NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA OBSERVATIONAL STATUS REPORT

December 1, 1980

The capabilities of the VLA vary with time because of the rapid changes during construction. This report is an attempt to communicate the current observational limitations of the VLA to both users and potential users.

The hardware configuration as well as the best estimates of the sensitivity of the VLA at the end of November are briefly outlined. More current estimates of the array status or information not covered in this report may be obtained directly from the VLA staff.

1.0 HARDWARE CONFIGURATIONS

Continuum observations at the four separate wavelengths 1.3 cm, 2 cm, 6 cm, and 20 cm are supported. Observations at seven different bandwidths (50 MHz/2^n where n = 0,1,2...6) are possible. Circularly polarized feeds are used at all bands.

There are typically twenty-five antennas operating at any given time. Three of these antennas are assigned to the test array and may be taken at any time without notice for instrumental testing purposes. We are currently in the A configuration except for station AE9 (E72). The reconfiguration schedule for the next year is outlined in Section 5.0.

2.0 OBSERVATIONAL LIMITATIONS

Tables I and V summarize the sensitivity and resolution of the VLA. The sensitivity parameters listed are based on theoretical estimates using the quoted system temperature.

2.1 Sensitivities

The sensitivity and system temperatures degrade near the band edges. Dynamic range, interference and/or confusion (particularly at 20 cm) may prevent one from reaching the sensitivity limits quoted in Table I.

The numbers refer to 50 MHz continuum observations using two IF correlations. Spectral line observations are limited to one IF correlation and the numbers in Table I should be increased by forty percent to allow for this fact [the different number of antennas and bandwidths must also be taken into account - see Section 2.11].

2.2 Large Scale Structures

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

2.3 Dynamic Range

The dynamic range, loosely defined to be the ratio of the maximum source brightness to the minimum believable source brightness, is mainly limited by phase stability. Many of the synthesized maps generated from VLA observations are limited by dynamic range and not by noise (Table I). Self-calibration can sometimes significantly improve on dynamic ranges if the signal to noise ratio on your source is sufficient.

2.4 Pointing

The large daytime antenna pointing errors of 1 arcminute or more will influence observational results to the extent that sensitivity and dynamic range may be seriously degraded at high frequencies.

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, airborne drones, etc) can be expected outside of these bands, particularly at 20 cm (1340-1730 MHz). In particular, interference is most probable below 1350 MHz and at 1714 and 1723 MHz. Self generated interference is mainly limited to harmonics of 50 MHz which occur in the 20 cm band. These should be below the noise in any continuum map with a bandwidth of 6.25 MHz or greater. Spectral line observations may be adversely affected.

2.6 Bandwidth and Averaging Time Smearing

Finite bandwidths and averaging times result in a decrease in correlation for sources farther from the observational phase center. This effect is manifested in two ways. The "central intensity" of a point source decreases and the apparent synthesized beamwidth becomes broader with an increase in distance from the phase center. The bandwidth smearing is purely a radial effect and the smearing due to finite averaging times is approximately tangental.

Table II(a) summarizes the influence of bandwidth smearing. Table II(b) lists the averaging time for which the loss in peak intensity resulting from bandwidth smearing and from averaging time smearing are approximately the same. These numbers are listed by bandwidth at four different frequencies. For example, if it is acceptable to observe an object with 50 MHz bandwidth at 26 cm, then there is no advantage using an average time less than 70 seconds. Increasing the averaging time has the advantage of reducing both the disk space and computer processing time.

2.7 Confusion

As indicated in Table I, confusion or the presence of other sources in the primary beam will be a problem at longer wavelengths, particularly at 20 cm. These sources can lead to aliasing problems in map making. Although bandwidth smearing will help suppress some of the influence of confusing sources in the primary beam, it may still be a major concern at 20 cm.

Another source of "confusion" is the Sun. It 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 "averaged" down to very low levels. However, this is not true for the narrow bandwidths of many spectral line observations. Spectral line observations of weak sources in the more compact configuration during the daytime may be degraded even when the sun is far away from the source.

2.8 Positions

As part of an extended, carefully calibrated astrometric observing run, source positions can be determined to approximately 0.03 arcseconds for sources in the north and about 0.1 arcseconds for sources south of -20 degrees declination.

2.9 Calibration

In general the fraction of time spent on calibrating will range from 10 to 50 percent (or more) depending on the frequency and the particular requirements of the observing program.

