VLA TEST MEMORANDUM NO. 108

Optical Measurements of the Pointing and Tracking Performance of Antenna #1

C. M. Wade and V. Herrero

March 1976

I. Introduction

The present report describes optical measurements of the pointing and tracking performance of Antenna #1, by means of a theodolite mounted in the dish. The pointing and tracking were commanded through the antenna stand-alone control unit (see VLA Electronics Memorandum 127), which was housed in a trailer near the antenna.

The purpose of these tests was to verify that the antenna drive system for Antenna No. 1 satisfied the pointing specification, as soon as possible after antenna acceptance and without spending the additional waiting time that radio pointing tests would have required.

The initial tests were performed at the alignment pad almost immediately after the servo drives became operational on August 25, 1975, and further tests were carried at the maintenance pad during September and October by the authors, with the participation of J. Spargo and G. Grove.

II. The Pointing Equations

The present section describes the formal basis which underlay the measurement program.

In order to point accurately at a specified altitude h and azimuth A, the commanded coordinates must be modified to compensate for the errors of the system. This is accomplished by adding the following polynomials to A and h:

$$\Delta A = a_i \, f_i \, (A, h)$$

$$\Delta h = b_i \, f_i' \, (A, h)$$

The functions f_i (A, h) and f_i' (A, h) are trigonometric expressions which depend on the geometric nature of the i^{th} type of error. The coefficients a_i and b_i, which are to be found from observation or calculation, express the magnitudes of the component errors.

The effects contributing to ΔA and Δh are listed in Table I, together with the corresponding terms of the above polynomials. Obviously the b_3 and b_8 terms are indistinguishable; in practice we ignored b_8 and solved for b_3, remembering that the value thus found is really the sum $b_3 + b_8$. The refraction terms b_6 and b_7 were allowed for by calculation, and hence were not sought from the measurements. Finally, the effects of a tilt in the vertical axis on ΔA and Δh are not independent; it can be shown that $a_4 = b_5$ and $a_5 = -b_4$.

The observations were therefore meant to provide 10 independent coefficients: a_1, a_2, a_3, a_6, a_7, b_1, b_2, b_3, b_4, and b_5. In principle, these can be found in a single least-squares solution; in practice, we evaluated the errors on the A and h axis separately. The observations provide a set of values of ΔA and Δh for a large number of values of A and h. Our procedure was to use first the Δh's to find $b_{1,..5}$ by least squares. The values thus found for b_4 and b_5 were then used to remove the influence of a_4 and a_5 from the measured ΔA's. The latter, finally, were used to make a least squares solution for a_1, a_2, a_3, a_6, and a_7. The analysis thus consisted of two successive least squares solutions, each for 5 unknowns.

The solutions were made with the Hewlett-Packard 9830 computer, using a program written by CMW in BASIC. Full documentation of this program is kept in a file maintained by Victor Herrero. In addition to the values of the unknowns, the program gives their r.m.s. errors and the correlation coefficients.

TABLE I

Pointing Error Terms

Effect	Azimuth Terms	Elevation Terms
Zero Point	a_1	b_1
Encoder centering	$a_2 \sin A + a_3 \cos A$	$b_2 \sin h + b_3 \cos h$
Vertical axis tilt	$(a_4 \sin A + a_5 \cos A) \tan h$	$b_4 \sin A + b_5 \cos A$
Axis perpendicularity	$a_6 \tan h$	(nil)
Collimation	$a_7 \sec h$	(nil)
Atmospheric refraction	(nil)	$b_6 \operatorname{ctg} h + b_7 \operatorname{ctg}^3 h$
Feed sag	(nil)	$b_8 \cos h$

III. Measurement Procedure

The Wild T2 theodolite (equipped with a special upper bearing to permit use in any position with respect to gravity) was fastened to a heavy aluminum plate securely bolted to the ladder which gives access to the dish surface. The observations were made through the dish access hatch. When the antenna was pointed at the zenith, the azimuth axis of the theodolite was closely perpendicular to both the elevation and azimuth axis of the antenna.

