NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VIRGINIA

VLA TEST MEMORANDUM #105

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PLANS AND SCHEDULES FOR TESTING THE PROTOTYPE ANTENNAS AND ELECTRONICS

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This memorandum is concerned with the test procedures for the first two antennas and their associated electronic equipment. It does not greatly change the basic ideas outlined in VLA Test Memorandum #101 by C. M. Wade, but attempts to give more precise technical details for the electronics testing and an estimated timetable (Figure 1). The following section outlines the sequence of events in the testing plan, and subsequent sections give details of the test procedures. Up to the time at which operation of a two-element interferometer is started, tests of the antennas and the electronics are best considered separately. In the interferometer mode, however, tests of antennas and of electronics are often closely interwoven in the scheduling and are described together.

The word testing is used in a broad sense to include making the modifications and adjustments indicated by the test measurements. Since the degree to which modifications are required cannot be determined without the testing, estimates of the time required at each stage can only be very rough.

I. The Test Plan and Schedule

The test plan is shown in a PERT type diagram in Figure 1. Dates corresponding to the circled numbers are given in a separate table to allow adjustments to the timing to be considered. The estimated date for completion of Antenna #1 by E-Systems, April 28, is assigned to point 7 and other dates in the table are calculated from this using the allocated times in weeks shown in the figure.

System testing of the electronics starts when the various modules and subunits, each of which has already been tested individually, are assembled together. Tests check the basic functioning of the electronics before it is connected to the antennas. This part of the testing starts in Charlottesville about the beginning of the year when a substantial part of the electronics has been completed, and later moves to the site so that the 1.25 km length of waveguide can be included in the tests. This phase of the testing should be completed before installation of the system on the antennas is commenced. It is described in more detail in Section IV.

The front end for Antenna #1 will be tested in Charlottesville and then must be shipped to the site ahead of the rest of the electronics so as to be ready for installation on the antenna for single-dish tests. Some special equipment required for single-dish testing must also be shipped out with it. This equipment is described in memoranda by A. R. Thompson dated June 14, 1974, and by P. J. Napier dated August 28, 1974. The front-end for Antenna #2 can go out to the site with the main electronics shipment, or later as in Figure 1.

On completion of Antenna #1 on April 28 it will be moved to pad 3, which is near the maintenance building. There it will undergo one week of mechanical testing by W. Horne and two weeks of optical testing by C. M. Wade. Much of the testing will be performed at night, so it is hoped that installation of cables and helium lines on the antenna can take place during the day in the same three weeks. Details of the optical tests are given in Section II.

Immediately after the end of the optical testing the front-end is installed on Antenna #1, and a period of single-dish radiometric testing is commenced by K. I. Kellermann. At this time it is hoped that the synchronous computer will be installed in a trailer at the site ready for use in data collection and analysis. If it is not ready conventional chart recorder techniques will be used. The single dish radiometric tests are discussed in Section III. It is not planned to repeat such tests on the second antenna.

Optical testing on the second antenna will again be made by C. M. Wade. In this case the antenna stays on pad 2 for the tests and on pad 3 installation of the full electronic system begins on Antenna #1. Installation of cables on Antenna #2 can also start during the optical testing. When the interferometer equipment has been fully installed in both antennas, and the antennas moved to stations on the 1.25 km waveguide run, tests of the full interferometer system can commence. These tests have been divided into three phases and are described in Sections V to VII.

In deriving the schedule in Figure 1 it has been assumed that development of software for the synchronous computer will not be a pacing item. This requires that for at least part of the initial electronic testing in Charlottesville the computer should be interfaced to the Digital Communications System (DCS) and be programmed to perform control and monitor functions on the electronics. At point 10 of Figure 1 it should be at the site and ready to use in the single-dish radiometric testing, and at point 13 it should be ready for operation in the interferometer mode.

II. Optical Testing

The following description of the optical tests is a slightly revised version of that given by C. M. Wade in VLA Test Memorandum #101.

