depends on the number of observing stations to be used as well as the number of sources to be mapped. These are details which will have to be settled later.