The theodolite axis was set approximately parallel to the collimation axis of the antenna in the following way:

a) The indicated elevation of the antenna was set to 90°. The collimation axis was then nominally vertical.

b) The theodolite was aimed vertically downward, with the aid of the autocollimating eyepiece and a Farrand self-levelling mirror. Fig. 1 shows the self-levelling mirror and Figs. 2 and 3 the theodolite installation.

c) The aximuth and zenith distance circles of the theodolite were set to read 0°05'00" and 270°05'00" respectively.

d) The theodolite telescope was reversed by rotation through 180° about its elevation axis. The zenith distance circle then read 90°05'00".

The collimation error of the theodolite itself is under 10" and was neglected.

Most of the measurements were made with the antenna on the maintenance pad. Unlike the regular observing pads, this pad is horizontal with respect to local gravity. Therefore, its vertical

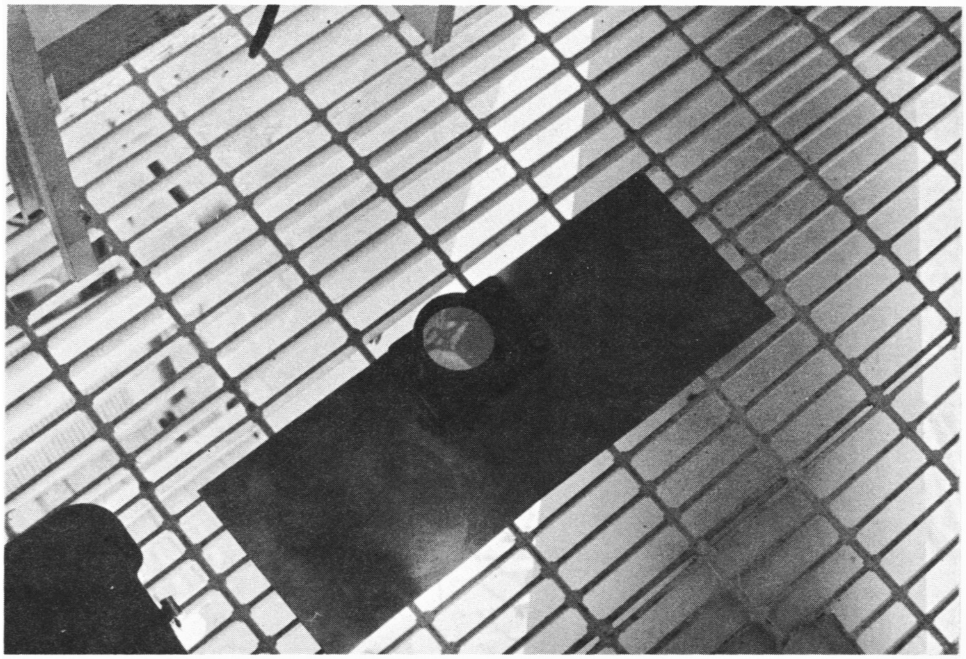

Fig. 1. Farrand self-levelling mirror.

