NATIONAL RADIO ASTRONOMY OBSERVATORY
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VERY LARGE ARRAY PROGRAM

VLA TEST MEMORANDUM No. 136

POINTING PARAMETERS FOR AN ALT-AZIMUTH MOUNT

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ABSTRACT

Various causes of repeating pointing errors are rediscussed. Including gravity and refraction, there should be eight independent pointing parameters. Two of these should be the same for all 28 antennas and can thus be obtained with higher accuracy; also, six of the parameters should stay unchanged when the antenna changes its location, and long-term averages could improve their accuracy.

Pointing calibration runs should be done at night only, in order to minimize thermal deformations. And they should be done preferably close to the cardinal angles of elevation and azimuth, in order to minimize the error correlations. Evaluation of a pointing run should yield the eight parameters, their eight mean errors, and the 28 independent elements of the error correlation matrix.

1. Definitions

The on-line pointing program of the telescope computer should correct for all repeating pointing errors, caused by misalignments, gravitational deformations, and atmospheric refraction. This is done using a set of N pointing parameters, P_1 ... P_N, to be obtained from a calibration with astronomical sources of known position, and then to be applied with various trigonometrical functions of elevation and azimuth. A normal alt-azimuth mount should have N = 8, while a polar mount has N = 11.

We call E = elevation with E = 0 at horizon, and A = azimuth with A = 0 North and A = 90° East. We define the error signs as

$$\Delta E = E(apparent) - E(true)$$
$$\Delta A = A(apparent) - A(true)$$

(1)

This means that the telescope must be given an apparent (indicated) coordinate equal to the true (catalog) coordinate plus the pointing error. And in the following listing, we tell in parentheses that case for which the error is positive. I would suggest that someone checks carefully all following functions and signs. The signs of P_1 and P_2 are especially important, because these parameters occur twice at different places.

2. The Parameters and their Causes

Azimuth axis off (top toward N) = P_1

$$\Delta E = + P_1 \cos A \qquad\qquad \Delta A \cos E = + P_1 \sin E \sin A \qquad (2)$$

Azimuth axis off (top toward E) = P_2

$$\Delta E = + P_2 \sin A \qquad\qquad \Delta A \cos E = - P_2 \sin E \cos A \qquad (3)$$

Elevation axis not perpendicular azimuth axis (encoder down) = P_3

$$\Delta E = 0 \qquad\qquad \Delta A \cos E = + P_3 \sin E \qquad (4)$$

Elevation zero, and vertical box offset (box up) = P_4

$$\Delta E = + P_4 \qquad\qquad \Delta A = 0 \qquad\qquad (5)$$

Horizontal box offset (away from encoder)
Beam not perpendicular elevation axis (toward encoder) $\Big\} = P_5$

$$\Delta E = 0 \qquad\qquad \Delta A \cos E = + P_5 \qquad\qquad (6)$$

Azimuth zero (clockwise) = P_6

$$\Delta E = 0 \qquad\qquad \Delta A = + P_6 \qquad\qquad (7)$$

Gravity (primary down, secondary up) = P_7

$$\Delta E = + P_7 \cos E \qquad\qquad \Delta A = 0 \qquad\qquad (8)$$

Refraction (rays curve down) = P_8

$$\Delta E = + P_8 \, f(E) \qquad\qquad \Delta A = 0 \qquad\qquad (9)$$

These single contributions then add up in the following way:

$$\Delta E = + P_1 \cos A + P_2 \sin A + P_4 + P_7 \cos E + P_8 \, f(E) \qquad (10)$$

$$\Delta A \cos E = + P_1 \sin E \sin A - P_2 \sin E \cos A + P_3 \sin E + P_5 + P_6 \cos E \qquad (11)$$

3. Values and Errors

The atmospheric refraction was treated in detail in Engineering Division Internal Report 101 (May 1976) for the 140-ft pointing program. The value of P_8 changes up to $\pm$ 30% with weather conditions which is automatically taken care of, using measurements of temperature, pressure, and water vapor. At Green Bank, we have P_8 = 62 arcsec in the average, which gives about ΔE = 6 arcmin at E = 10°. Regarding f(E) in equations (9) and (10), we could neglect the curvature of the Earth and use f(E) = cot E, but then we have a systematic error of 15 arcsec at E = 10°, and of 60 arcsec at E = 6°. A useful approximation was derived in Report 101 and is now used at the 140-ft,

which is off by $\leq$ 2 arcsec for E $\geq$ 3°. Regarding the measuring error of our weather data, and the unknown change of these data with height above ground, the accuracy obtained for P_8 is about $\pm$ 3 arcsec.

