US/GR BK/

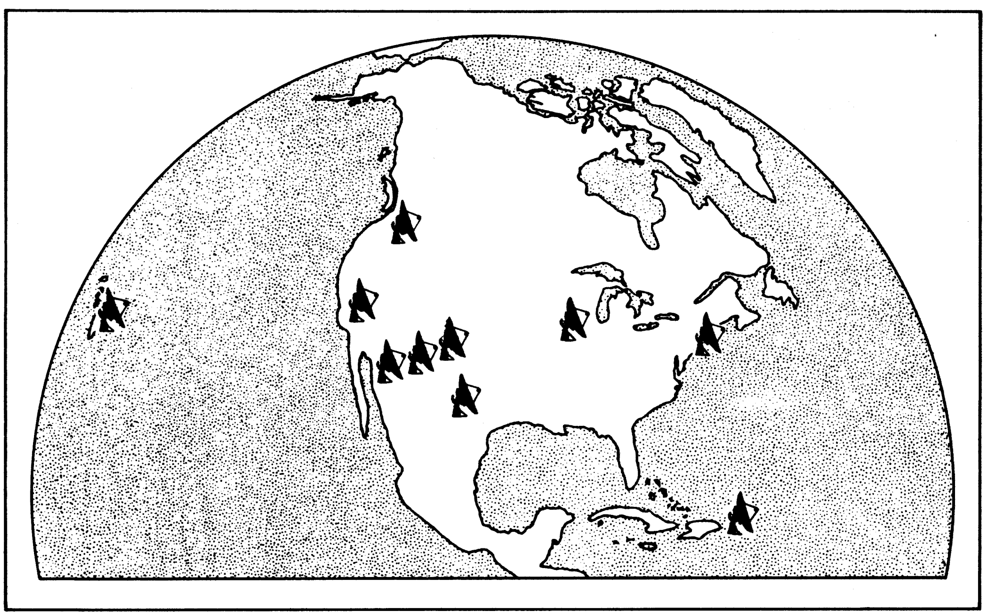
Very Long Baseline Array Project

VERY LONG BASELINE ARRAY

PROJECT BOOK

Version 7

October 1, 1988



NATIONAL RADIO ASTRONOMY OBSERVATORY

P. O. Box O • Socorro, New Mexico 87801

OPERATED BY ASSOCIATED UNIVERSITIES INC.,

UNDER COOPERATIVE AGREEMENT WITH THE NATIONAL SCIENCE FOUNDATION

VERY LONG BASELINE ARRAY

PROJECT BOOK

Version 7

October 1, 1988

VLBA Project Office
Box 0
Socorro, NM 87801
505 - 835 - 7000

National Radio Astronomy Observatory
Edgemont Road, Charlottesville, VA 22903

Operated by Associated Universities Inc.
under contract with The National Science Foundation

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLBA PROJECT BOOK
880930

Version #7

Table of Contents

THE VLBA PROJECT BOOK

INTRODUCTION

K. I. Kellermann

The Very Long Baseline Array is an aperture synthesis radio telescope which will be used for a variety of astronomical and geophysical measurements. It will consist of ten 25-meter antennas located throughout the United States, positioned to optimize the image quality as well as to provide convenient access for operation and maintenance.

Each antenna element will be equipped with receivers covering frequency bands between 330 MHz and 43 GHz, and will be controlled from an Array Operations Center located in Socorro, New Mexico. Hydrogen masers will be used to provide independent coherent local oscillators at each antenna element. The I.F. data will be recorded on magnetic tape which will be sent to the Array Operations Center, where it will be simultaneously replayed and correlated with the data from the other antennas. The Array Operations Center will also contain post-processing facilities, and will house most of the staff involved in the operation and maintenance of the array. In addition, two or three people will be stationed at each element to provide routine support.

The VLBA Project Book describes the technical design as of the date of issue, and is regularly updated as the design evolves. The following "Specifications Summary" delineates the main design parameters. They are explained in more detail in the main text. Comments on the design, as well as errors or inconsistencies in this report, will be welcome by the individuals responsible or the project management.

VLBA SPECIFICATION SUMMARY

J. D. Romney
National Radio Astronomy Observatory
Charlottesville, Virginia

INTRODUCTION

This document summarizes the essential specifications of the Very Long Baseline Array (VLBA) project in a concise list for quick reference. It is compiled from the much more detailed "VLBA Book", and various general and specialized Array memoranda, which should be consulted for definitive information. For the sake of brevity, however, no references are given.

Progress in construction of the Array is outlined in a companion report, the VLBA Status Summary, which is kept current through frequent updates.

Both documents are maintained in plain ASCII text in NRAO's computer network, in directory CVAX::UMA3:[VLBA] under file names SPECS. and STATUS., respectively. They are also available from the VLBI-SERVER bulletin board on node PHOBOS at Caltech, as VLBA-SPECS and VLBA-STATUS.

SITES

Code	Location *1*	N Latitude [o,',"]	W Longitude [o,',"]	Elev [m]	Operational
PT	Pie Town, NM	34 18 03.61	108 07 07.24	2371	88/5
KP	Kitt Peak, AZ	31 57 22.39	111 36 42.26	1916	89/4
LA	Los Alamos, NM	35 46 30.33	106 14 42.01	1967	89/4
FD	Fort Davis, TX	30 38 05.63	103 56 39.13	1615	90/11
NL	N. Liberty, IA	41 46 17.03	91 34 26.35	241	89/11
BR	Brewster, WA	48 07 52.80	119 40 55.34	255	90/4
OV	Owens Vly., CA	37 13 54.19	118 16 33.98	1207	90/6
SC	St. Croix, VI	17 45 30.57	64 35 02.61	16	90/11
MK	Mauna Kea, HI	19.81 deg	155.46 deg	3725	91/3
HN	Hancock, NH	42 56 00.96	71 59 11.69	309	91/7

Note: *1* Listed in planned order of construction.

ANTENNAS

Main Reflector --

Diameter	25 m
f/D	0.354
Surface	Shaped figure of revolution
Accuracy	(see below)

Cassegrain Reflector *1* --

Diameter	3.5 m
Surface	Shaped asymmetric figure
Accuracy	0.150 mm

Structure --

Type	Wheel-and-track, with advanced-design reflector support structure.
Elevation Motion	0 -> 125 deg; 30 deg/min
Azimuth Motion	-90 -> +450 deg; 90 deg/min

Operating Conditions:	Precision	"Normal"	Survival
Temperature [C]	-18 -> +32	-30 -> +40	
Temp. Change [C/hr]	2	--	
Temp. Diff'l. [C]	3.5 *2*	--	
Wind [m/s]	6	18	50
Gusts [m/s]	1	2.5	
Rain [cm/hr]	None	5	
Snow or Ice	None	None	20 psf, OR 1 cm

Accuracy --

Main Surface (panel manufacturing RSS)		0.125 mm
Main Surface (total RSS)	*3* *4*	0.282 mm
Pointing (repeatable)	*4*	3'
Pointing (non-rep., short term)	*4*	8"
Pointing (non-rep., long term)	*4*	14"

Notes:
1 Not used for all bands; see "Frequencies".
2 This condition to be met for 95% of observations.
3 See "Frequencies" for corresponding aperture efficiencies.
4 Under precision operating conditions.

FREQUENCIES
===========

Band Designation *1*			Frequency Range [GHz]	Aperture Efficiency *2*	Noise Temp. [K] *3* Rcvr	System
330	P		.312 - .342	.50	30	104
610			.580 - .640	.57	30	64
1.5	L	*4*	1.35 - 1.75	.57	7	25
2.3	S		2.15 - 2.35	.71	8	28
4.8	C	*4*	4.6 - 5.1	.72	10	25
6.1		*5*	5.9 - 6.4	.71	12	32
8.4	X		8.0 - 8.8	.69	16	37
10.7		*5*	10.2 - 11.2	.69	20	36
15	U		14.4 - 15.4	.68	30	48
23	K	*4*	21.7 - 24.1	.66	60	87
43	Q		42.3 - 43.5	.51	90	125
89	W	*5*	86? - 92?	.18	?	?

Notes:
1 MHz/GHz frequency, to 2(+) significant figures; Conventional radio (and VLA) letter codes.
2 Total aperture efficiency, including all known effects.
3 Receiver noise temperature based on lab measurements; Estimated system temperature from all causes.
4 Initial complement, installed as antenna is completed; All standard VLBA bands except 43 GHz installed at PT.
5 Optional receivers, not included in basic Array budget. (6.1-GHz receiver would share 4.8-GHz feed; one 10.7-GHz receiver already installed at PT.)

Feeds / Foci --

Below 1 GHz:	Crossed dipoles / Prime focus
Above 1 GHz:	Corrugated horn / Cassegrain focus; Compact corrugated horn at L-band.

Amplifier Types --

Below 1 GHz:	Ambient-temperature GaAsFET amplifiers.
1 - 43 GHz:	Cooled (15K) HEMT amplifiers.

Dual-Frequency Pairs --

Planned:	S/X bands.
Options:	C/U, C/K, U/Q, U/W bands.

SIGNALS

IF Processing --	
Number of IFs	4
IF Frequency Range	500 -> 1000 MHz
Baseband Conversion --	
Number of Converters	8 (expandable to 16)
Number of Channels	16 -- USB and LSB from each converter
Bandwidths	16, 8, 4, 2, 1, .5, .25, .125, .0625 MHz
LO Quantization	10 kHz
Aggregate Bandwidth	256 MHz
Sampling --	
Number of Samplers	16
Sample Rates	32, 16, 8, 4, 2, 1, 0.5 Msmp/s
Level Quantization	2 or 4 levels
Aggregate Data Rates	512 Msmp/s, 1024 Mbit/s *1*
Formatting --	
Number of Bitstreams	32
Multiplexing	4:1, 2:1, 1:1, 1:2, 1:4 bitstream:track
Format	Programmable, including Mark 3
Framing	Transparent or data-replacement
Aggregate Bit Rate	512 Mbit/s (expandable to 1024 Mbit/s)
Recording --	
Number of Data Tracks	64 (expandable to 128) -- on 2 recorders
Record Rate per Track	8, 4, 2 Mbit/s (plus 9/8 parity) *2*
Duration per Pass	1 hour *2*
Passes per Tape	16
Duration per Tape	16 hours *2*
Capacity per Tape	7.37 Tbit
Aggregate Bit Rates	128 Mbit/s sustainable *2* 512 Mbit/s peak

Notes: *1* Maximum aggregate bandwidth/sampling capacity cannot be formatted or recorded without expansion.

2 Durations refer to "sustainable" 4 Mbit/s track record rate which allows unattended operation for 24-hour period.

CORRELATOR

Basic Dimensions --

Stations	s = (10), (15), 20	*1* *2*
Channels	c = 1, 2, 4, 8	
Spectral Points	l = 32, 64, 128, 256, 512, 1024	

Other Capabilities --

Oversampled Input Data	f = 1, 2, 4, ...
Interleaving	n = 1, 2 (n <= f)
Overlapping	v = 1, 2, 4, ...
Interpolation	z = 1, 2
Polarization	p = 1 (normal), 2 (polarized)
Polarized Spectroscopy	y = 1, EXCEPT when p = 2 AND:
	l = 256 --> Polarized Resol'n Factor = 2
	l = 512 --> Polarized Resol'n Factor = 4

Mode Limits --

"F" (FFT section)	s c n v z y / f <= 160	*1*
"X" (XMult/Acc section)	s (s+1) c p l /2 <= 262,144	*2*

Timing --

Sample Rate	32, 16, 8, 4, 2 Msmp/s
Speedup Factor	1, 2, 4 -- constant, full-speed playback
Integration Time Quantum	100 ms
Integration Time, max.	102.4 s
Archive Data Rate	0.5 Mbyte/s, maximum

Tracking --

Delay Range	Unlimited, via playback offset
Delay Switching Range	6000 samples
Coarse Delay Rate Range	+/- 50 sample/s
Fine Delay Range	+/- 1/2 sample
Fine Delay Accuracy	0.001 sample
Phase Accuracy	0.002 turn
Fringe Rate Range	Unlimited (+/- full bandwidth)
Fringe Acceleration Range	+/- 10.4 Hz/s

Pulsar Gate --

Gate Profile	Arbitrary
Pulse Phase Resolution	1024 points/period
Pulse Timing Resolution	Equal to FFT length

Simultaneous Correlation --

Sub-Arrays	10
Switched Models	> 8
Switching Interval Quantum	100 ms

Notes: *1* For "F" mode limits, s = 10, 20 only.
2 For "X" mode limits, s = 15, 20 only.

SECTION 1

CONFIGURATION

R. C. Walker

1.1 Design Goals

The configuration of the VLBA is the result of an extensive search for an optimal distribution of telescopes that would meet the goals and constraints defined in the original program plan. Those constraints are briefly:

1.1.1 Performance goals

1.1.1.1 Highest possible resolution.

The longest possible baseline within U.S. territory is about 8000 km using Hawaii.

1.1.1.2 Large field of view.

The shortest baseline in the array should be no longer than 200 km and that baseline should be placed near the VLA so even shorter baselines could be obtained to elements of the VLA.

1.1.1.3 2-Dimensional configuration.

The array should be able to observe low declination sources.

1.1.1.4 Image quality.

The VLBA should provide high dynamic range images over a wide range of source scale sizes. Uniform coverage is desired for the high dynamic range while an emphasis on short baselines is desired for coverage of a wide range of scale sizes.

1.1.2 Practical Constraints

1.1.2.1 Low cost.

The smallest possible number of antennas should be used consistent with the performance goals. Also as many sites as possible should be at facilities where local support can be obtained.

1.1.2.2 Proximity to the VLA.

The short baselines should be near the VLA in order to take most effective advantage of that instrument for additional, short baselines and for a wide range of very sensitive baselines. This constraint has become especially important now that the value of eventually adding telescopes near the VLA to fill the hole in the coverage between the VLA and the VLBA has been clearly recognized.

1.1.2.3 Dry Sites.

The VLBA is expected to operate at 22 and 43 GHz (and optionally at 86 GHz) so it is important to use as many high, dry sites as possible to minimize problems caused by water vapor. Such sites are most commonly found in the Southwest.

1.1.2.4 Ease of Access.

If feasible, each antenna should be near a major transportation center.

1.1.2.5 U.S. Territory.

The VLBA sites are restricted to U.S. territory in order to minimize the administrative and logistical difficulties and the expense of operations.