2.10 Polarization

Circular polarization measurements are restricted to sources with very large degrees (>>10%) of circular polarization. This limitation is due to the large circularly polarized sidelobes.

Linear polarization observations are possible at all bands. The on-axis instrumental polarization can usually be determined to an accuracy of much better than 1.0 percent at 6 and 20 cm.

The uncertainties at the shorter wavelengths are larger. The limit of this accuracy is partly a result of known pointing problems. Mapping the polarization of sources more than one arcminute away from the beam center at 6 cm may be subject to uncertainties greater than one percent because of the large linear polarized sidelobes. This limitation is also present at the other bands; the location of the polarized side lobes scales with wavelength. Polarization observations in the 20-cm band are sometimes hampered by ionospheric Faraday rotation. The amount of Faraday rotation has been occasionally as large as 35 degrees and will probably continue to be a factor in observations at 20 cm. Observations at the short wavelengths, particularly 1.3 cm, are hampered by pointing problems. More information can be obtained from the Linear Polarization Measurements document.

2.11 Spectral Line Capabilities

Spectral line observations are possible, but only one polarization mode (right or left circular polarization) is supported. Switching between line and continuum observations during an observing program is very difficult. Spectral line calibration is currently difficult.

The amount of observing time devoted to spectral line observations is very limited and will be determined by computer resources. The basic combination of bandwidth channels and antennas are listed in Table III. Further trade offs between number of channels and antennas by bandwidth are possible. See "A Short Guide to Spectral Line Observing" for more information.

2.12 VLBI Observations

VLBI observations using the VLA are now possible. There are currently some restrictions. No in absentia VLBI observing will be supported. A VLBI observer must be on site to prepare the observing files, maintain the phasing of the array, ascertain that the VLBI terminal is operating correctly and monitor the performance of the VLA if necessary.

Two types of observing modes will be supported. Normal VLBI observing will include all the privileges of a regular VLA observer. These privileges include the right to utilize the full data and map processing facilities available. The requirement is that the VLBI proposals be submitted in the same manner as any other proposal for VLA observation. The second mode of observing permitted will utilize scheduled VLA downtime. Approximately one week every two months will be set aside and will coincide with the VLBI Network when enough advance warning is given. During this period the VLA will be available as a VLBI station for any observing scheduled on the Network. Only a very limited amount of data processing will be permitted. The calibration of VLBI data at the VLA taken in this observing mode may be more difficult than the calibration of data taken in the normal mode. More details can be obtained from the memo on NRAO policy governing VLBI observing with the VLA.

2.13 Solar Observing

Some scheduled down time will be used in a special solar observing mode in which larger periods of telescope time (but not processing time) are made available to catch strong flares. If a flare occurs in this period FILLER can be run from a ModComp backup tape and normal reductions done with a limit of about one hours data per day.

2.14 Snap Shot Mode

The quality of short observations is much enhanced now that the array is in a regular wye configuration. When signal to noise is not critical adequate observations of small sources can be made in a short period of time. However, our ability to support use of this mode to observe very large numbers of objects is limited by computer resources.

Single snap shots with good phase stability should give dynamic ranges of about 50 to 1 for sources whose angular size does not exceed the numbers listed in Table VI.

3.0 VLA CALIBRATORS

The general philosophy adopted by the VLA staff towards the measurement and compilation of "unresolved" radio sources used to calibrate the gain and phase of the VLA is to compile a list of sources which are sufficiently unresolved and unconfused to permit calibration at all bands to a few percent.

The list of phase and gain calibrators as of December 1 has reached several hundred. The list is not repeated here because the choice of a particular calibrator depends very strongly on the observing frequency and configuration. The list is by no means complete and will be updated several times a year.

The instrumental polarization can be calculated from observations of almost any regular gain and phase calibrator, provided that there are enough observations to ensure both a high signal-to-noise ratio in the cross hands and reasonable change in parallactic angle. In most long synthesis programs it is possible to use the gain calibrator to calibrate the instrumental polarization. Alternatively, some strong sources which can be used to calibrate the instrumental polarizations are 0316+413 (3C84), 0552+398, 0923+398, 1328+307 (3C286), and 2005+403 at 6 cm and 0316+413 (3C84) at 2 cm. 1328+307 (3C286) and 0518+165 (3C138) are currently used to establish the absolute position angle of the linear polarization.