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;

B. (cont.)

2. Subreflector deflection as a function of elevation;

3. Subreflector movement under changing thermal conditions;

4. Lateral displacement of the subreflector under wind loads.

Almost immediately after E-Systems complete their tests of Antenna #1 it will be moved from pad 2 to pad 3 so that the second antenna can occupy pad 2. Most of the above tests will thus be made on pad 3, but it is hoped to make some measurements on pad 2 so that any effects of the move can be detected. Weather permitting, the tests will run around the clock, the "A" measurements being done through the night while those under "B" are done during the day. These operations should require one to two weeks for completion.

III. Single Dish Radiometric Testing

Single dish radiometric testing will be performed by K. I. Kellermann, and the following list of six objectives is taken from a memorandum by him written in March 1974.

1. Determine the aperture efficiency and beamwidth as a function of orientation and temperature. Search for hysteresis in the gain.

2. Determine the pointing at each wavelength and in both polarizations as a function of time, temperature, antenna orientation and wind velocity. Search for hysteresis in the pointing. Determining the reproducibility of the pointing on a short time scale.

3. Determine the effective focal length as a function of antenna orientation and temperature. Determine how variation in the radial position of the feed affects the direction of the beam.

4. Investigate the polarization properties of the antenna, in particular the response to off-axis sources.

5. Investigate the chromatism, its stability, and the effect of variations in focal length on chromatism.

6. Determine the performance of the dichroic reflector, i.e., bandwidth, the effect on the gain, pointing, and chromatism.

The only radio measurements that can be made better in the single dish mode than the interferometer mode are those of aperture efficiency, but before these can be made it is necessary to check the focusing and determine pointing corrections. Some measurements are required in all four frequency bands although it should not be necessary to put in the same amount of observing time for each one. If it is determined that the aperture efficiency is satisfactory at the shorter wavelengths then the main reflector and subreflector must be satisfactory at 21 cm and measurements at this wavelength test only the 21 cm feed. Since there are likely to be some problems with interference in the 21 cm band it would be wise to concentrate on the shorter wavelengths, and make relatively brief 21 cm measurements to check out the feed. Thus, the 21 cm measurements probably need not be made as a function of elevation. At 1.4 cm the sensitivity is lowest and water vapor problems are most severe. So 6 cm and 2 cm appear to be the best frequencies to concentrate on initially.

IV. Tests of Basic Functioning of the Electronic System

The various electronic modules and subsystems will mostly be completed during the period December 1974 through February 1975, and testing of how these units function together should begin about January 1, 1975. Tests are also aimed at optimizing the stability of the system. Stability of operating characteristics is perhaps the most desirable feature of an interferometer since in principle any characteristics of the instrument can be calibrated out if they are stable enough. Tests include the following procedures:

1. Checking of interconnection of analog signals from one unit to another for:
   a) correct power levels;
   b) absence of unwanted signals and responses;
   c) absence of unwanted coupling through power supplies, etc.
2. Check of local oscillator system for:
   a) correct lock-up at all required frequencies;
   b) the occurence of spurious signals which may arise with particular frequency combinations.
3. Check of IF signal channels for:
   a) satisfactory overall frequency responses,
   b) correct operation of ALC loops;
   c) no deterioration of signal to noise ratio along signal path.
4. Investigation of interconnection of digital signals at the equipment/DCS (Digital Communications System) interfaces and the DCS/computer interface. Check of:
   a) control functions from computer;
   b) monitor functions, digital;
   c) monitor functions, analog.
5. Measurement of error rate in the DCS as a function of signal to noise ratio in the communication channel.
6. Check of operation of the special system controller for the delay and multiplier system and its interface with the computer.
7. Measurements of correlator outputs with correlated noise injected into IF channels to investigate:
   a) correlation as a function of delay differences for different IF bandwidths;
   b) stability of output as delays are varied together;
   c) stability of output with respect to power supply voltages;
   d) stability of output with respect to temperature.

8. Set up the two slave LO systems (to be located at the two antennas) in the laboratory and measure relative phases of various LO signals to check for:
    a) operation of fringe rotator system;
    b) phase stability with respect to power supply voltages;
    c) phase stability with respect to temperature (with special attention to effects of harmonic mixers and generators);
    d) phase stability with respect to oscillator levels.