The minimum number of antennas required to cover the range of spacings from 200 to 8000 km, with the limitation on north-south coverage given by the U.S. territory constraint, is ten. With fewer than ten antennas, large holes in the coverage of the transform (u-v) plane appear or the minimum spacing must be larger than 200 km. Also, with fewer than ten antennas, the fraction of the total information contained in the calibration independent closure parameters, upon which VLBI depends for its mapping capabilities, drops rapidly.

1.2 The Configuration

The configuration that has been chosen is shown in Figure 1.1. The sites are discussed individually below. The coverages of the transform plane for the array, for maximum scales of 8000, 4000, 2000, 1000, 500, and 200 km are shown in Figures 1.2.*. The plots on the 1000, 500 and 200 km maximum scales include baselines that would be provided if 4 elements of the VLA were used with the VLBA. It is expected that the VLA will be equipped with the record units necessary for combined experiments and that the resulting science will justify the frequent use of VLA antennas.

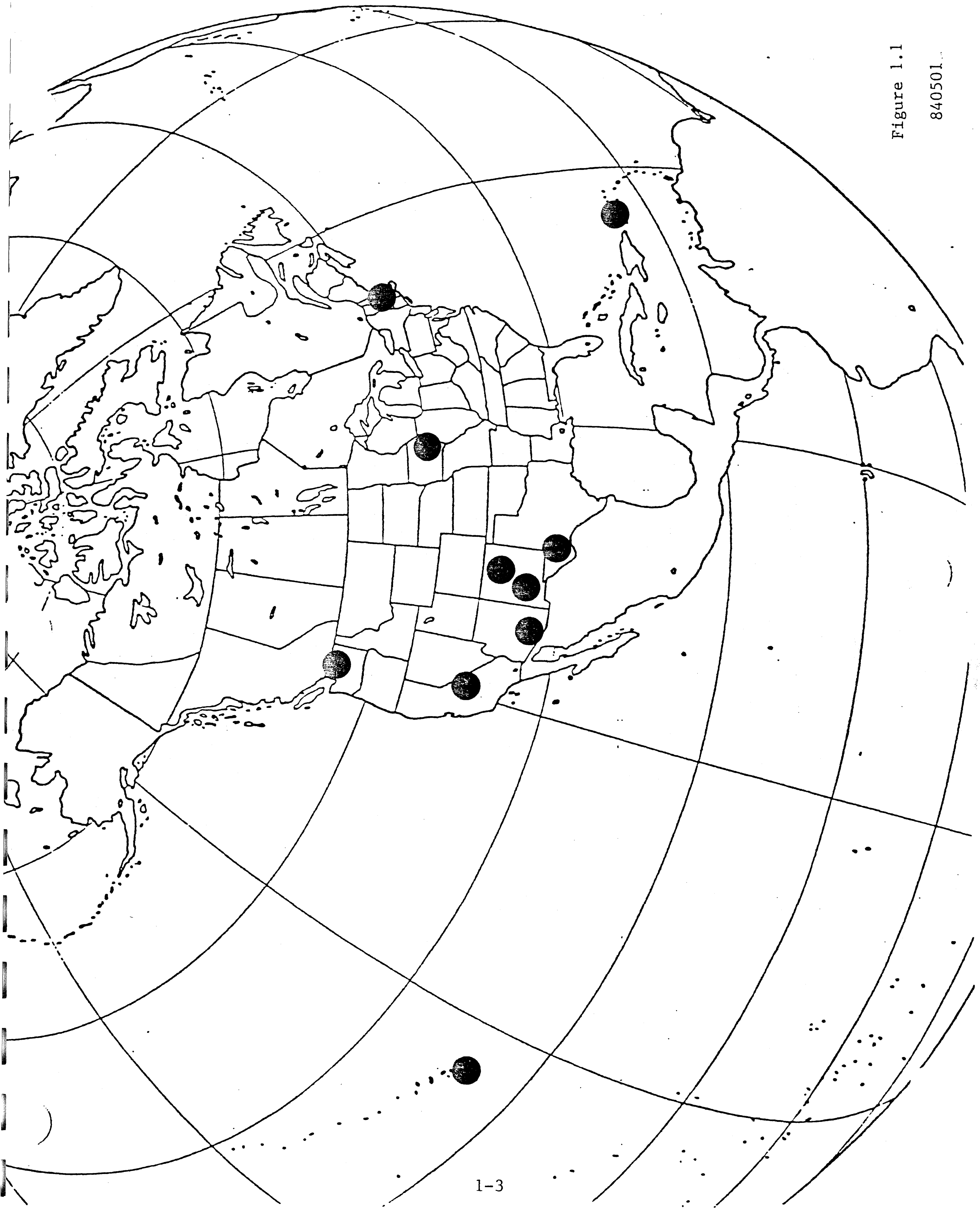


Figure 1.1

840501

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58

Scale in km
(kilometers x 10^3)

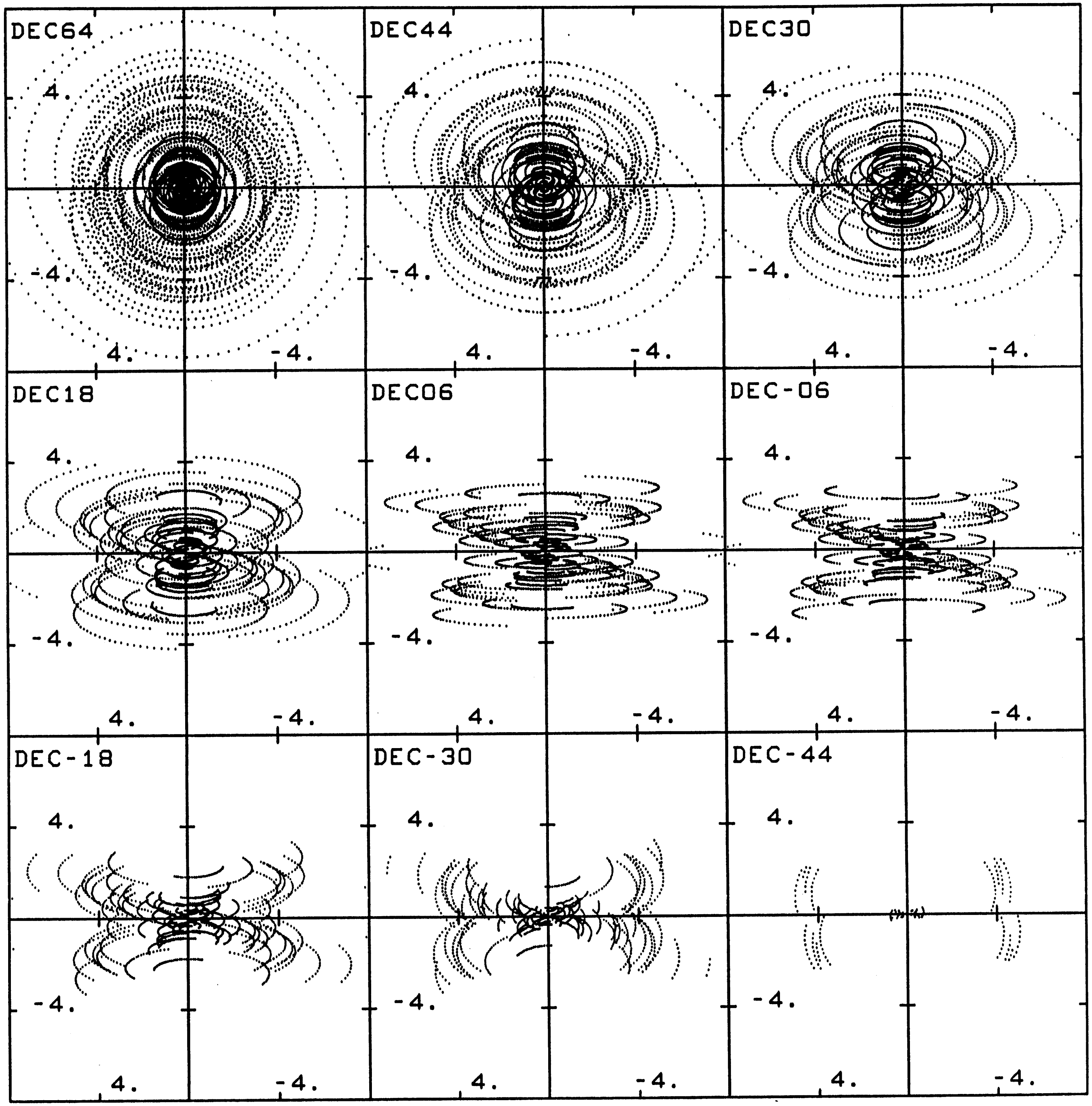


Figure 1.2a
8000 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58

Scale in km
(kilometers x 10^3)

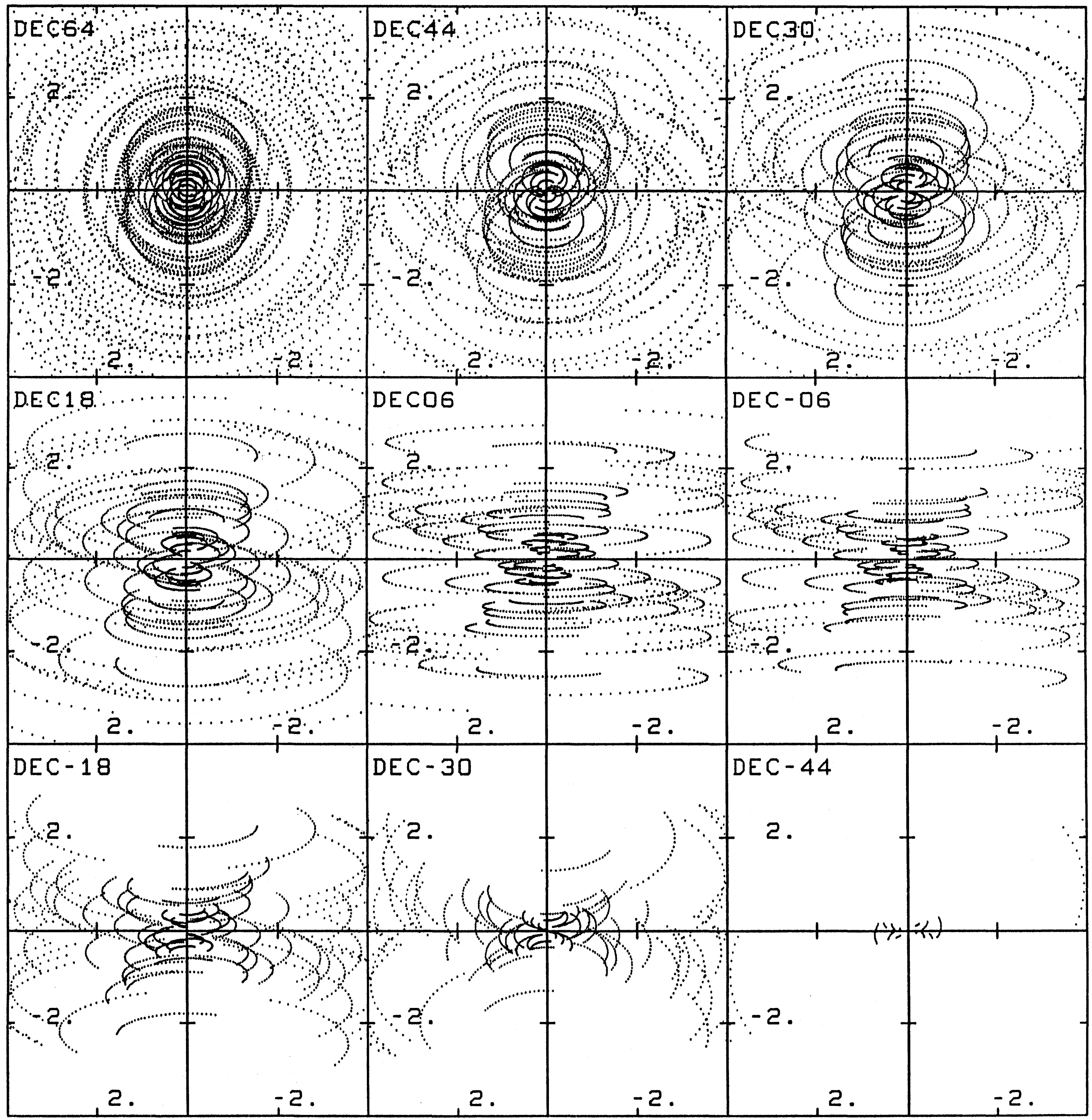


Figure 1.2b
4000 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58

Scale in km
(kilometers x 10^2)