4.0 SOFTWARE STATUS

The current on-site VLA software capabilities for converting raw visibility data into well-calibrated maps 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. Documentation for VLA data reduction, map making, observing preparation, etc. is found in three main manuals: An Introduction to the NRAO Very Large Array (Green Book), COOKBOOK and Observers Reference Manual. The Green Book is currently being rewritten because many parts of it are presently out of date. The COOKBOOK describes some simple (and limited) recipes for observing strategies and calibration of data. The Reference Manual describes the computer options in a reference style.

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. The latter correction may be turned on or off at the astronomer's option and by default is turned on at 6 cm and 20 cm only.

All further processing required to take the initially corrected visibility data from the Modcomps through calibration to the final maps is accomplished using the DEC-10 general purpose computer and the PDP-11/70 minicomputer. The software is quite extensive and employs an antenna-by-antenna 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. First order antenna shadowing corrections and system temperature corrections for all bands utilizing the measured system temperature data are possible. The antenna gain, phase and polarization characteristics are calculated from calibrator source observations, interpolated in time and stored with the visibility data. There is additional software which allows the observers to calculate baseline and pointing errors from suitable calibrator observations. However, the pointing and baseline parameters are regularly determined by the VLA staff.

The tasks for conversion of calibrated data to maps on the DEC-10 and the PDP-11/70 include sorting, gridding, fast Fourier transform, source subtraction in the u,v plane, the clean algorithm and self-calibration. Both u,v plane convolution (to aid in reducing the aliasing problems) and tapering are supported. Much of the mapping and cleaning is carried out on the PDP-11/70. Map display formats include: character display on computer terminals and line printer output; contours with or without polarization on the Tektronix storage tube terminal and the Versatec dot matrix plotter; and gray scale and color images on the Comtal graphics terminal attached to the PDP-11/40.

NRAO is developing a post-processing system to process VLA maps. The software system is initially being developed to analyze dirty maps made from good quality data. The present options are limited to making and cleaning maps, display of maps on the IIS graphics terminal, contour maps on the VERSATEC printer, reading maps (FITS) or u,v data (EXPORT) and source fitting. An identical system is being developed for a VAX 11/780 computer which will be at the VLA and a Modcomp Classic to remain in Charlottesville.

Complete processing of VLA data from editing through calibration to mapping and cleaning is possible with the NRAO IBM 360 computer located in Charlottesville, Virginia.

5.0 VLA OBSERVING REQUESTS

Observing requests should be sent to the NRAO Director:

Dr. Morton S. Roberts
Director
NRAO
Edgemont Road
Charlottesville VA 22901

The requests should be brief (no more than 3 pages), but they should state clearly:

1. The scientific objectives of the proposed observing program;
2. The amount of observing time required, frequencies, and configuration. These items should be repeated in a concluding summary.

3. Sufficient signal to noise estimates to demonstrate feasibility.
4. The names and addresses of the proposers.

Closing dates for receipt of observing requests are listed in Table IV.

Prospective users are advised to submit their proposals well in advance of reconfigurations and certainly no later than the appropriate deadlines listed in the Table. Proposals submitted requiring a specific configuration other than the one for the next quarter will be held for evaluation and scheduling at the appropriate time. Proposals which are unsuccessful during the evaluation and scheduling process for a given quarter will be retained by the NRAO for further consideration only if they are appropriate for the configuration available in the next quarter.

Proposals will also be accepted for programs which will benefit from the use of a non-standard or hybrid array configurations. Such proposals will be carried out during the reconfiguration phase, which could be stretched out over a two-three week period if required.

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 in order to guarantee GSA car reservations from Albuquerque to the VLA site.

6.0 PLOTS OF U,V COVERAGE

The u,v coverage of the full 27-antenna VLA for the A, B, C, and D configurations is shown in Figure 1 for 7 different declinations. These displays refer to continuous observations tracking the source between elevations for sources at declinations less than 64° and tracking the sources for 12 hours for sources at declinations greater than 64°. A summary of the standard configurations is displayed in Table V. In addition, Figure 2 displays the uv coverage of a snap shot observation at 50 degrees declination and for a duration of 15 minutes at zero hour angle. More detailed plots are available in the uv coverage manual at the VLA site.