9. Measure the differential phase response of two IF channels as a function of frequency.

10. After the equipment is moved to the site and the appropriate parts set up in the central control trailer, set up one rack of LO and IF equipment for an antenna in a small trailer at the other end of the 1.25 km of buried waveguide. Test for correct operation of the waveguide communication system including:
    a) correct lock up of oscillators at remote end;
    b) no deterioration in signal to noise ratio of IF signals from remote location;
    c) correct functioning of control and monitor signals through DCS;
    d) correct return to operation of equipment at remote end after a simulated power failure.

As much as possible of the testing listed under 1 to 9 above should be performed in Charlottesville rather than after shipment of the equipment to the site, because of the better test facilities at Charlottesville. In the event that these tests become the pacing item in the schedule, there are strong arguments for not cutting them short. Tests listed under 10 which involve the waveguide could be done after the equipment is installed on the antennas and the whole system set up for interferometer operation. This would be the way to go if the electronics should not arrive at the site before the end of the radiometric testing of Antenna #1. However an earlier checkout of the waveguide transmission system, as planned above, should greatly help in getting the interferometer into operation.

V. Interferometer Testing, Phase I

It is useful to divide the interferometer mode testing into three arbitrary phases to help define the progress made as the testing continues. Phase I is concerned with bringing the system onto the air and verifying basic operation. To keep the system as simple as possible operation should be confined to one or two frequencies using only the 6 cm band to avoid interference but otherwise get the best sensitivity. We should not get involved with details like fine tuning or polarization characteristics at this stage. Procedures are as follows:

1. Obtain signals from a strong point source at 6 cm wavelenth using pointing corrections from single dish tests and baseline constants from surveyed antenna positions.
2. Continue observing point sources for a few days to establish a routine observing procedure and to identify the causes of any frequent failures or gross instability.
3. Check sensitivity.
4. Check how well the system as a whole can be controlled from the computer - can we change between two frequencies or turn on after power failure without manual adjustment at the antenna?
5. Refine pointing corrections.
6. Make first attempt to improve baseline constants by using source observations.

One month should be allowed in planning for these tests; if all goes well they will take less time but equipment problems could hold up completion.

VI. Interferometer Testing Phase II

As a result of Phase I testing the point should have been reached at which observations can be made at one or two frequencies with good reliability and sensitivity within a factor of two of theoretical. The next task is to optimize the sensitivity, if necessary, and to perform a final series of tests aimed at checking and optimizing the stability.* Procedures include the following:

1. While observing a point source vary each power supply in turn to change the voltage by about 5% for a period of about 5 minutes and then go back to the nominal voltage. Identify supplies which cause the largest changes. Then identify the most sensitive components in the electronic system possibly by substituting an extra supply that is not varied. Tests should include power supplies both at antenna and central location. Make modifications to attempt to reduce the voltage sensitivity. Goal would be less than 1% amplitude or 3° of phase change for 0.1% variation in any power supply.
2. Monitor power supply voltages as a function of ambient temperature. Do these results together with those of 1. above explain the output variations seen while observing a point source?
3. Again while observing point source vary temperature in vertex room and if possible in separate racks of control room, each in turn. Identify temperature sensitive parts of system and attempt to locate individual modules using heat gun.

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*As in Phase I observations shoud still be confined mainly to 6 cm wavelength

4. If highly temperature sensitive areas are found attempt to modify design to reduce sensitivity or investigate the possibility of installing temperature sensors so that the effects can be calibrated out.
5. Observe a point source and investigate phase effects as a function of temperature of waveguide run up an antenna, probably using flexible heating wire. Can any effects found be calibrated out?
6. Try varying some other quantities such as local oscillator power levels at various points.

It is to be expected that in such a complicated instrument responses to voltage or temperature changes will not always be consistent or unambiguously interpretable. But at least by this stage it should be possible to say that any components which contribute much more than average to unwanted variations will have been identified and if possible modified. The quasi-random output variations resulting from temperature and voltage effects will, of course, be superimposed upon a pattern of variation that repeats on a sidereal daily basis, resulting from elevation angle effects in the antennas, incompletely determined baseline corrections, source polarization (with linear feeds) etc. These latter effects can in principle be calibrated out. In practice when using an interferometer for astronomical observations all residual variations are reduced by observing calibration sources at regular intervals. In the testing this can be simulated by making alternate observations of two point sources. At the end of the above tests we should determine how often a source designated as a calibrator must be observed to reduce the variations to 1% rms in amplitude and 3° rms in phase. If the answer is once in two or three hours the stability is good although it could perhaps be further improved. If more frequent calibration is required further testing of the type outlined in this section is called for.