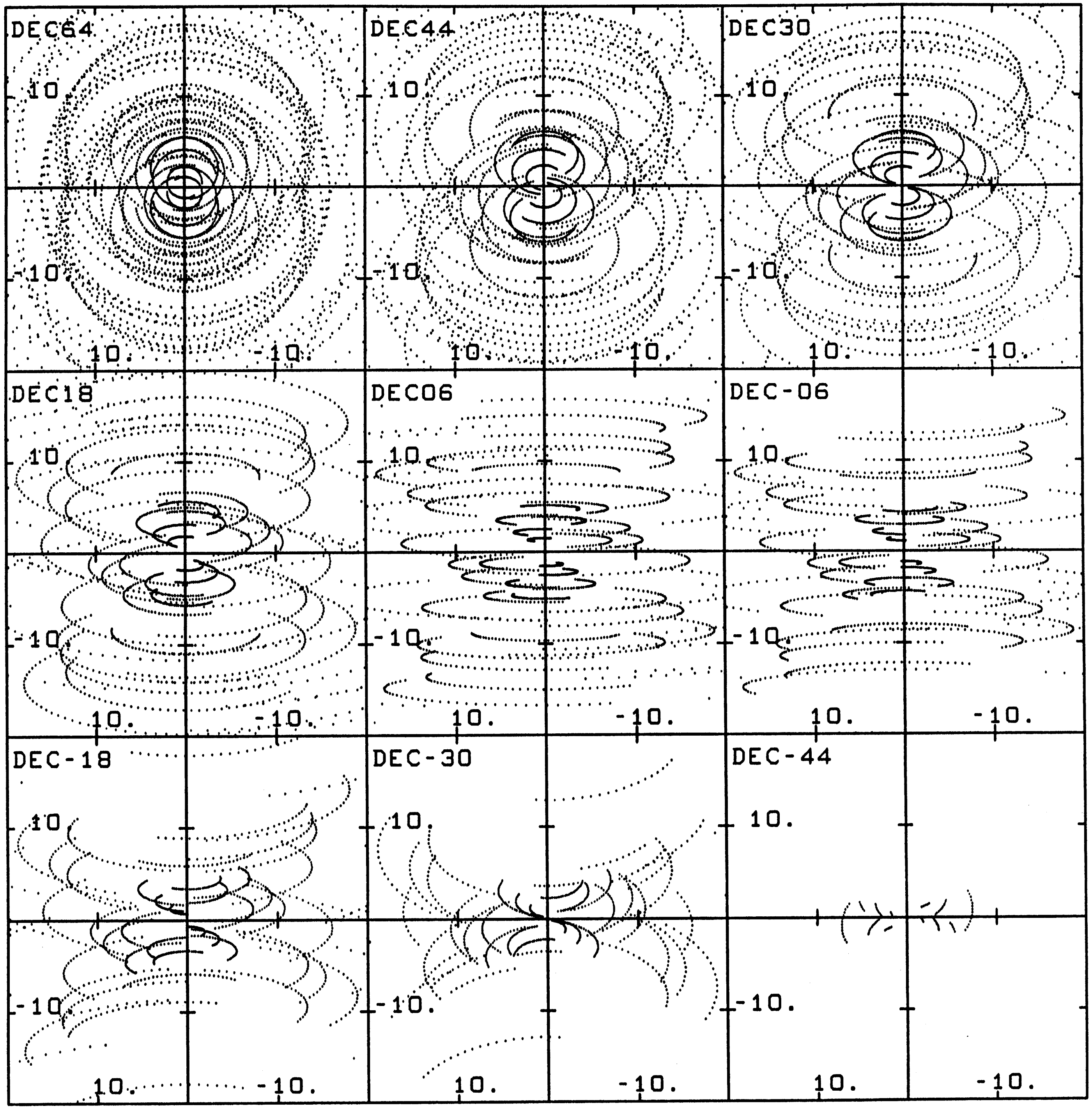


Figure 1.2c
2000 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64

Scale in km
(kilometers x 10^2)

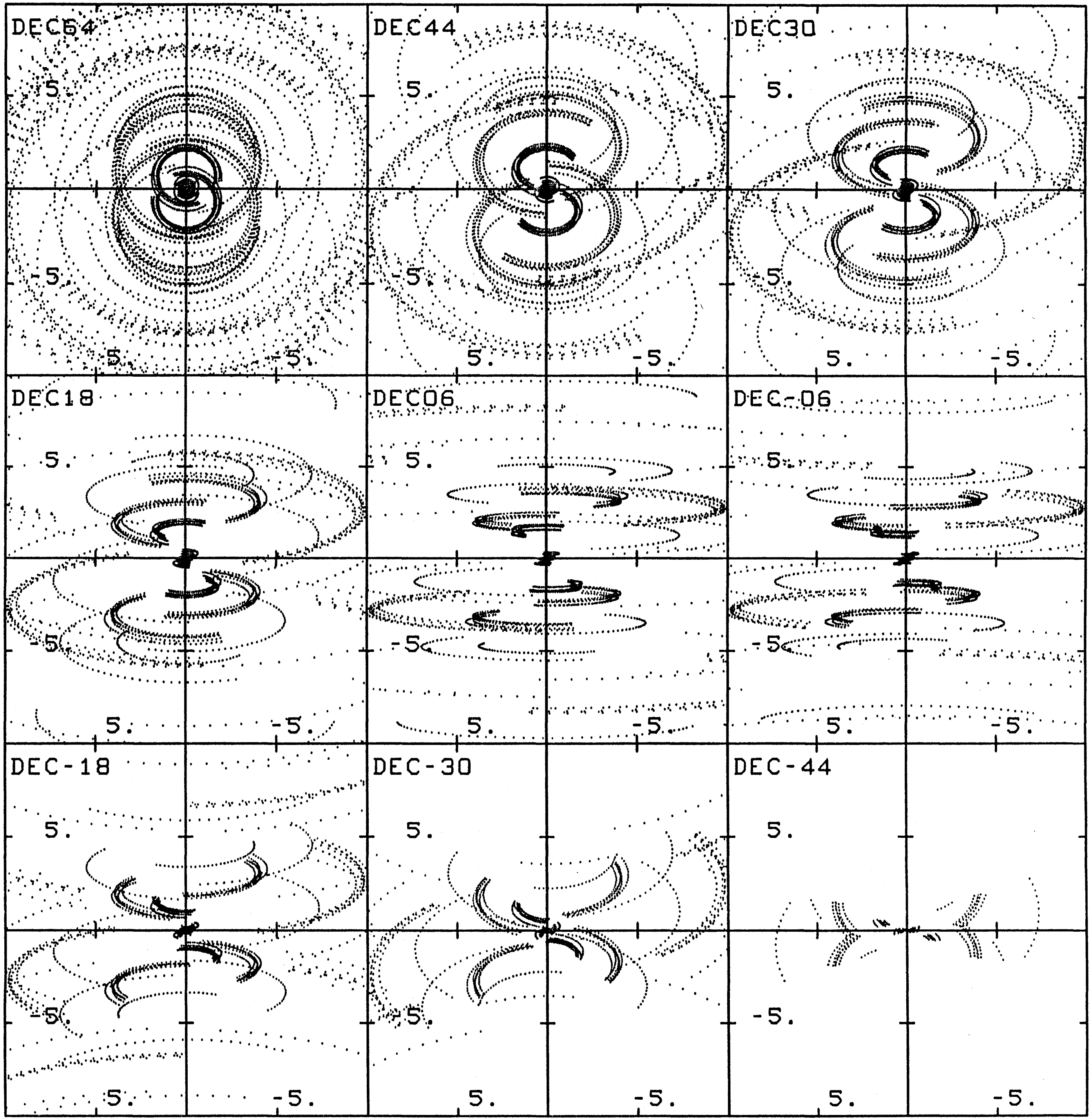


Figure 1.2d
1000 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64

Scale in km
(kilometers x 10^2)

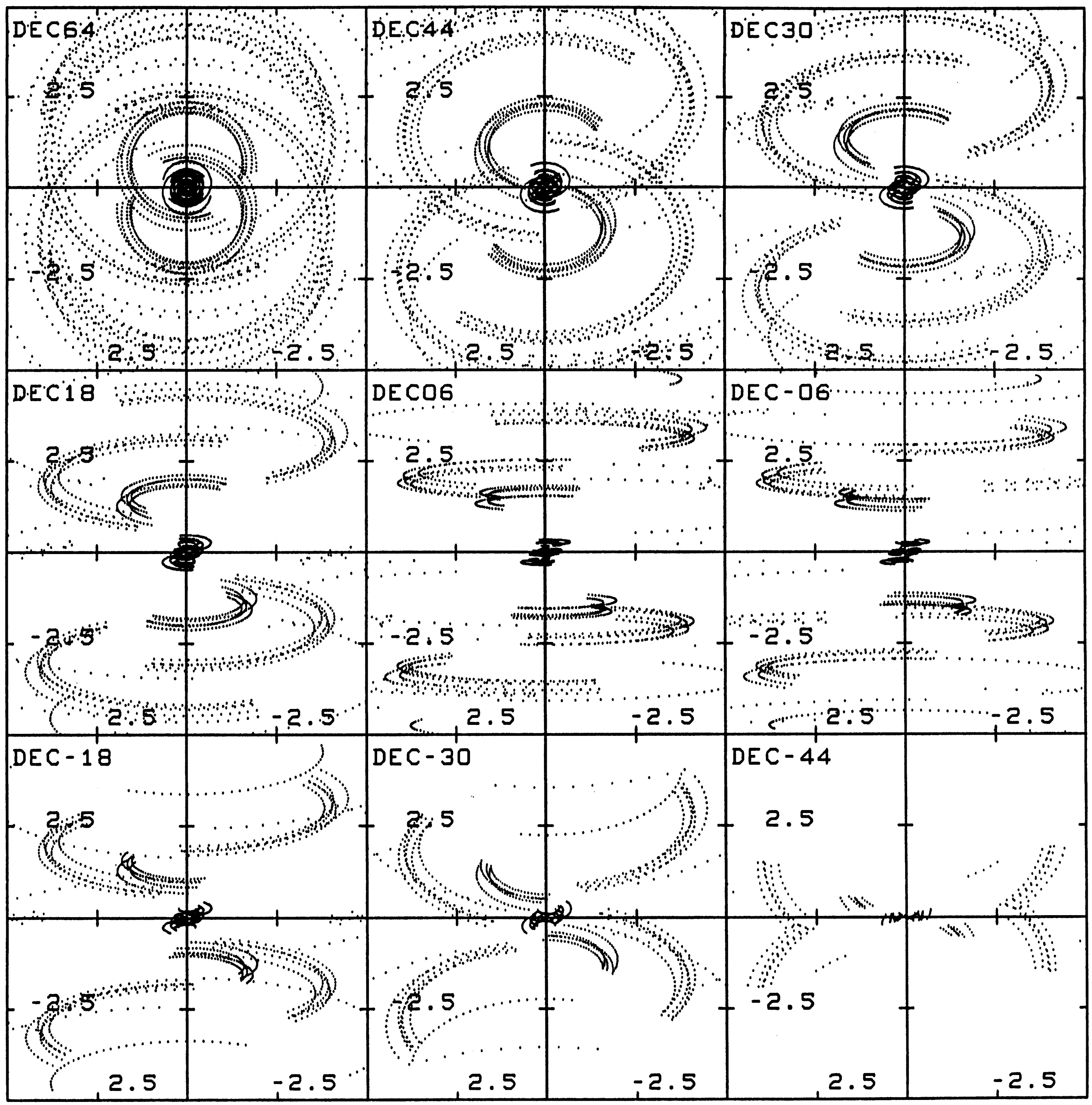


Figure 1.2e
500 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64

Scale in km
(kilometers x 10^1)

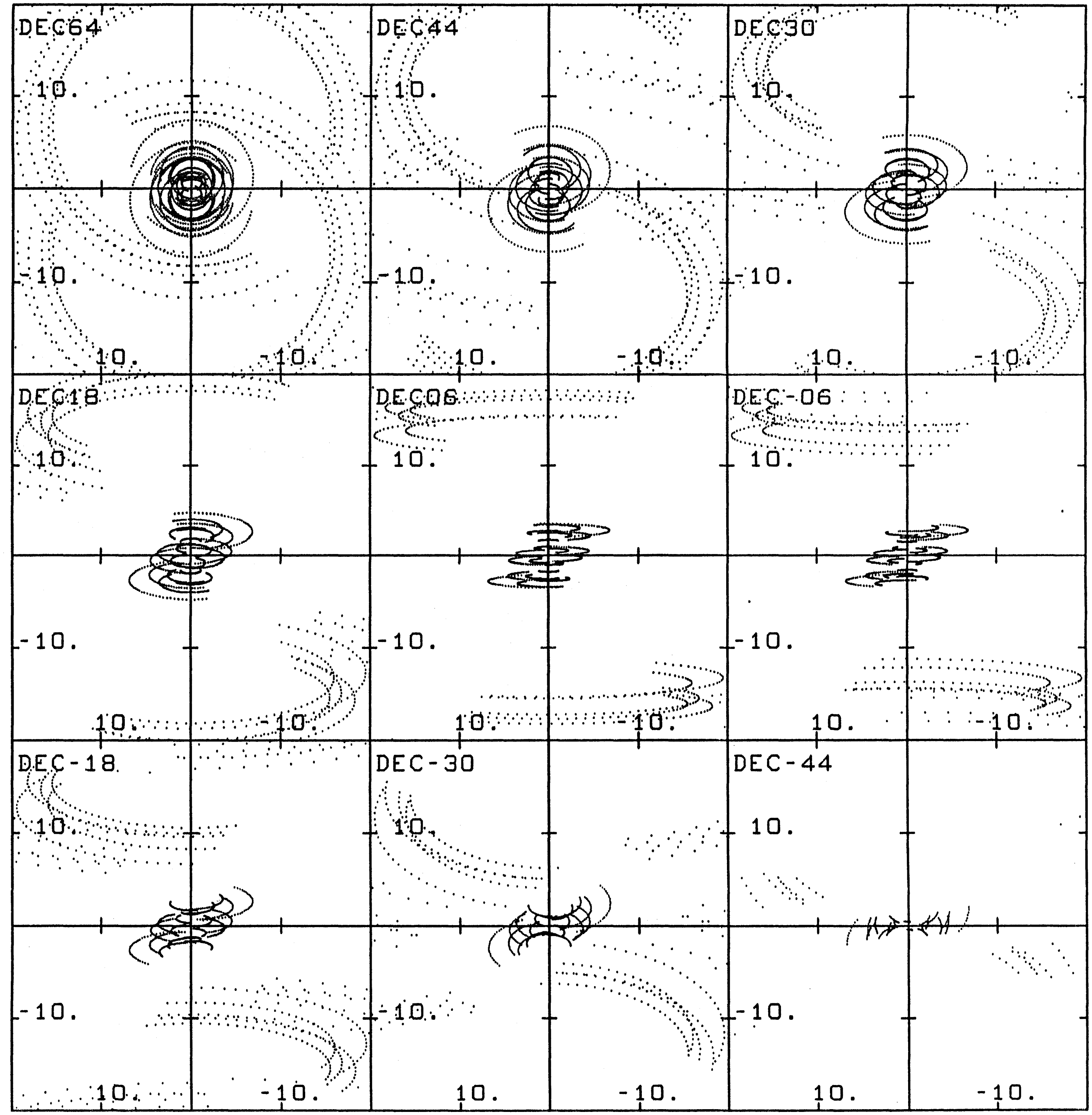


Figure 1.2f
200 km

The sites of the antennas of the VLBA are listed below in west-to-east order.

1. MAUNA KEA, HI: A high altitude site is needed to avoid the high atmospheric water vapor levels that occur in tropical, maritime regions such as Hawaii. Water vapor measurements have been made and confirm that a high site is needed, although the minimum altitude is not clear. The water vapor fluctuations appear to be significantly lower than in Puerto Rico, even at sea level. The site selected on Mona Kea is at about 3725 m (12,200 ft) elevation. This is just low enough to avoid the severe weather near the summit that might threaten the survival of the antenna, but high enough to avoid most atmospheric problems.