TABLE I: VLA SENSITIVITY AND RESOLUTION*

Frequency (GHz)	1.34 - 1.73	4.5 - 5.0	14.4 - 15.4	22.0 - 24.0
Wavelength (cm)	22.4 - 17.3	6.67 - 6.00	2.08 - 1.95	1.36 - 1.25
System Temperature (°K)	60	60	300	400
RMS Sensitivity (mJy) in 10 minutes (50-MHz bandwidth - 27 antennas)	.13	.10	.60	1.0
RMS Sensitivity in 12 hours (50-MHz bandwidth - 27 antennas) mJy	.015	.012	.07	.12
**Untapered brightness temperature (A configuration) K	6.9	5.5	34	54
***Dynamic Range without Self-Calibration	100	50	10 - 20?	10?
Antenna Beam Size (FWHP - arcsecs)	1800	540	220	120
Brightest Source (mJy) Expected in Antenna Beam	100	2.3	<.1	<.01

* Table entries are theoretical estimates (sensitivities are for a point source and refer to both IF pairs).

** RMS sensitivity in brightness temperature for the untapered map is given approximately by

$$\Delta T \cong \frac{1.46\ \lambda^2}{HBW_1 HBW_2}\ \Delta S$$

where $HBW_{1,2}$ are half-power synthesized beamwidths in arcsec
λ is wavelength in cm
ΔS is rms sensitivity/beam area in mJy

***Extremely dependent on declination, time of day, season, and frequency of calibration.

TABLE II(a)

VISIBLE FIELD FOR A GIVEN DEGREDATION DUE TO BANDWIDTH SMEARING IN A 50 MHz BANDWIDTH

DISTANCE FROM PHASE CENTER (arc seconds)*

Loss of Central Intensity of Point Source	5%	10%	20%
Configuration A	11"	15"	22"
B	36"	49"	72"
C	120"	162"	240"
D	406"	549"	813"
Increase in approximate synthesized beamwidth in radial direction	2%	5%	10%

* Distances at other bandwidths can be calculated by linearly scaling these numbers.

TABLE II(b)

AVERAGING TIMES (sec) FOR CASE WHEN LOSS OF INTENSITY DUE TO BANDWIDTH AND TIME AVERAGING SMEARING ARE APPROXIMATELY THE SAME

Bandwidth (MHz)	50	25	12.5	6.25	3.125
Frequency (MHz)					
1460	140	70	35	18	9
4885	70	35	18	9	4*
15000	35	18	9	4*	2*
23000	18	9	4*	2*	1*

* Minimum integration time is 10 seconds.

TABLE III

COMBINATIONS OF BANDWIDTH CHANNELS AND ANTENNAS WHICH CAN BE USED FOR SPECTRAL LINE OBSERVING

Bandwidth	# Channels	Channelwidth	# Antennas
50 MHz	8	6 MHz	All
25	16	1.5 MHz	25
12	32	400 kHz	18
6	64	100 kHz	13
3	128	25 kHz	9
1.5	256	6 kHz	6
0.8	256	3 kHz	6

TABLE IV

Configuration	Quarters Available	Proposal Deadline
A	Q1 + Q2 1981	Oct. 15, 1980 and Jan. 15, 1981
B	Q2 + Q3 1981	Jan. 15 and Apr. 15, 1981
D	Q3 1981	Apr. 15, 1981
C	Q4 1981	July 15, 1981
A	Q4 1981 + Q1 1982	July 15 and Oct. 15, 1981

TABLE V: CONFIGURATION SUMMARY

CONFIGURATION	MAXIMUM DISTANCE DOWN ARM FROM ARRAY CENTER (km)	MINIMUM ANTENNA PAIR SEPARATION WITHIN ARM (km)	APPROXIMATE SYNTHESIZED* HALF-POWER BEAMWIDTH FOR HIGH DECLINATION SOURCES (arcseconds)				APPROXIMATE LARGEST SCALE STRUCTURE "VISIBLE" TO VLA (arcseconds)			
			20 cm	6 cm	2 cm	1.3 cm	20 cm	6 cm	2 cm	1.3 cm
A	21	1.1	1.7	0.5	0.17	0.11	38	11	4	2
B	6.4	.34	5.4	1.6	0.54	0.35	121	36.4	12	7.9
C	2.0	.10	17.5	5.3	1.8	1.1	413	124	41	27
D	.59	.045	59.3	17.8	5.9	3.9	917	275	92	60

*A Gaussian taper has been applied to a uniformly illuminated aperture such that the visibilities in the longest baselines are reduced by approximately 12 dB.