Some polarization measurements should also be made during the Phase II testing to verify the antenna geometry using the combination of off-axis feeds and a non-parabolic dish. Single dish measurements of polarization properties will probably not have been accurate enough, making further tests very desirable before feeds and subreflectors are ordered for antennas 3 to 6. Only measurements at 6 cm wavelength are required.

VII. Phase III Interferometer Testing

At this stage the interferometer should be working at 6 cm wavelength about as well as can be expected. A broader investigation into the characteristic of the system can then be started. Several of the tests are of a more open ended nature and are best assigned to individual engineers. Procedures include the following:

1. Commence observing in all four frequency bands and determine pointing corrections at each frequency. Also focus as a function elevation.
2. Determine baseline constants at each frequency band. Check for consistency. Repeat at regular intervals for several months to look for any changes. Is it necessary to use more than three baseline constants to specify the phase versus hour angle function?
3. Investigate limitations of use of the 21 cm band resulting from interference. Tune across band investigating signals picked up using spectrum analyzer. Also try observing sources in the presence of interference. The goal is to specify the optimum filter to place at the input, and to determine percentages of time lost in different parts of the band.

4. Begin a detailed investigation of antenna characteristics, including characteristics of dichroic reflector, aperture efficiency as a function of elevation, etc. It should be possible to improve the data obtained in the single-dish radiometric testing, especially at 1.4 cm wavelength.
5. Investigate polarization characteristics of the antenna in all four frequency bands. Observations of sources in the crossed feed mode will indicate stability of instrumental polarization, and hence the extent to which instrumental effects can be calibrated out. The goal should be to estimate the lower limits of measurable polarization in each band (limit should be highest at shortest wavelength). This investigation could continue for several months and should probably be assigned to the feed engineer.
6. Investigate waveguide characteristics particularly amplitude ripples as a function of frequency. Observe sources using the narrowest IF bandwidth and tune across the full 50 MHz IF band. The goal is to specify effects of waveguide ripples on the spectral line system. The VSWR of the waveguide can be deliberately varied,
7. Investigate the chromatism of the antennas, i.e, the change in gain as a function of frequency resulting from reflections between the feed horns and subreflector. Method of investigation may be similar to (6) and again goal is to determine effects on spectral line system.
8. Observe strong sources such as the sun and Cassiopeia A and determine what values of attenuators have to be switched in for each frequency band.

9. Integrate records of weak sources to determine for how long noise continues to decrease as (observing time)$^{-1/2}$. If this maximum integration time is too short investigate probably instrumental cause.

10. Look for spurious responses when the fringe frequency is equal to the phase-switching frequency (see VLA Electronics Memo #116.)