2. BREWSTER, WA: This site is near the Canadian border in central Washington State. This is the only site in the configuration that is not near known local support, although Penticton in Canada is not far away. Land has been purchased near the Comsat station at Brewster. That station is scheduled to be closed so it may serve as a source of qualified personel.

3. OWENS VALLEY, CA: This site is at The Owens Valley Radio Observatory (OVRO) near Big Pine, California. The observatory is an existing VLBI site with good local support. Some consideration was given to choosing a site far enough from OVRO to provide interesting baselines to the 130' antenna.

4. KITT PEAK, AZ: Kitt Peak, Arizona, is an existing NRAO site with good local support. The specific site is near the picnic ground on the mountain. There is some concern that wind may be a problem but an evaluation of wind measurements and of the effects of wind on the antennas led to the tentative decision to favor the logistical advantages of being on the existing facility over an undeveloped, low elevation site.

5. PIE TOWN, NM: This site is west of the VLA on Rt. 60. Access from the VLA is good and power and phones are nearby. Maintanence from the VLA or from the VLBA headquarters will be relatively easy.

It is attractive to link this antenna to the VLA, probably with fiber optics. This would allow Pie Town to be used as an outrigger of the VLA to double the resolution of the VLA on northern sources. It also would allow tape recording for Pie Town to occur at the VLA, thereby reducing manpower requirements at Pie Town. However, funds for such a link are not in either the VLBA construction budget or the near term NRAO budget.

6. LOS ALAMOS, NM: The site is on the southern border of the Los Alamos Scientific Laboratory property. The site should be easy to maintain from headquarters in Socorro.

7. FORT DAVIS, TX: The Fort Davis, Texas, site is adjacent to the existing radio observatory (George R. Agassiz Station - Harvard) that is active in VLBI but has limited high-frequency capability.

8. NORTH LIBERTY, IA: The North Liberty Radio Observatory is an existing VLBI facility with a relatively small, low-frequency antenna. The obvious, although probably not serious, hole in the coverage at Dec 64 at a little over 2000 km could have been filled by moving this site to Illinois with some corresponding, but more subtle, degradation of performance in other parts of the u-v plane. There was considerable freedom in the choice of the location of this site so that local factors became dominant. It was decided to take over the University of Iowa's lease of this observatory site from the Corps of Engineers. The antenna is being built adjacent to the existing antenna and the existing antenna will be dismantled when the new one comes on-line.

9. HANCOCK (SARGENT CAMP), NH: This site was originally expected to be at the existing radio astronomy facilities of the Haystack Observatory in Massachusetts where there is very good local support. However the severe interference environment at that site has caused its rejection. A site about 40 miles northeast of Haystack, at Boston University's Sargent Camp in New Hampshire has been chosen. This site is both farther from Boston and is in a hilly region that should provide some terrain shielding.

10. VIRGIN ISLANDS: The u-v coverage provided by a station in the West Indies is very attractive although the high water vapor content of the atmosphere in the area is a concern. Unlike Hawaii, neither Puerto Rico nor any of the Virgin Islands has high altitude sites. VLBI experiments at 6 cm using Arecibo and a rubidium vapor frequency standard give coherence times of 1 - 3 minutes (probably limited by the frequency standard) which suggests that useful observations can be made at frequencies at least as high as 10 GHz. Measurements have been made at various sites in Puerto Rico using a water vapor radiometer to try to predict the performance of an Array telescope at 22 and 43 GHz. The results show that observations should be possible and that a site on the South Coast may be best.

A specific location in a wildlife refuge on the South Coast or Puerto Rico was identified in 1984. However the Voice of America has informed NRAO that it intends to build about 10 Megawatts worth of transmitters about a mile away. As a result of concerns about Puerto Rico, the island of St. Croix in the Virgin Islands was investigated in mid 1985 and found to offer considerable advantages in access and local conditions. A site near the eastern end of St. Croix on territorial land has been chosen.

The quality of the u-v coverage is sufficiently good that Puerto Rico or the Virgin Islands will be used even though observations at the highest frequencies will sometimes require special calibration techniques such as simultaneous observations at lower frequencies to remove the atmosphere. Note that the uv coverage of the array degrades gracefully if this site is lost for an observation - some resolution is lost and the beam becomes somewhat elongated, but no big holes at the shorter spacings are opened up.

1.3 Possible Extensions

The 10 stations described above make a very powerful instrument that meets the specifications given at the beginning of the VLBA project. Recent impressive results from MERLIN in Britain and experience gained on current large VLB Network and VLA experiments have increased the awareness of the importance of a wide range of spacings. An attractive eventual goal would be an interferometer that covers the full range of baseline lengths possible on the surface of the Earth, allowing us to construct a "matched u-v filter" to the needs of any mapping experiment.

The combination of the VLBA described above and the VLA comes close to providing this capability. However, there is a range of spacings between 35 km and about 200 km that is poorly covered. It has been found that three or four additional stations in New Mexico can fill this gap. The 10 station VLBA has been partially optimized (with very little sacrifice of capability as a 10 station array) as part of a 13 station array that fills the gap. A superior, but more expensive, 14 station array that shares 12 sites with the 13 station array has also been identified and would be favored if sufficient funds were available. In any such array, as many of the VLBA stations as possible would be operated remotely from the VLA by microwave link. Data from these stations could be correlated in real time with the VLA and/or recorded on tape for later processing with the rest of the VLBA. The two additional sites shared by both the 13 and 14 station options are:

1. DUSTY, NM: This site is south of the VLA. It is easily reached by a well graded dirt road from the VLA or by paved road from the Rio Grande Valley.

2. BERNARDO, NM: This site is near Bernardo, New Mexico, between Socorro and Albuquerque near Interstate 25.

The thirteen station option uses a site near Roswell, New Mexico. The 14 station option uses sites in Holbrook, Arizona and Vaughn, New Mexico.

The u-v coverage provided by the 13 station array plus 4 elements of the VLA on scales of 500 km and 200 km are shown in Figures 1.3.*. The extra stations listed above are an extremely attractive addition that should be made at a future date.

It must be emphasized that the scientific capability they provide greatly extends that originally specified for the VLBA and is not necessary for the VLBA to be a valuable and capable instrument. The 14 station option fills the large percentage hole at about 200 km that is slightly offset from the east-west direction.

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64
DUSTY	33.62	107.65
BERNARDO	34.35	106.90
HOLBROOK	34.90	110.20
VAUGHN	34.60	105.20

Scale in km
(kilometers x 10^2)

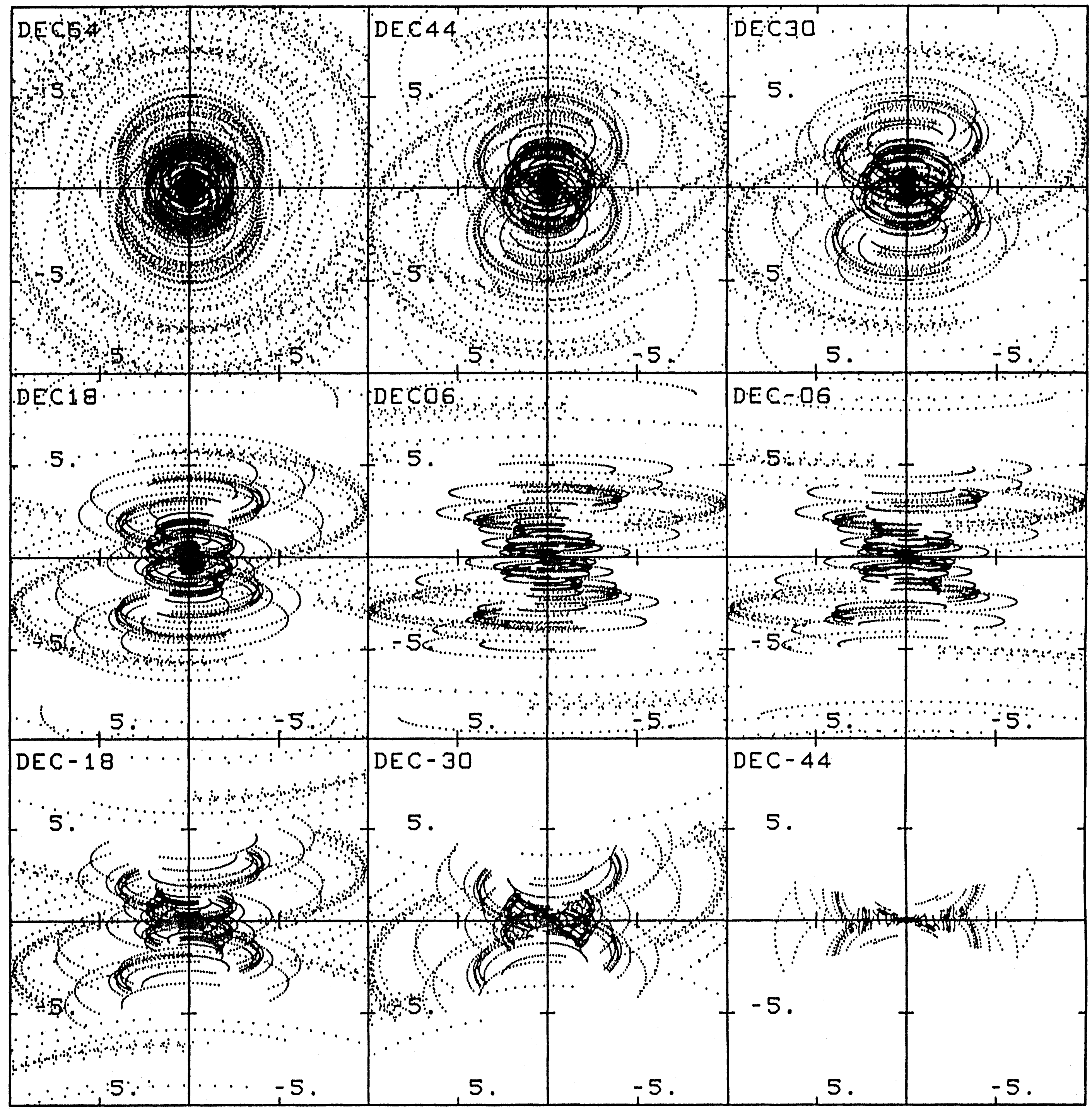


Figure 1.3a
1000 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64
DUSTY	33.62	107.65
BERNARDO	34.35	106.90
HOLBROOK	34.90	110.20
VAUGHN	34.60	105.20

Scale in km
(kilometers x 10^2)

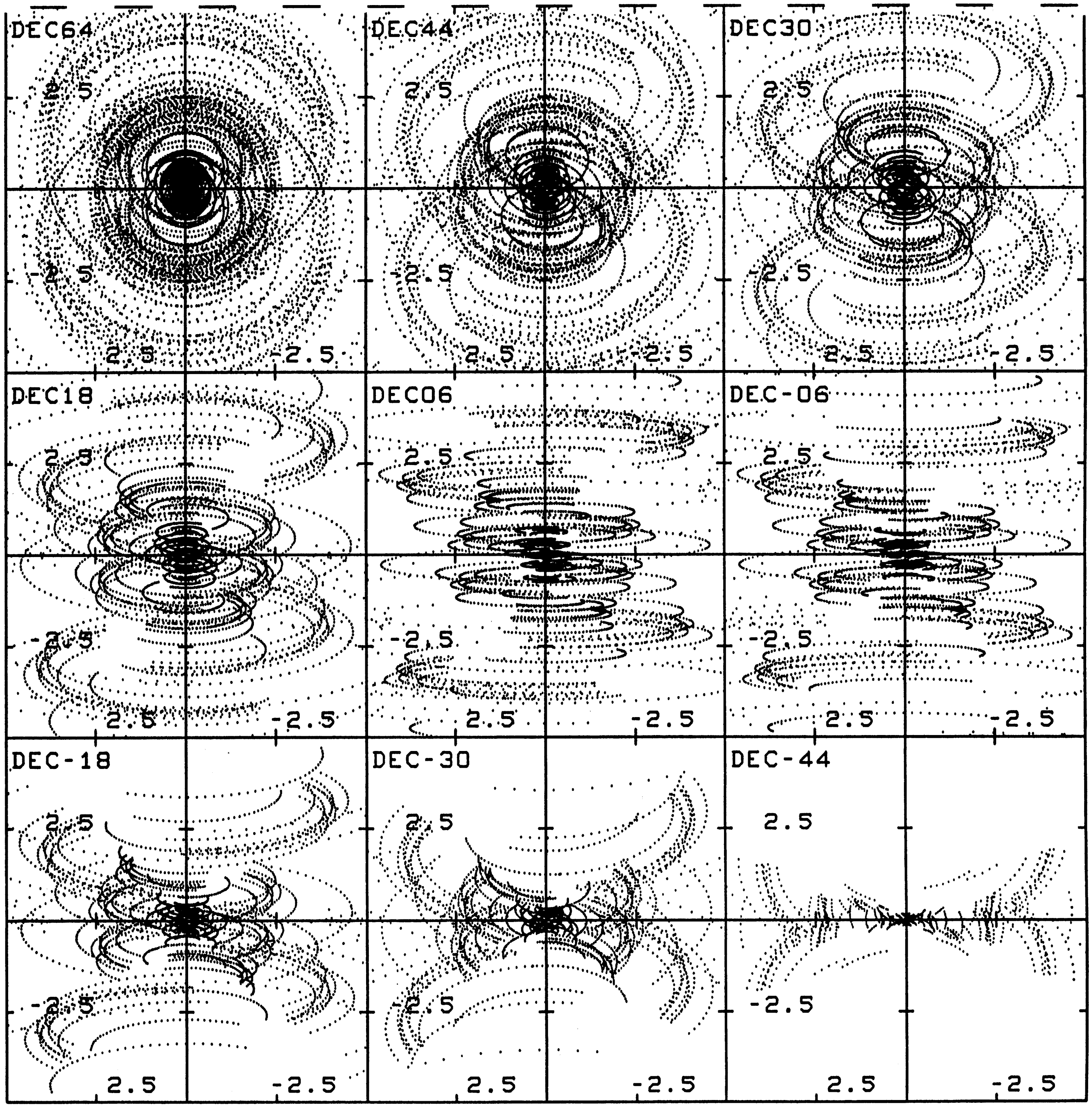


Figure 1.3b
500 km

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64
DUSTY	33.62	107.65
BERNARDO	34.35	106.90
HOLBROOK	34.90	110.20
VAUGHN	34.60	105.20