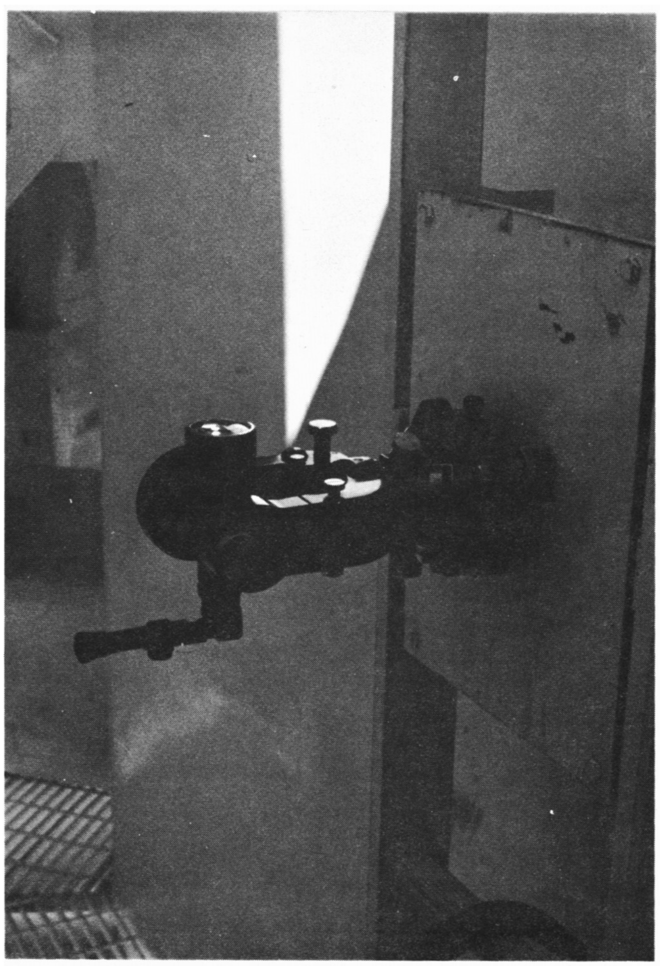

Fig. 2. Wild T-2 theodolite installed on the reflector access ladder.

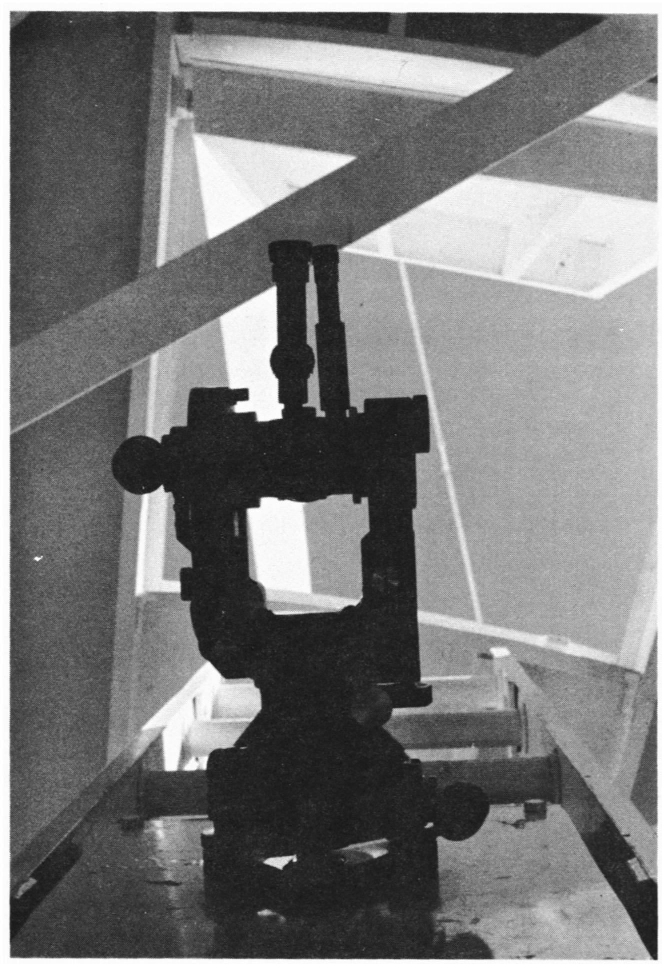

Fig. 3. Field of view through the access hatch.

corresponds to its true geodetic coordinates: $34°04'27''.18$N, $107°37'26''.27$W. The sidereal clock in the antenna control unit was set to apparent sidereal time for the true longitude, with an error not exceeding $0^{s}.05$. The true latitude was stored in the control computer for use in converting from equatorial to alt-az coordinates. Finally, the refraction coefficients for the approximate atmospheric temperature and pressure were stored in the computer so that refraction could be allowed for in the commanded coordinates.

An observing list was prepared in advance. It consisted of stars in Apparent Places of Fundamental Stars, of 4th magnitude or brighter. The list was designed to give good coverage in azimuth and altitude.

While observing, one man (the "driver") stayed in the trailer, where he operated the antenna control unit and recorded the data. The other man (the "observer") rode the antenna and worked the theodolite. The two communicated by telephone. The procedure used for each star observation was the following:

a) The driver dialed the equatorial coordinates of the star into the control unit. When the antenna was on position, it tracked automatically.

b) The observer set the theodolite cross-hairs on the star, signalled the driver to note the sidereal time, and read the theodolite horizontal and vertical angles (H and V) to him.

This was repeated from star to star until it was judged that an adequate altitude and azimuth coverage had been achieved.