How to obtain the values of all N parameters, and their mean errors as well, from observations of celestial sources with known positions, is described in Engineering Division Internal Report 102 (Nov. 1976). The method uses simple matrix operations and the inversion of a NxN matrix. This empirical derivation of the mean errors of the parameter values is quite important, if we want to know how stable or variable the parameters are over longer time ranges.

The method used for the 140-ft (Report 102) yields the values of the P_k, their statistical mean errors σ_k, but also the error correlation matrix C_{ik}. A good schedule for a pointing calibration run should try to minimize the error correlation. This is done by spending most of the observing time close to the cardinal angles: close to E = 0 and 90°, and close to A = 0, $\pm$ 90° and 180°, with equal weight on all. One should not waste too much time at intermediate angles, for example at 45° where there is no difference between sine and cosine.

Regarding thermal deformations, the pointing calibration runs should be done only at night, from several hours after sunset until sunrise. Even on most overcast days there is more thermal sky radiation than can be tolerated; just watch the temperature difference inside and outside of a parked car on cloudy days.

4. Differences and Changes

We should know which ones of the N parameters must be the same for all 28 antennas of the VLA, or which parameters change when an antenna is moved

to a different location, or when a receiver box is remounted. For example, P_7 and P_8 can be obtained from all antennas together with much better accuracy (factor $\sqrt{28} = 5.3$) than from each single antenna. Also, the six parameters $P_3 \dots P_8$ should not change when antennas change to a new location, thus old and new values could be averaged; however, if one of these six did change significantly, this would indicate that some rough or improper treatment did occur, and we should do some checking for any damage. Table 1 gives a summary of these items.

Table 1. Different or changing parameters

	28 antennas	antenna moved	receiver remounted
P_1	different	changed	unchanged
P_2	different	changed	unchanged
P_3	different	unchanged	unchanged
P_4	different	unchanged	changed
P_5	different	unchanged	changed
P_6	different	unchanged	unchanged
P_7	same	unchanged	unchanged
P_8	same	unchanged	unchanged

5. Some Odd 140-ft Features

I would like to mention some items which must be considered for the 140-ft pointing, although they may not be relevant for the VLA. The concrete building of the 140-ft shows seasonal movements up to 50 arcsec between summer and winter. Thus, the pointing should be calibrated in spring and

fall, if a single set of pointing parameters is wanted; or one should have two different sets, calibrated in summer and in winter. We also need different sets for prime focus and Cassegrain. This has been done at the 140-ft.

At very short wavelengths the beam deteriorates, and pointing becomes a matter of definition. If we define it by the maximum of the main beam, by "peaking up on a source", the pointing will depend on wavelength λ if we have strong asymmetric sidelobes; at long λ, a one-sided sidelobe is smeared into the main beam and pulls the maximum to its side, but at short λ the sidelobe is a separate independent entity. This gets still more complicated by the fact that the strength of our one-sided sidelobes depends on the pointing angle (worst close to horizon). Thus, so far nothing was done about it.

6. Some Odd VLA Features

Equations (2) and (3) assume a simple planar rotation in azimuth, about a fixed axis. But in our VLA Test Memo 135, we described two types of actually observed deviations from this plane of rotation: a "warp" with second and third order Fourier terms of about 5 arcsec amplitude at yoke top, which stays constant and repeatable in time; and a "hysteresis" at a single narrow azimuth range, which changes erratically between 5 and 26 arcsec.

An on-line pointing program could take care only of the repeatable warp, which would need 8 additional pointing parameters (amplitude and phase, second and third term, for elevation and azimuth). This was not recommended, because it seems too much trouble for a small gain, and because the larger variable hysteresis would still remain.