Scale in km
(kilometers x 10^1)

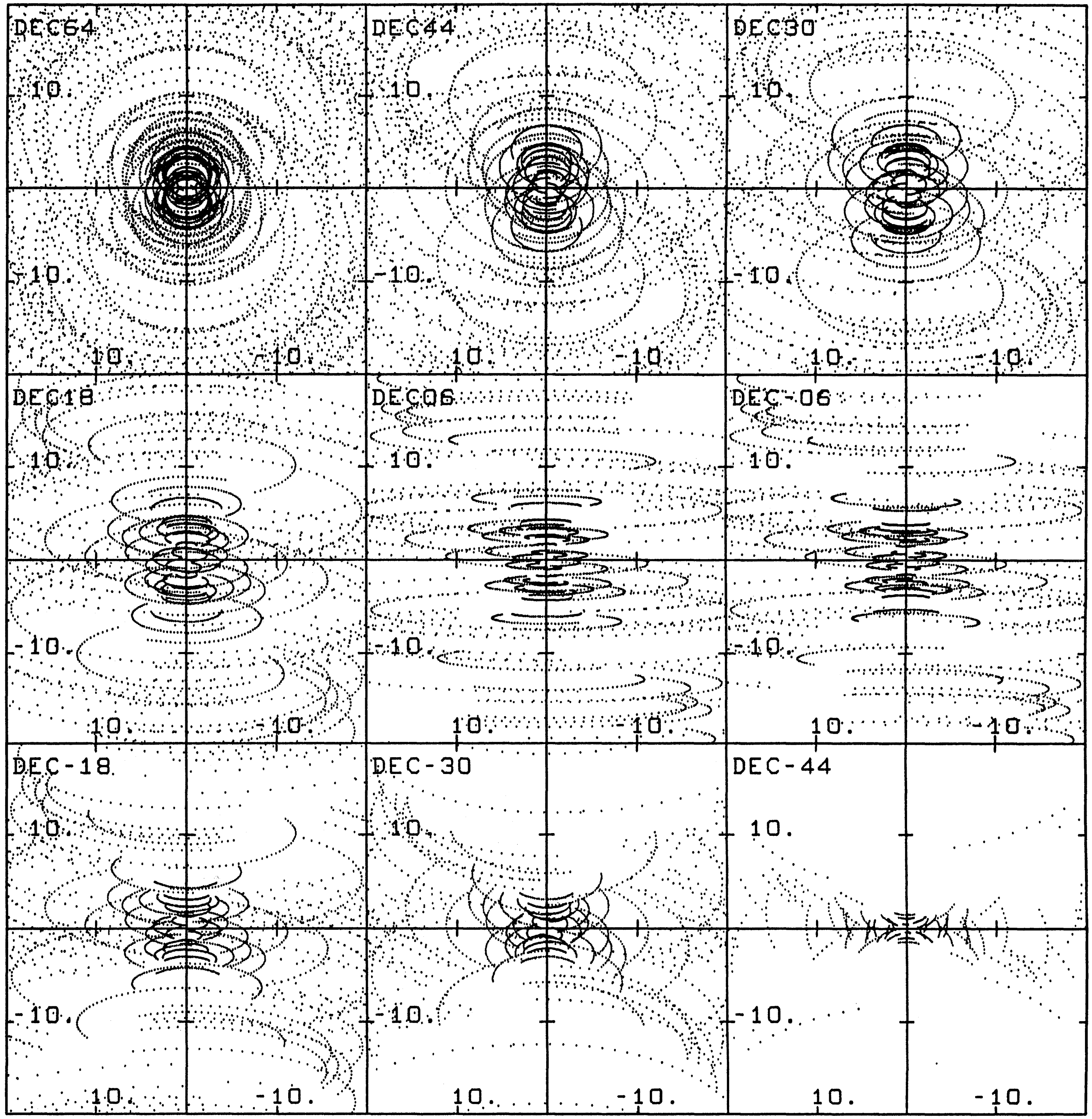


Figure 1.3c
200 km

One constraint placed on the configuration of the VLBA has been that all antennas be on United States territory. That constraint limits the coverage of north-south spacings at the low declinations to approximately that obtained by the final configuration. Another addition that might be made to the VLBA at some future date is an antenna in northern South America (for example, in Equador). The improved performance that such an antenna would provide for observations of sources at low declinations is very attractive. The uv coverage of the VLBA plus a station in Quito, Equador is shown in Figures 1.4.*. This addition would be independent of the 3 antenna addition for filling the hole between the VLA and the VLBA.

1.4 Configuration Selection Criteria

1.4.1 Meeting the Constraints

The configuration given above was derived using a combination of educated guesses and a systematic exploration of large numbers of possibilities using numerical quality measures. The large number of constraints, desired characteristics, and degrees of freedom in the problem made identification of a straight-forward method of finding arrays difficult, if not impossible.

The procedure used involved exploring the coverage provided by many general classes of configurations by inspecting plots of the u-v coverage such as those in Figure 1.2 and then measuring the relative performance of large numbers of variations within each of the promising classes. In this usage, a class of configurations is a group of configurations with sufficiently similar distributions of antennas that there is an identifiable, one-to-one correspondence between each element of one array and some element in each of the other arrays in the class. For example, all members of the class to which the final array belongs have a Northeast site, a Midwest site, a Northwest site, a California site, a Southern Texas site etc.

With the experience gained during the configuration search, it is clear why an array of the adopted class was chosen. Each of the sites is important for some special aspect of the coverage. Hawaii, along with the east coast and Puerto Rico provide the longest baselines possible in the U.S. Puerto Rico to New England provides the longest possible north-south baselines available without using Alaska. Alaska is so far north that it cannot see sources at the southern declinations where the north-south baseline is most important.

Intermediate length east-west baselines require stations near the east and west coasts. At least two such baselines are needed to avoid holes near zero declination. With New England already specified and the water vapor conditions so poor in the Southeast; the obvious way to get those baselines is with a site in Washington and one in California. Intermediate length north-south baselines are best obtained using a site in southern Texas but that station should not be too near the Gulf Coast where the water vapor content is high.

VLBA_MK	19.80	155.47
VLBA_OV	37.23	118.28
VLBA_BR	48.13	119.68
VLBA_KP	31.96	111.61
VLBA_PT	34.30	108.12
VLBA_LA	35.78	106.25
VLBA_FD	30.63	103.94
VLBA_NL	41.77	91.57
VLBA_HN	42.93	71.98
VLBA_SC	17.76	64.58
QUITO	-0.20	77.00

Scale in km
(kilometers x 10^3)

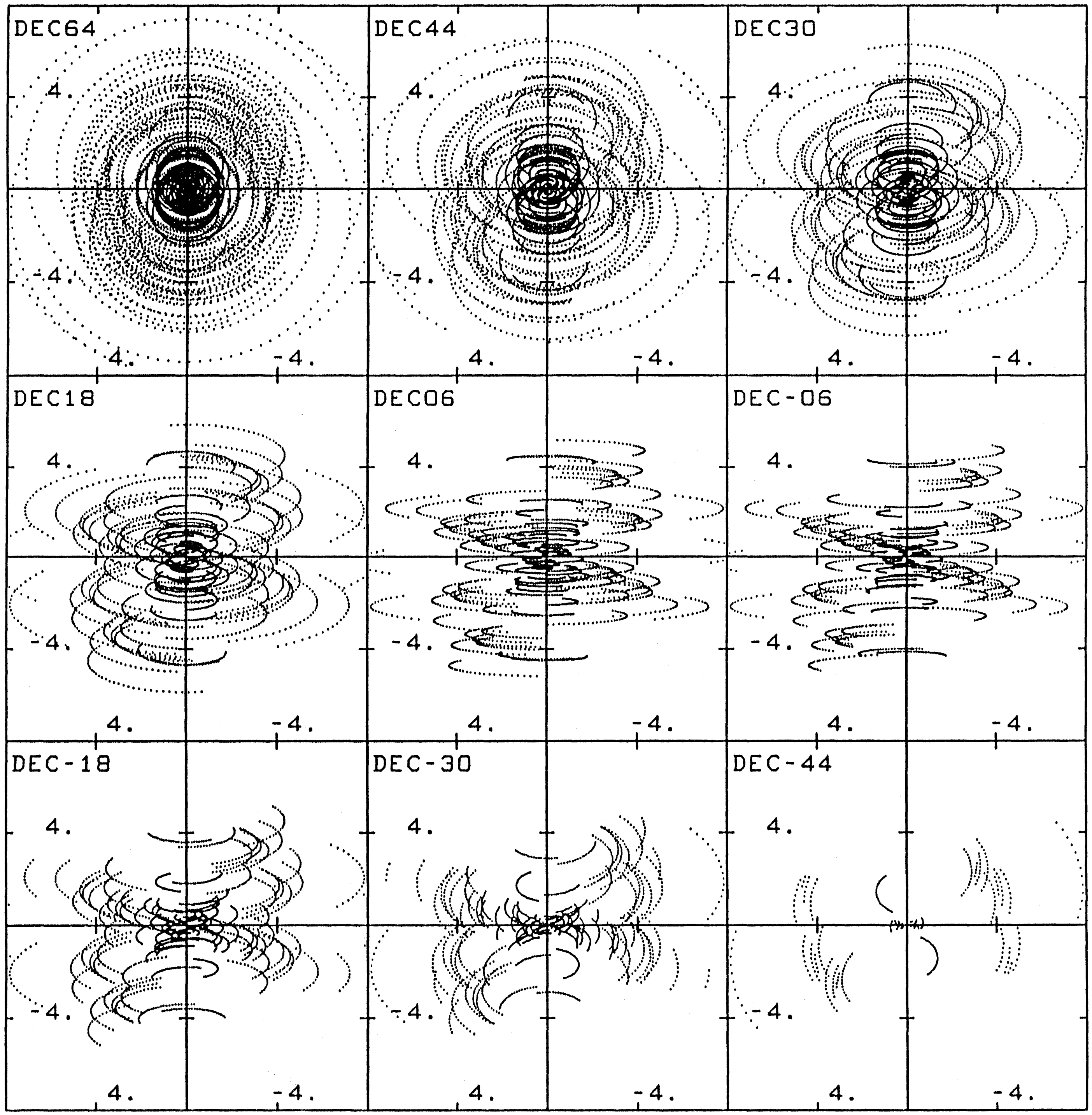


Figure 1.4
8000 km

The shortest baseline should be across the VLA as discussed earlier so two sites should be in New Mexico, within less than 200 km of the VLA. One of those two sites might as well be close enough to the VLA to constitute one of the VLA outriggers that have been discussed for many years. With the concentration of telescopes in the Southwest, there is a large hole between the Hawaii-New England baselines and the Hawaii-New Mexico baselines that must be filled with a Midwest site. One more site is needed to complete the coverage of short to intermediate length baselines. It should go somewhere in the Southwest although it is not tightly constrained from first principles.

In the end, the array was optimized to be a good 10 station array that is a subset of a good 13 station array that fills the gap between the VLA and the VLBA. To fill the gap, two additional sites close to the VLA plus one about 200 km away are needed. The three "VLA outrigger" antennas (one of which is among the original 10) should be about 50-70 km from the VLA in three different directions.

1.4.2 Quality Measures

Once a general class of configurations was identified by the criteria outlined above, numerical quality measures were used to search for the actual location of antenna sites. Such factors as ease of access, existing facilities, climate etc. were considered in choosing the sites to examine. A strong bias was given to sites with existing radio astronomy activity. In general, at least half of the sites can be picked on grounds other than coverage, as long as they are in the general regions specified by the requirements of the class. The rest of the sites can be adjusted to give performance almost indistinguishable from that of an array for which all sites were chosen purely for the coverage. This allows considerable freedom to use existing facilities.

Several quality measures were explored and used to varying degrees:

1.4.2.1 Dynamic Range.

Pseudo data is generated using the coverage that would be provided by the configuration under study if it were observing some model source. A clean map is made using that data and is compared with the original model. The dynamic range is the ratio of the peak on the map to the maximum difference between the map and the model. This method tests the mapping capability of the array but is somewhat sensitive to the model used and to the mapping methods used. (ref: CIT and NRAO Design Studies, Linfield, VLBA Memo No. 49)

1.4.2.2 Distance between Grid Points and Sampled Points.

This quality measure is based on measuring the distance from each point on a uniform grid in the u-v plane to the nearest point sampled by the array. An inverse radial weighting is applied to the points to emphasize the coverage on short spacings and the analysis is performed for a wide range of declinations. The method tests the uniformity of the coverage but is sensitive to edge effects and to the choice of the grid. (Ref: Mutel and Gaume, VLBA Memo 84)

1.4.2.3 Match of Density of Points to Desired Density.

This method is an analog of a statistical test known as the Cramervon Mises test. The test measures the discrepancy between the cumulative distribution function of the sampled points in the u-v plane and the desired distribution function. As with all tests, it is sensitive to the choice of the desired distribution function. (Ref: Schwab, VLBA Memo 100)

1.4.2.4 Number of Sampled cells in a Polar, Logarithmic Grid.

This method counts the number of sampled cells in a polar grid in which each cell has a radial width of some fixed percentage of the u-v distance. The count is made for several declinations, each representative of an equal fraction of the total sky, and summed (weighted so that all declinations are equally important) to produce an overall measure. It relies on the concept that, since all configurations give about the same total number of samples, an array with big holes will have more redundancy elsewhere and will receive a lower rating.

The polar, logarithmic grid was chosen because an array that gives uniform coverage on such a grid will give mapping capability that is independent of scale size within the limits imposed by the maximum and minimum baselines of the array. For 10 element arrays with a minimum spacing of 200 km, the number of sampled cells in a second, smaller grid with even radial spacings were counted and added (weighted) to the total quality figure. The second grid was needed to avoid problems in the inner regions where the cells in the main grid are small. The results from the method are sensitive to the choice of the sizes of the grid cells and to edge effects. (Ref: Walker, VLBA Memo No. 144)

The last of the above tests was the one most heavily used toward the end of the configuration search. It was originally designed as a first pass test to narrow down the field of good arrays and was coded to run nearly 100 times faster on the computer than the other methods. However the results were sufficiently good that the other tests were not used for the final selection. The program was coded so that many members of a given class of arrays could be tested easily. The user would specify several possible sites for each region required by the class and the program would test all possible combinations. The number of sites so tested was large but was still severely limited by the fact that many thousands of combinations are possible with only a few test sites in each region.