The data then consisted of:

a) the apparent equatorial coordinates of the star;

b) the local apparent sidereal time;

c) $\Delta A = -(H-0°05'00'') \sec h$;

d) $\Delta h = V-90°05'00''$.

IV. Results

NRAO specifications for the VLA antennas (RFP-VLA-01 p. 03.8) require:

a) Repeatable errors under 3 arcminutes

b) Non repeatable errors under 15 arcseconds RSS for winds gusting up to 15 MPH in any antenna attitude.

We have found Antenna No. 1 meets both specifications as far as can be determined from observations with an optical instrument mounted in the reflector structure.

The contribution to the pointing error due to the quadrupod legs and the subreflector assembly has been investigated with radio pointing tests conducted during December and January and will be reported separately.

A brief daytime pointing test tracking the sun with a Roelof's prism was performed, but much more extensive daytime data are now available from radio tests.

We have indirectly confirmed that the errors for:

a) Azimuth axis perpendicularity to base

b) Azimuth-elevation axis perpendicularity

c) Encoder offsets and cyclic errors

d) Reflector axis collimation error

are all within specifications. The accuracy of our measurements is much lower than what can be obtained from direct mechanical measurements, and we cannot add any significant new information to what is already known from the mechanical alignment test results.

The individual components of the pointing errors cannot be determined meaningfully from our data. This is disappointing but probably inevitable in measurements of this type. The solutions for the various unknown tend to be highly correlated and hence individually unreliable. To some extent this is due to the imperfect coverage of A and h by the observations, but the real difficulty is more fundamental. The functional form of the expressions for ΔA and Δh simply does not allow a good separation of the unknowns. The overall solutions describe the pointing errors of the telescope quite well, but the individual coefficients can not be interpreted meaningfully in terms of component instrumental errors.

On October 3, with wind speeds of less than 5 MPH, a series of 49 observations produced an RMS error of 9 arcseconds. On October 22, with the wind gusting to 34 MPH, a run of 39 observations yielded an error of 17 arcseconds.

Figure 4 shows the plot of 3 typical star tracks in the field of view of the instrument as observed October 3 over a 3 hour period.

Figure 5 shows as an example, the sky coverage of the observing run on October 22.