TABLE VI

APPROXIMATE MAXIMUM SOURCE SIZE FOR SINGLE SNAP SHOT OBSERVATION*

	A	B	C	D
20	35"	2'	6'	20'
6	10"	35"	2'	6'
2	3"	10"	35"	2'
1.3	2"	6"	20"	1'

* Larger sources can be mapped by combining a few snap shots taken at different hour angles.

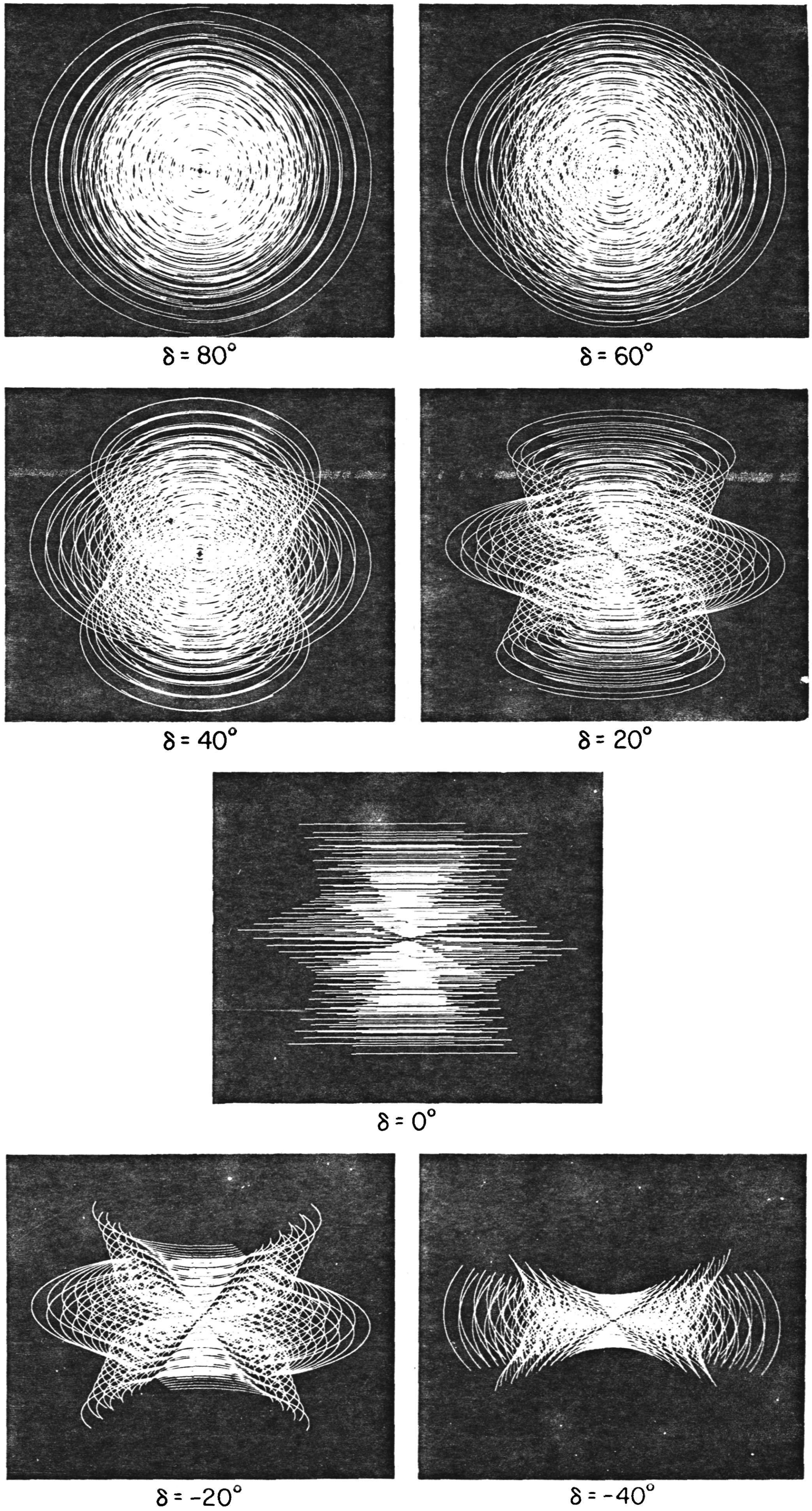
$\delta = 80^\circ$
$\delta = 60^\circ$
$\delta = 40^\circ$
$\delta = 20^\circ$
$\delta = 0^\circ$
$\delta = -20^\circ$
$\delta = -40^\circ$