All of the quality measures generally agreed on the ranking of tested arrays and those rankings agreed with the impressions derived from examination of u-v plots (the method trusted most by the workers in the field). The final configuration is not necessarily the absolute best according to any given quality measure but it is among the top few for which measured differences are as much a result of details of the measuring methods as of real differences in coverage. It has the distinct advantage that it uses a large number of sites with good local support.

1.5 Remaining Tasks

The work on the configuration is essentially complete. Construction has begun or completed on the first seven sites. Access has been obtained on all but the Hawaii site, where the environmental approval procedure is moving on schedule. There will be more work ahead if a realistic possibility of adding more antennas appears.

SECTION 2

OBSERVING STATIONS

C. M. Wade

2.1 Specifications

2.1.1 Number of Stations

The VLBA comprises ten observing stations at widely separated locations, and an Array Operations Center in Socorro. The AOC is described elsewhere in this book.

2.1.2 Siting of Observing Stations

All stations are on United States territory, and placed to optimize UV coverage while using existing radio astronomical facilities where possible, as described in the configuration chapter. The exact locations follow criteria described in Section 2.1.3.

2.1.2.1 Rough Station Locations

In planned order of construction, the general locations of the ten observing stations, and their two letter site identification abbreviations are:

1.	Pie Town, New Mexico	PT
2.	Kitt Peak, Arizona	KP
3.	Los Alamos, New Mexico	LA
4.	Fort Davis, Texas	FD
5.	North Liberty, Iowa	NL
6.	Brewster, Washington	BR
7.	Owens Valley, California	OV
8.	Saint Croix, Virgin Islands	SC
9.	Mauna Kea, Hawaii	MK
10.	Hancock, New Hampshire	HN

2.1.2.2 Exact Locations, Stations 1 - 8

Accurate geodetic coordinates for the first eight stations have been established by survey:

Station	N. Latitude	W. Longitude	Elev.(m)
Pie Town, NM	34 deg 18'03.61"	108 deg 07'07.24"	2371
Kitt Peak, AZ	31 deg 57'22.39"	111 deg 36'42.26"	1916
Los Alamos, NM	35 deg 46'30.33"	106 deg 14'42.01"	1967
Fort Davis, TX	30 deg 38'05.63"	103 deg 56'39.13"	1615
North Liberty, IA	41 deg 46'17.03"	91 deg 34'26.35"	241
Brewster, WA	48 deg 07'52.80"	119 deg 40'55.34"	255
Owens Valley, CA	37 deg 13'54.19"	118 deg 16'33.98"	1207
Saint Croix, VI	17 deg 45'30.57"	64 deg 35'02.61"	16
Hancock, NH	42 deg 56'00.96"	71 deg 59'11.69"	309

2.1.2.3 Approximate Location, Station 9

The Mauna Kea site has not yet been surveyed. Its coordinates are approximately:

Station	N. Latitude	W. Longitude	Elev.(m)
Mauna Kea, HI	19 deg 48'	155 deg 28'	3725

2.1.3 Requirements of a Typical Station

The considerations described below guided the siting of the stations, within the tolerances allowed by configuration requirements. Details were adapted to local conditions when necessary.

2.1.3.1 Land Area

Each station requires a minimum fenced area measuring 150 ft x 250 ft (0.86 acres). Additional land may be needed outside the fence for site protection, drainage control, access, etc.

2.1.3.2 Control Building

Each station requires a control building.

2.1.3.2.1 Function

The building houses (1) the IF processing, digitizing, and recording systems; (2) micro-computer to control and monitor the entire site and communicate with the array control computer in Socorro; (3) radiometers; (4) hydrogen maser clock system; (5) magnetic tape storage space; (6) building environmental and electrical power system; (7) storage area for spare parts and components; (8) sanitary facilities; and (9) shop space.

2.1.3.2.2 Area

An inside area approximately 43 x 25 ft (1075 sq ft), divided into five rooms, is needed for the items listed above. Fig 2.1 illustrates the general arrangement.

2.1.3.2.3 Specifications

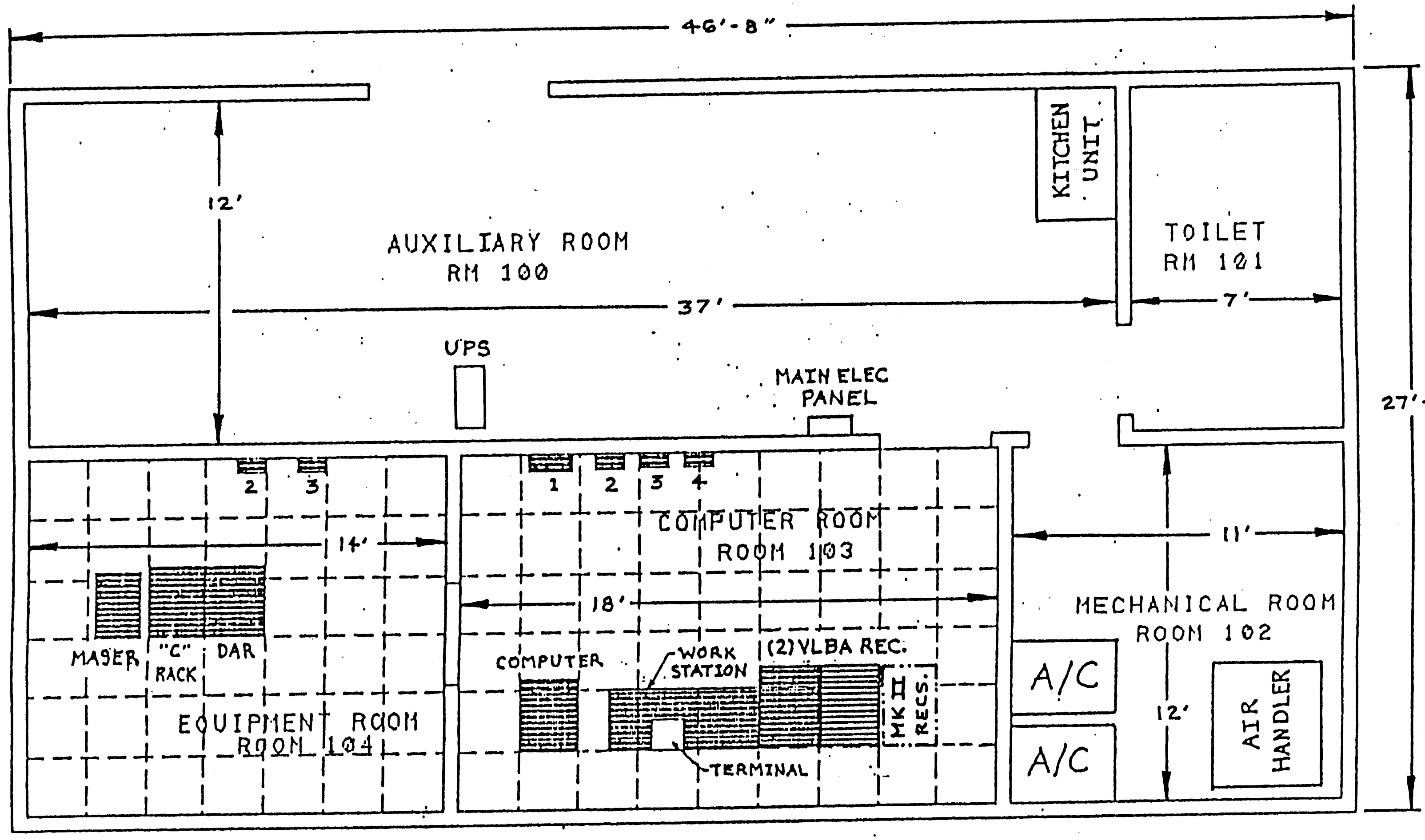
The control building is a windowless energy-efficient, single-story masonry structure. Security doors deter vandalism. The environmental control system maintains temperature at 25 (+/- 1) deg C at 40% (+/- 10%) relative humidity. The exterior walls, ceiling, and some interior walls contain a grounded metal screen to shield against radio frequency interference. "Computer room flooring" is used in the equipment and control rooms. The building meets applicable building and safety codes. Automatic burglar and fire alarms are provided as needed.

2.1.3.3 Access

The stations are sited as conveniently as feasible to daily air service for rapid transportation of tapes, parts, and personnel to and from the central facility. Stations are as near as is reasonable to roads of a quality and status that assures ready access under all weather conditions.

2.1.3.4 Weather

Sites are chosen to minimize problems due to wind, snow, ice, and water vapor.



1 - STATION J BOX
2 - CB PANEL
3 - UPS CB PANEL
4 - TELEPHONE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES +/- N/A
3 PLACE DECIMALS (.XXX) +/- N/A
2 PLACE DECIMALS (.XX) +/- N/A
FRACTIONS (1/x) +/- N/A

MATERIAL: N/A

PROJECT: VLBA 25 METER ANTENNA

TITLE: STATION BUILDING FLOORPLAN

NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NM 87801

DRAWN BY: OTY DATE
DESIGNED BY: OTY DATE
APPROVED BY DATE

SHEET NUMBER 1 OF DRAWING NUMBER REV. SCALE

Fig. 2.1

NOTE: ROOM DIM'S ARE APPOX.

2.1.3.5 Utilities

Reliable commercial electric power and telephone service are necessary. The expected power demand is 100 to 125 kW at 120/208 volts, on a 3 phase, 4 wire system. An uninterruptable power system supplies "clean" power to equipment requiring it. Four telephone lines of digital transmission grade are needed. Where existing sewer and water systems are not accessible, a septic system and well are installed. The approach road and the parking area are of thoroughly compacted gravel. Drainage is controlled by grading and culverts. An auxiliary generator (75 kVA capacity) will supply emergency power during commercial outages.

2.1.3.6 RFI Protection

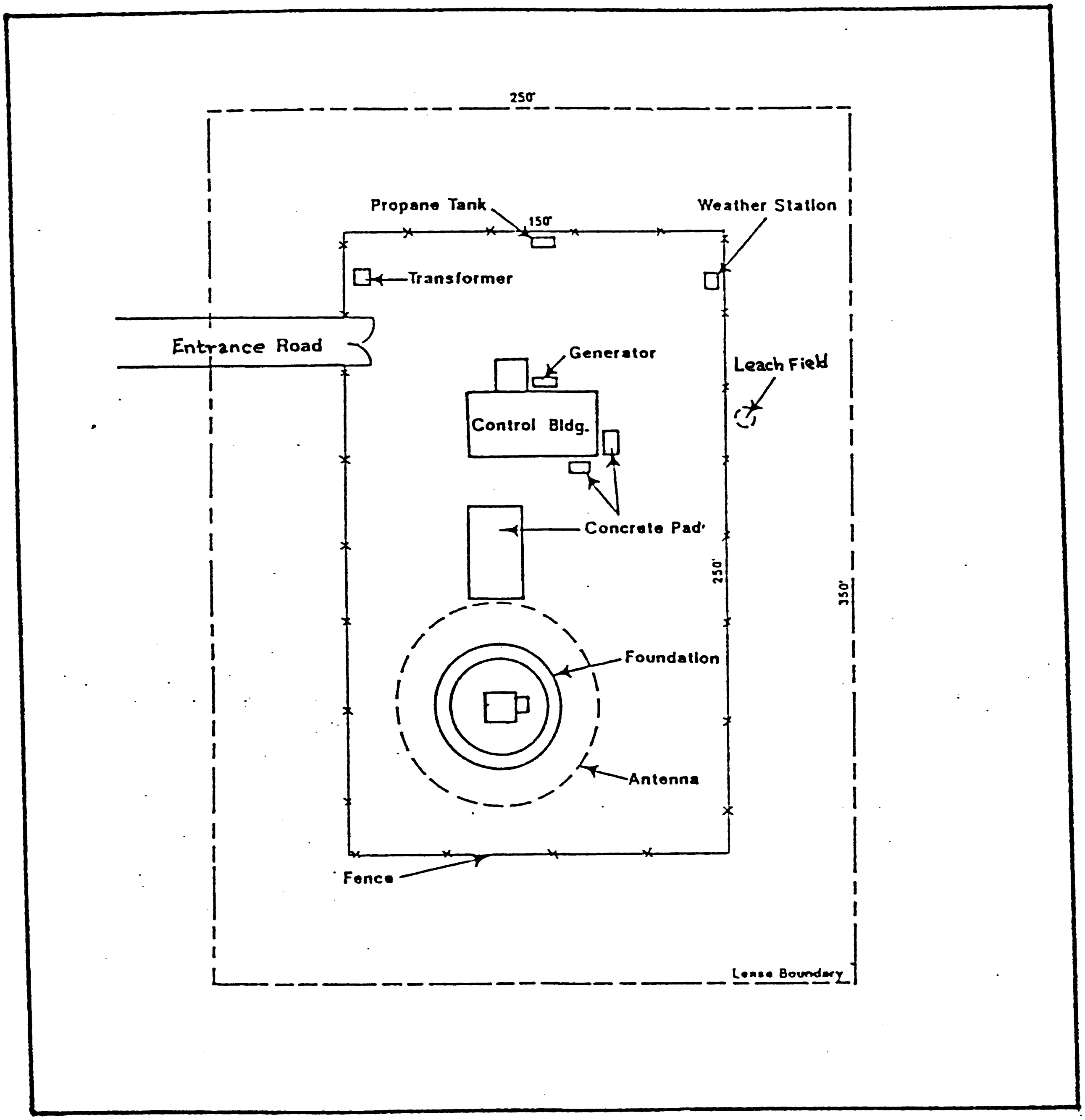
Stations are sited to minimize interference from transmitters, power lines, and industrial activities.

2.1.3.7 Terrain

Stations are situated to minimize the fraction of the horizon which rises above 0 degrees elevation.

2.1.4 Typical Station Plan

Fig. 2.2 shows a generic observing station layout. The control building is approximately 100 feet from the center of the antenna foundation.



VLBA Site Plan

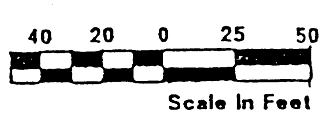


FIGURE 2.2.