11. Begin a study of atmospheric fluctuations at the shorter wavelengths.

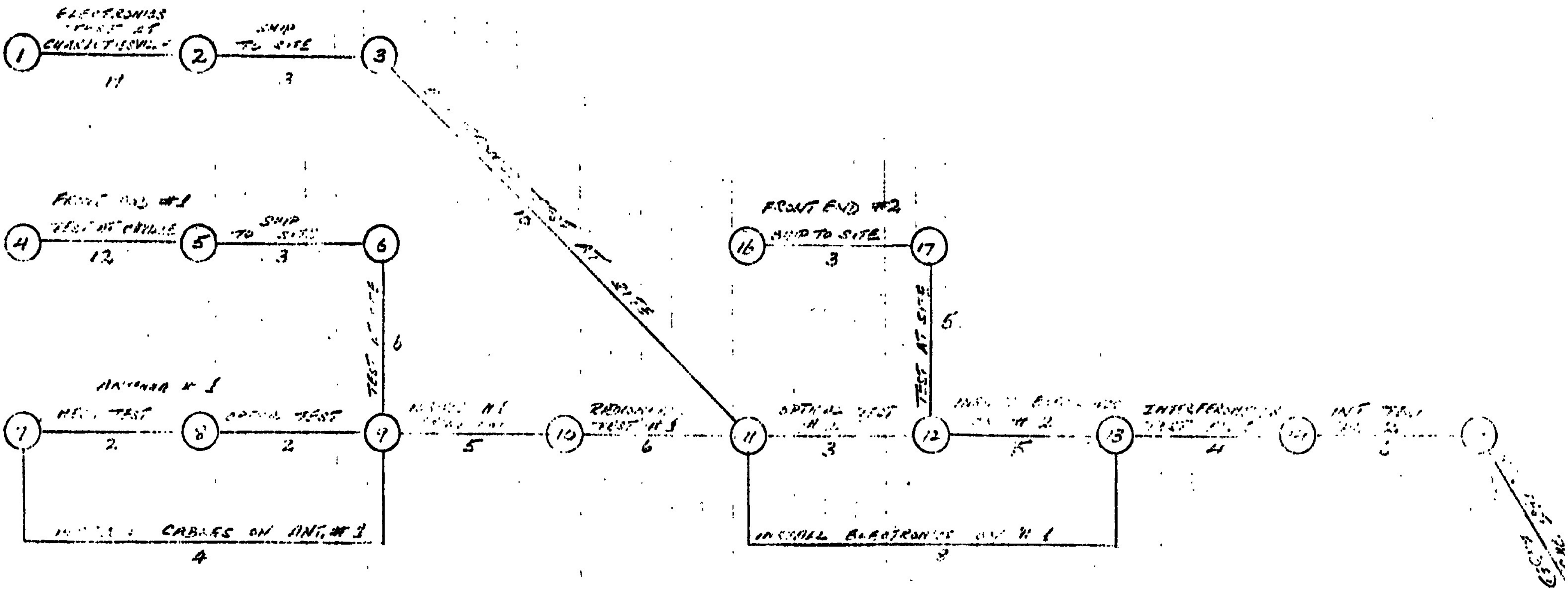
Investigations 2, 3, 4, 5, and 11 are likely to continue for some months after initiation.

As this phase of the testing progresses a point will be reached at which it will be useful to have a few astronomers make observations of the type that indicate the quality of performance of the instrument. These would include astrometric position measurements, detection of very faint sources and polarization measurements. In planning such observations it must be remembered that the goal is to learn more about the instrument rather than the sources, and in particular to point out areas where the performance can be improved. Data should not be accumulated for more than a few days without making an analysis to determine what they can reveal.

All of the instrumental tests discussed in this memorandum can be performed with a single antenna spacing. A change of spacing in the Phase III interferometer testing would however indicate possible problems associated with starting up after a move. Since interferometer testing in the early phases will require frequent movement of people between the antennas and the control trailer, it would be logical to start out with a spacing of about 0.5 km if a station is available, and move out to the full 1.25 km spacing in the later stages of Phase III testing.

VIII. Testing of Later Antennas

Changes in the electronics indicated by testing of systems 1 and 2 will be incorporated into the electronics for later antennas, although this will involve some retrofitting in the case of systems 3 to 6. For antennas later than #2 tests intended to reveal design improvements need not be repeated, and it will therefore be possible to formulate a simpler test procedure for bringing antennas #3 onwards into operation. Tests will be made in the interferometer mode so far as is possible, using one of the antennas that has already been checked out. Procedures will continually be modified, and hopefully simplified, in the light of experience, and it should eventually become possible to check out any new antenna and its electronics in two or three weeks.



TIME SCHEDULES FOR TEST PLAN			
EVENT NUMBER	DATES		
	SCHEDULE 1		
1	JAN 1 1975		
2	MAY 15		
3	JUNE 5		
4	JAN 1		
5	MARCH 27		
6	APRIL 17		
7	APRIL 28		
8	MAY 13		
9	MAY 27		
10	JULY 3		
11	AUG 14		
12	SEPT 2		
13	OCT 7		
14	NOV 4		
15	DEC 16		
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Figure 1. TEST PLAN FOR PROTOTYPE ANTENNAS AND ELECTRONICS