Figure 1

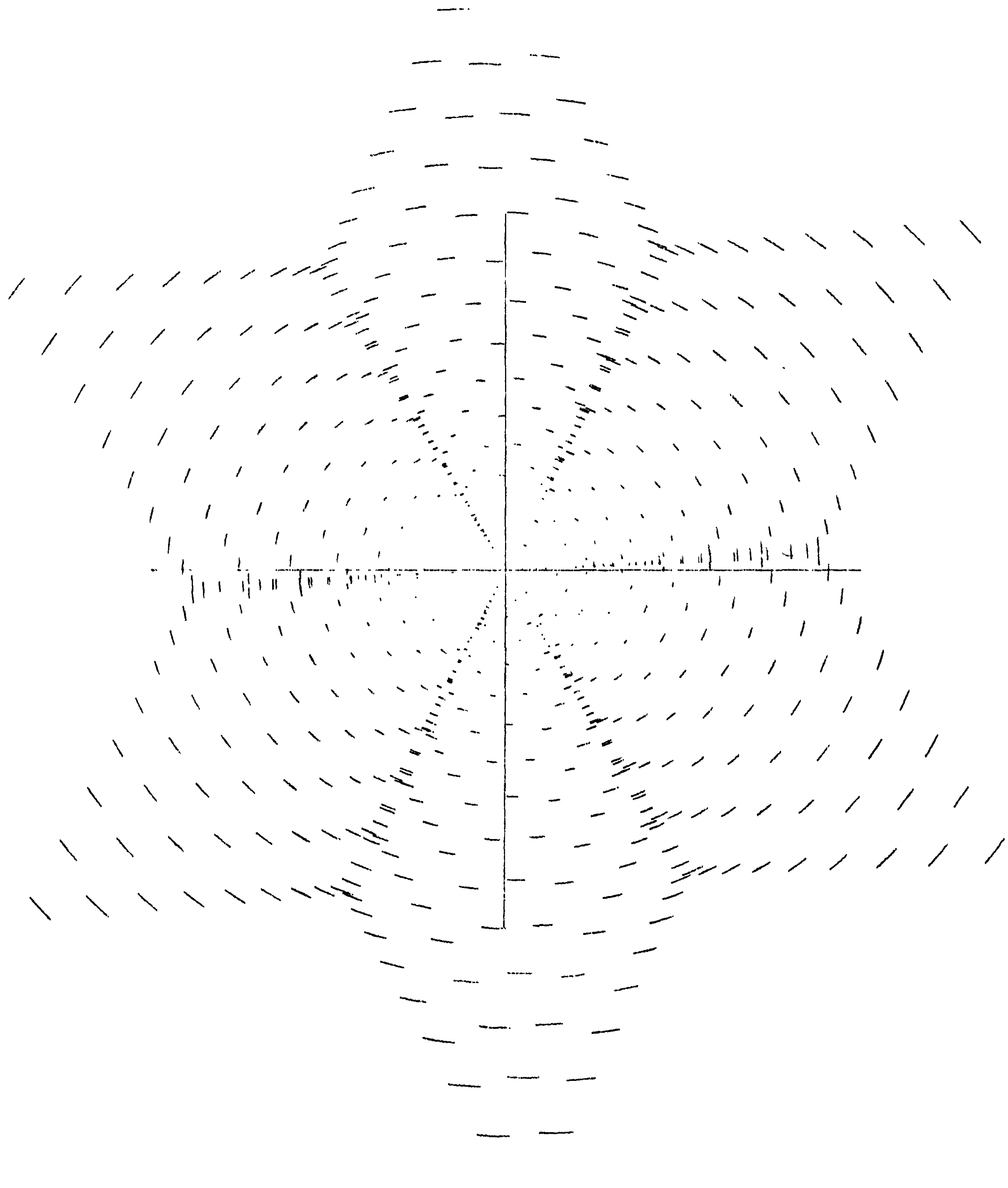

Figure 2

DEC=50^{d}
HA =0^{h},0 to 0^{h},20^{m}