SECTION 3

THE ANTENNA ELEMENTS

L.J. King and L. Serna

3.1 Specifications

3.1.1 Mechanical Parameters.

Diameter:	25 meters
Focal Length:	8.85 meters
f/D:	0.354
Elev.Sky Coverage:	+0 deg to 125 deg;
Azimuth Sky Coverage:	-270 deg to +270 deg (zero south)
Operational Frequencies:	Cassegrain (1.5 GHz to 43 GHz) Prime Focus (610 MHz, 330 Mhz)
Reflector Surface:	Shaped parabola of revolution
Counterbalancing:	Tail heavy by 15,000 lb.ft.
Drive Requirement:	30 deg/min in elevation 90 deg/min in azimuth Accel. to full speed in 2 sec.

3.1.2 Operating Conditions.

	Precision (Primary)	Normal (Secondary)	Slew to Stow	Slew dump Snow	Survival in Stow
Wind,m/sec	6	18	27	11	50
Gusts,m/sec	1	2.5	--	--	--
Snow	--	--	--	4 psf	20 psf
or Ice	--	--	1 cm	--	1 cm
Temp Range,degC	-18/32	-30/40	--	--	--
Temp.Change	2 degC/hr	--	--	--	--
Temp.Diff.	3.5 DegC	--	--	--	--
Rain	--	5 cm/hr	--	--	--
Rel. Humidity	--	0%-99%	--	--	--

3.1.3 Surface RMS accuracy at precision operation condition (Surface to be set at 50 deg elevation):

A.	Surface Panels:		
	Manufacturing	0.125 mm	
	Gravity	0.075 mm	
	Temperature	0.050 mm	
	Wind	0.040 mm	
	Subtotal RSS		0.160 mm
B.	Measuring and Setting:		
	Subtotal RSS		0.125 mm
C.	Reflector Structure:		
	Gravity	0.140 mm	
	Temperature	0.125 mm	
	Wind	0.055 mm	
	Subtotal RSS		0.196 mm
	Total Surface RSS		0.282 mm

3.1.4 Pointing Errors at precision operation condition:

Repeatable rms pointing errors,		
	total	3 arc min.
	elev struc (gravity only)	1 arc min.
Non-repeatable rms pointing errors,		
	time constant < 1 min.	8 arc sec
	time constant > 1 min.	14 arc sec

3.1.5 Apex deflections due to gravity:

Translation	2.5 mm
Rotation (elevation axis)	4 arc min
(collimation axis)	1 arc min

3.1.6 Blockage.

Geometric blockage by feedlegs, apex, subreflector, etc. will be 5.8% of the 25m aperture area.

3.2 Description.

The VLBA antenna is based on a design developed from the continuing research and study of the NRAO Engineering Division. Major dimensions are given in Figure 3.1.

3.2.1 The apex. The donut-shaped apex structure is supported by four feedlegs of 11" by 16" cross-sections. The focus-rotation mount is supported from the interior of the donut ring.

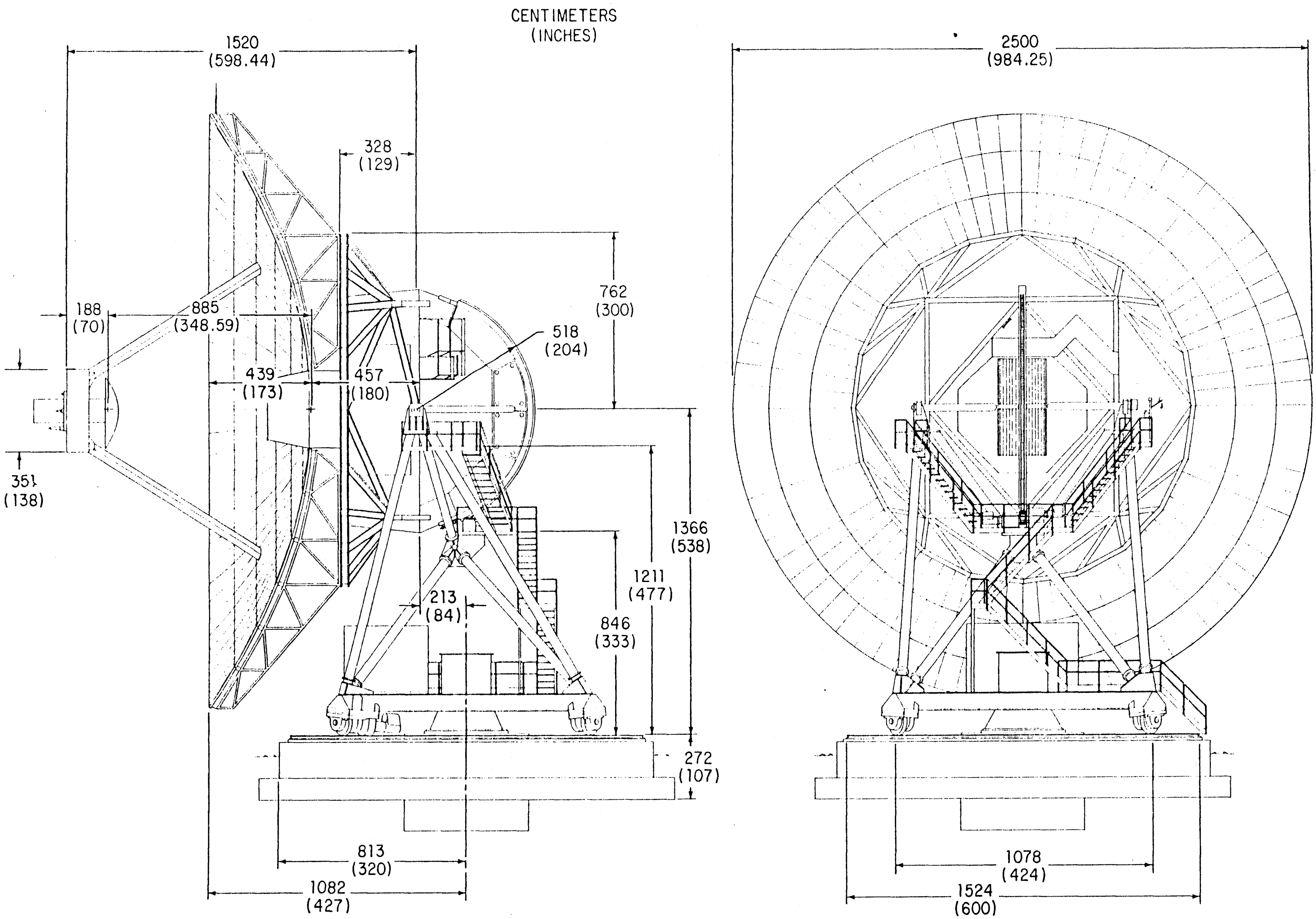


Figure 3.1 VLBA Antenna

3.2.2 The focus-rotation mount (FRM). The FRM provides two motions (in and about the collimation axis) for focusing and feed selecting functions of the antenna. The offset subreflector and the prime focus feeds are supported by the FRM by means of a cylindrical tube.

3.2.3 The reflector. The reflector back-up structure is a conventional radial-rib and circular-beam design. It supports 200 surface panels of no larger than 1.8m by 2.1m in size arranged in six concentric tiers. Each panel has four supports and is made of doubly curved skin rivited to "Z" stiffeners of all aluminum material.

3.2.4 The cone. The upside-down cone-shaped structure is the center of the VLBA antenna design. It provides the following:

(1) 20 equal rigidity supports for the reflector.
(2) four supporting trusses for the feedlegs.
(3) interfacing with the counterweight and the elevation bullgear. (The elevation limit switches are mounted on the bullgear sector support.)
(4) housing for the vertex equipment room and feed cone structure.

3.2.5 The elevation shaft and bearings. The elevation bearings support the cone structure through the elevation shaft. The angle encoding box and the servo data box are mounted at the ends of the shaft for the elevation control of the antenna.

3.2.6 The pedestal. The pedestal is a tower structure which supports the elevation structure on two bearings 9m apart. It is supported by four trucks on a 15m diameter rail, two of which are powered by the azimuth drives. The lower equipment room and the cryogenic compressor platform are located on the large beams at the ground level of the pedestal.

The azimuth cable wrap is located at the lower center. The limit switches are mounted on the lower ring of 0.9m in diameter. The azimuth angle encoding box is mounted to the top hanger of the wrap, and connected by a shaft to the center of the foundation.

Stairs and platforms are designed for easy accesses to the reflector surface, the vertex equipment room, the elevation bearing and drive areas.

The vertical axis of the pedestal is the antenna azimuth axis which is offset by 1.2m from the intersecting point of the elevation and collimation axes.

3.2.7 Foundation. The circular foundation under the rail has an inverted-T cross section. Four radial beams are connected to the center of the foundation for pintle bearing support.

3.2.8 Servo System.

The antenna control system consists of a number of components mounted in various locations about the antenna complex. The central assembly of the system is the 93C-15 Antenna Control Unit (ACU) which houses the electronics that generate motor drive commands in all modes of operation. Motor commands are produced by the ACU as a result of input commands from the front panel rate controls (manual mode), the position commands (position designate and manual modes), or computer commands generated by the host computer. The control system is a closed loop system consisting of the 93C-15 Antenna Control Unit, Drive Cabinet, Drive Motors, Tachometer and Encoders. System operation is achieved at the ACU front panel, over the supervisory computer link or by the portable control unit.

The related equipment connected to the ACU is as follows:

AZ & EL Data Gearboxes - Provide synchro antenna position information for each axis to the ACU. In this system they are to be used primarily as a backup in case the main inductosyn position indicators fail.

AZ & EL Inductosyn Encoders - Provide precise antenna position information for each axis to the Data Converter Unit.

Data Converter Unit - Transforms the Inductosyn Encoder position information to parallel binary for the ACU. Resolution is 22 bits angular data. (.31 Arc-seconds/lsb).23 bits in AZ (MSB=360 deg.) 22 bits in EL (MSB=180 deg.). Min. accuracy of 2.16 arc-sec peak and 1.5 arc-sec RSS, with repeatability + or - 4 lsb (.31 arc-sec.), and AZ,EL interchangeability of + or - 4 lsb's. Natural binary with internal self checks on electronics unit.

Supervisory computer - Connects to the ACU through an interface board (AUI M&C) placed inside the ACU. The Supervisory computer will monitor and control the ACU when the system is in computer control.

Auto Stow Interlocks - These are independent status signals provided to the ACU that signal when the antenna must be driven to the stow position in Computer Mode only. Conditions for automatic stowing of antenna are:

1) Winds greater than 60 mph
2) Single motor operation and winds greater than 30 mph
3) Outdoor temperature less than -20 deg. C
4) Inductosyn Encoder fault
5) Loss of Azimuth drive
6) Loss of computer link (10 min.)
7) Emergency Power

Drive Cabinet - The Drive Cabinet connects to the ACU obtaining axis enables and rate commands from the ACU. The ACU obtains binary status information and analog rate feedback information from the Drive Cabinet.

AZ & EL Motors - Two DC motors per axis. Straight shunt field with armature controlled speed and torque. Motors have cooling blowers, brakes, and tachometers.

AZ & EL Travel Limit Switches - These switches located on both axes will ensure that the antenna will not exceed the point it was designed to travel. Three different sets of limits are used on each axis of the antenna to guarantee it will not travel past its limit.

Emergency Switches - These switches are located throughout the antenna and are used as antenna movement stops when pressed in case of emergency.

EL Stow Pin Switches - Located on the stow pin cradle and stow pin location, providing stow pin status and interlock to the ACU. (Manually operated stow pin.)

Warning Horn - Relay contact closure switching 120 VAC in the Drive Cabinet to power a horn as a warning when antenna motion is pending. This warning lasts 5 sec. prior to the drives going active.

3.3 Antenna Contracts

The antenna elements have been contracted to Radiation Systems, Inc. (RSi) in two parts:

Subcontract No. VLBA-100, "Design, Manufacture, and Transportation of Ten Radio Telescope Antennas"

Subcontract No. VLBA-101, "Assembly and Testing of Ten Radio Telescope Antennas"

Three Divisions of RSi are involved with the project:

(1) Universal Antennas Div., Richardson, TX.
----- Design, Assembly, and Testing.
(2) Mexia Fabaricators Div., Wortham, TX.
----- Manufacturing.
(3) Technical Products Div., Sterling, VA.
----- Panel Design and Manufacturing.

3.4 Progress Summary

3.4.1 Antenna Design has been completed.

3.4.2 Antenna Fabrication.

The structures for the first 5 antennas have been fabricated and pre-assembled in Mexia Fabricators. Fabrication for #7 antenna will be completed in October, 1988, and #8 in February, 1989.

3.4.3 Surface Panels. The panel manufacturing and acceptance tests for all ten antennas has been completed. The first four sets of panels have been installed on the antennas.

3.4.4 Antenna Installation Schedule

Antenna installation starting/completion schedule:

1.	PT	-----	Sept.'86/ Jun.'87.	(done)
2.	KP	-----	Jan. '87/ Oct.'87.	(done)
3.	LA	-----	Jul. '87/ Apr.'88.	(done)
4.	FD	-----	Dec. '87/ Jun.'88.	(done)
5.	NL	-----	May '88/ Oct.'88.	(85% done)
6.	BR	-----	Sept.'88/ Mar.'89.	
7.	OV	-----	Jan. '89/ Jun.'89.	
8.	SC	-----	May '89/ Nov.'89.	
9.	MK	-----	Oct. '89/ Mar.'90.	
10.	HN	-----	Feb. '90/ Jul.'90.	

3.4.5 Results for the first four antennas.

	PT	KP	LA	FD
Surf. Plate Manuf. rms	.117 mm	.112 mm	.107mm	.107mm
Setting rms	.097	.107	.091	.075
Natural Frequencies, AZ.	2.19 Hz	2.22 Hz	2.20 Hz	2.22 Hz
EL.	2.67	2.64	2.65	2.60 Hz
Az. Rail Waviness *	20 arcsec	26 arcsec	28 arcsec	16arcsec*

* Note: Rail surfaces will be corrected to meet 10 arcsec specification.