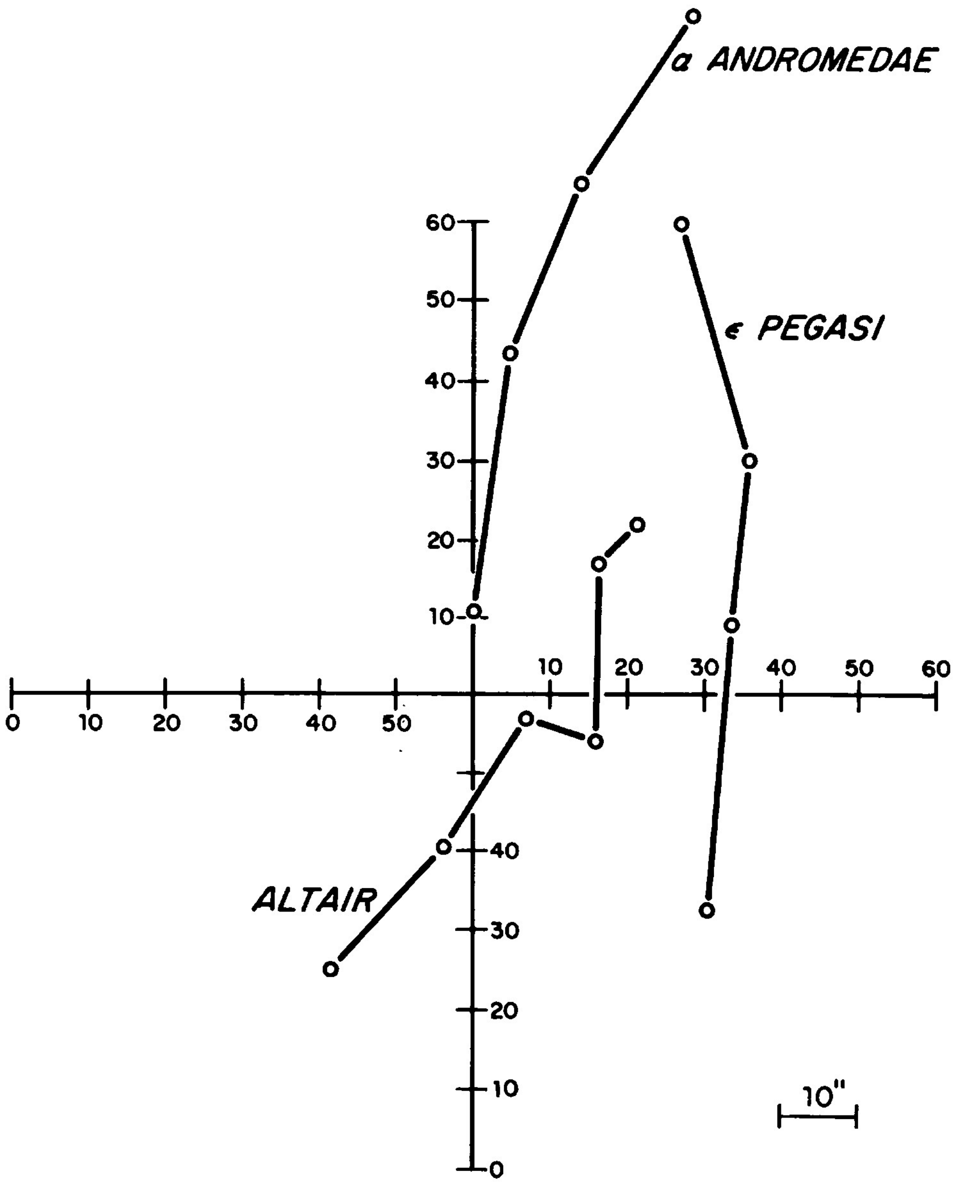

Fig. 4. Typical star tracks observed over a three hour period, October 3, 1975.

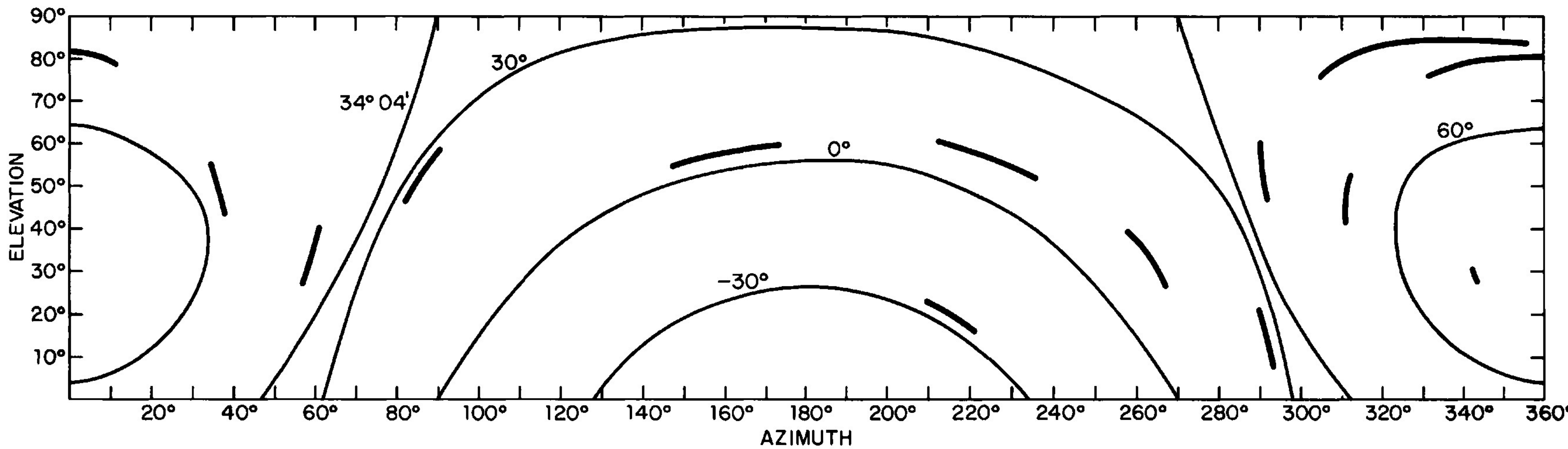

Fig. 5. Sky coverage, October 22, 1975.