SECTION 4

CONTROL AND MONITORING

B. G. Clark

4.1 Specifications

Monitor and Control Bus: 55001N001

Standard Interface: 55001N001A

4.2 Description

4.2.1 Concept

The overall concept of the Control and Monitor System includes a central control computer linked by telephone lines to a small computer at each VLBA station, which in turn communicates digitally with all of the observing equipment at that station. Commands to the equipment are

obviously needed to set it into the state required for a particular observation. Monitor information serves several purposes:

- verifying that the equipment is in the desired state and is functioning correctly;

- measuring parameters which must be known at correlation and used during post processing of the data tapes, such as receiver gains and phase calibrator line lengths;

- allowing detailed diagnosis of failures from the control center, where the most expert technical personnel will be located, thus minimizing travel requirements and downtime; and

- compiling a historical record (log) of the equipment state, in order to allow post-facto flagging of data, analysis of failures (especially intermittent ones), and studies of equipment performance.

Particularly because of the last two requirements, designers of antenna-based equipment will be encouraged to provide signals to the monitor system well beyond those needed to verify normal operation. It turns out that this will not result in very high data rates.

As an additional overall check on performance, small amounts of received signal data will be transmitted to the control center via the telephone link for crosscorrelation in near real-time.

A major consideration in the system design is reliability. It seems likely that the communication process will be one of the less reliable elements of the system, and it is a process for which we can make fairly easy provisions for failure. The primary provision is that each station will be made, as much as possible, autonomous, capable of running many hours without communication with Socorro (although it is not envisioned that this shall be any sort of normal or even common mode). Control information (in the form of a text file provided by the observer) will be sent well in advance. Monitor data will be buffered in the computer main memory for a few minutes, and then, if not sendable by real-time communications, written to disk, for later transmission.

The physical form of the interconnection between Socorro and the various stations is still being studied. The possibilities being considered are:

- Leased permanent telephone lines.
- Public data networks.
- VSAT (small satelite dishes and a bit of bandwidth on a transponder).
- Dial-up service on a rotating call basis.

The first three are comparable in cost, with the differences in cost dominated by details about how we will use the communications that we must yet learn from experience. The fourth is rather less expnsive, because the system spends most of its time disconnected from the telephone system, especially if we invest in high speed modems. However, it leads to a rather different flavor of operation. One would have a timescale of minutes between the polling of each station, instead of seconds, as the other methods have, and so global displays at the operator's console would have a leisurely rate of update with which NRAO has no experience.

Strong efforts are being made to make the user interfaces as uniform as possible for the real-time VLBA functions, the real-time VLA functions, and the correlator control functions.

4.2.2. Central Control and Monitoring of the Array

In normal operation, the Array will be controlled from a previously prepared schedule and will require no direct intervention from an operator; the array operator's main responsibility will be to ensure that the correct schedules are operational and to monitor the performance. However, the array operator will be able to send commands directly to individual antennas or the whole array at any time.

Although from one point of view, the system will appear as an array, from another, the antennas will simply be working according to a schedule sent to them by the array control computer, and each antenna will require no knowledge of what any other antenna is doing. Therefore, the array operator can control the division of the array into subarrays in a very simple manner, just by controlling the communication of the schedule sent to the stations. Subarraying in the correlator is a much less simple matter, and careful records must be kept in the logs, so that correlation between a given pair is done when, and only when, it is sensible to do so.

4.2.1 Array Control Computer Tasks

SENDER/RECEIVERS. These programs match the programs which run at the station computers and accomplish the transmission of data. Depending on which particular program, they would be initiated on a regular cycle or by the operator. There are two such programs currently functional: the SCHED/TALK pair, which sends the schedule to the station computers; and the PHONE/USEPHONE pair, which sends monitor logging data from the station computer to the array control computer.

MONITOR DATABASE FILLER. This program puts monitor data sent from the various stations into a conveniently accessible disk data base for access by the array maintenance engineers.

MONITOR DATABASE PRUNER. Because of the lack of the capability of putting a chart recorder on a monitor point directly that we have, and use, at the VLA, we will make a very much denser monitor data base for the VLBA than is done for the VLA, an order of magnitude more voluminous. This dense database would be kept only for a couple of days. A roughly VLA style monitor database would then be made by pruning the original down to a manageable size.

ARRAY LOG WRITER. Additional data, other than the monitor information, is inserted in the monitor data stream, for the use of the correlator control programs and other purposes. This data includes all of the control schedule sent to the stations.

MONITOR DATA PLOTTER/LISTER. Equivalent to the VLA programs Monplt and Monlst. These programs would have access to any material stored in the array database. As well as running on the array control computer, they will be accessible by remote login to the station computers.

REAL TIME FRINGE CHECK. Receives data from the fringe check buffers from the array and does the correlation. On a MicroVAX this program would probably require several seconds per baseline and per lag. This is much less than the data transmission time, and poses no real problem, unless we lose a station and have to go hunting for it over many tens of lags, or unless we decide we want to do this on such weak sources that all baselines must be processed and global fringe fitting done. The output of this program would be stored in the array database.

OBSERVATION PLANNING AID/OBSERVATION REQUEST GENERATOR. The paradigm for the functionality of this program is the VLA program OBSERV. It is clear that additional auxiliary functions will be needed, such as display of rise/set times at various stations, (u,v) tracks, etc. A single dish scheduling program is also being writen at Greenbank (CAESAR). A resemblance to this program is also desired, for an astronomer interface.

TAPE INVENTORY. This program will keep track of all movements of tapes between the remote stations and the processors, and maintain statistics on tape usage and tape quality.

MAINTENANCE RECORDS. A database must be kept of maintenance done in order to find the weak links in the system that need further design work. In such a far-flung system as the VLBA, it may well be profitable also to automate the spare parts inventory, so that a needed spare part can be located quickly or automatic reminders to ship spare parts may be generated.

It could be noted that several of the above (but not, we have concluded, the monitor database proper) can be conveniently implemented with a general database system using a database query language.

4.2.3 Station Computer Tasks

DEVICE CONTROL PROGRAMS. These are the equivalent of the VLA Modcomp DMT overlays. They will, for the most part, execute in the station computer, but there is essentially transparent access from terminals on the array control computer. Although most of these programs execute in the station computer, there will be others of very similar appearance that execute in the array control computer, that deal with functions involving more than one station.

DATA FLAGGER (task name FLAGER). This will automatically set three flags - antenna off source, subreflector not set, and LO chain malfunction - based on the monitor data. These bits will eventually become part of the array database, and inform the correlator computer systems that the associated data are invalid.

MONITOR DATA CHECKER (task name CHECKER). This program will notice out-of-range monitor points and call them to the attention of the array operator. At the VLA, this program and the above are combined into a single package. The advantages of this have been less than expected, and do not, for instance, constitute a constraint that the programs must run in the same computer.

THE ANTENNA DRIVER (taskname TIC). This program sends az-el to the antenna controller at a 21.3Hz rate. The VLA uses a linear extrapolation for ten seconds, with the full spherical triangle solved only every 10 seconds. For the VLBA antenna, the spherical triangle is solved at the full 20Hz rate. This eliminates one level of tasking and the concomitant handshaking. The price is about twenty percent of the CPU, for a Motorola 68010 programed in Alcyon C.

THE NEW SOURCE DESCRIPTOR EXECUTOR (taskname TOC). This program is responsible for switching between two observation control blocks. The program would primarily set all of the receiver switches to the correct position.

NEW SOURCE ORGANIZER (taskname LDSCHED). The observation requests are sent as text, rather than binary. In fact the text string is sufficiently powerful and convenient that one can actually use this language for scheduling, instead of the full astronomer interface program. LDSCHED converts this text string into the binaries more convenient for the actual observing programs. It also does precession from the J2000 coordinate system.

MONITOR DATA LOGGER (taskname LOGER). This program samples the monitor data image at appropriate intervals and stores it into a buffer, with appropriate identifying information, still in the station computer. If the buffer is not emptied by the real-time communitions, it activates another program which writes the buffer to disk for future transmission by another mechanism.

TAPE SYSTEM CONTROLLER. This program will do the bookkeeping about how much tape is available, when to switch tapes with minimum disruption, and generally supplies any information that the tape subsystem needs.

DATA SENDER/RECEIVERS. These programs are discussed with their MicroVAX partners above.

4.2.4 Hardware

The array control computer is a DEC MicroVAX II computer running the VMS operating system. A fairly large memory, nine megabytes, is on the system. The main peripherals include two 1600/6250 bpi tape drives, a single drive of 450 Mbytes of disk memory (later to be expanded to a second drive when appreciable amounts of monitor logging data appear on the system), a laser printer, and a console printers and a number of CRT terminals. When several stations are ready to be controlled from Socorro, and when the appropriate software system is in place, a hardware/firmware multiplexor system will be added. Hardcopy graphics are needed on this system, and will be provided through the laser printer output device.

It is necessary to have some sort of backup for the array control computer. It may well be possible to have this by arranging to use one of the post-processing computers or the correlator control computer as a backup, if the software and communications systems are compatible. If not, it may be necessary to have redundant devices to provide the required backup.

The station computers are Motorola 68010 microprocessors. A second Motorola 68010 is used in a dedicated coprocessor configuration to move the fast serial Monitor/Control Bus intrastation communications.

4.2.5 Communication

As discussed above, several options are being considered for the implementation of the communications hardware. A final decision is being reserved until we begin to accumulate some operating experience with the array. The current pricing of communication links is such that conventional dialup lines, with long phone calls of many hours duration, remains economically competitive with the other options until the array is in operation more than one third of the time, which will not occur until after 1990.

In addition to whatever hardware we eventually provide as the primary system, we propose to have a dial-up line available at each station as a backup. In fact, the current dial-up system of communicating with the sites may be regarded as an early implementation of the backup system. But, even with a backup system, we should continue to assume that occasional communication outages will occur, because most of the stations are at remote sites, and experience at similar locations has shown that a loss of communication often involves all lines to the site.

The decision has been made to run a private network with the X.25 protocol (more elegant protocols appear not to be available for the Motorola station computers).

4.2.6 Control and Monitoring At Each Station

All equipment at each station is connected to a common digital bus, over which control and monitor signals are sent in a simple serial format. The system has sufficient capacity not only to handle normal operation, to support remote diagnosis of faults when they occur, to support special fast monitoring programs when needed to investigate phenomena that occur on short timescales, and still provides a substantial reserve for future expansion.

It turns out that the data rates required for routine control and monitoring are extremely modest, both within the station and between the station and the control center. This is because very little equipment needs to be commanded more often than once per source change (normally several minutes), and because quality control requires status checking no more often than once per integrating period (normally 2 sec or more). Within the station, the highest data rate is required for commands to the antenna servo, whose azimuth and elevation must be updated about twenty times per second. To reduce the data rate on the communication link, we require that the conversion from RA-DEC to AZ-EL coordinates be done at each station, so only the former need be sent.

The communication between the station computer and all station equipment is by means of a fast serial communication bus. The bus protocol and electrical properties are specified in specification 55.001N001. The bus protocol specifies two fifteen bit address spaces, one for commands and one for monitor data. The addresses to which a given interface responds will be determined by that interface. No assumption is made that there is a one-to-one relationship between "interfaces" and "devices"; a given "device" may be monitored or controlled by more than one interface, or a given interface may control more than one device.

Most of the equipment will be able to interface to the bus through a "standard interface," which is a microprocessor based device occupying a PC board approximately 4" by 6" in size. The standard interface will provide analog to digital conversion, some analog multiplexing, address decoding, and error checking. Devices for which the standard dataset is not appropriate can contain special interfaces. This scheme provides an address space about ten times larger than appears necessary for initial operation of the telescope. Its speed is about twenty times more than will be needed initially. There is thus plenty of room for future growth.

The station computer is equipped with very few peripherals, chiefly the monitor/control bus of the antenna hardware, and the modem connecting it to the central computer. We have purchased these computers with three terminal ports. The expected use of the terminal ports is that one will be a standard terminal in the control room (currently we are buying Visual 102 or Visual 603 terminals), one will be put on a party line for use with a portable terminal with connectors in the electronics room, the pedestal room and the vertex room (we are currently buying Fivestar laptop computers for the portable terminal), and one will be devoted to a modem for dialup communications. We are currently planning to equip many stations with inexpensive serial printers; it is not yet clear whether all stations should have a printer.

The residence of the programs has not been decided. It may be that the standard programs are downloaded by the central computer at startup, with a backup of being able to load them from local disk, or the other way around. On the other hand, it may make things substantially more reliable to have programs in local ROM memory. It may even be profitable to split residence, having a kernal program in ROM, and others, changed more frequently, on disk. The decision is reserved until such time that we begin to find out about the relative reliabilites of the equipment through actual operational experience.

A duplicate station controller will be maintained at the operations center to facilitate software development.

4.2.7 Programming

The monitor/control programing effort is centered in Socorro. Programs will, when possible, be written in the C language. Efforts will be expended to make the programming compatible with the VLA on-line system, the Greenbank telescope control systems, and the VLBA correlator control system.

A software documentation and control procedures have been put into place. The principal source code residence is currently VVAX1::[VLBSOFT]. Documentation is maintained in the area UVAX1::[VLBSOFT.DOC] The casual reader is directed especially to those files with filetype .TXT, which describe systems of modules. In particular, a list of programs in the system is found in UVAX1::[VLBSOFT.DOC]PROGLIST.TXT, a keyword index is found in UVAX1::[VLBSOFT.DOC]PROGINDEX.TXT and a brief description of each program in UVAX1::[VLBSOFT.DOC]SYNOPSIS.TXT.

SECTION 5

FEEDS, SUBREFLECTOR, RELATED OPTICS.

P.J.Napier

5.1 Specifications.

(a) The optics and feed system will provide outputs for each of the following nine frequency bands: 0.31-0.34 GHz, 0.58-0.64 GHz, 1.35-1.75 GHz, 2.15-2.35 GHz, 4.60-5.10 GHz, 8.00-8.80 GHz, 14.4-15.4 GHz, 21.7-24.1 GHz, 42.3-43.5 GHz.

(b) All feeds will provide dual circularly polarized outputs with less than -30db cross coupling between orthogonal polarizations in the on-axis direction.

(c) A dual-band capability for the 2.3 GHz and 8.4 GHz bands will be provided so that both bands can be used at the same time with coincident beams in the sky.

(d) Frequency changes from one band to another will be performed under computer control without requiring personnel to visit the antenna.

(e) The feeds will be optimized to provide the maximum possible on-axis G/T performance from the antenna and low-noise receiving systems.

(f) Space will be provided so that 2 feeds, in addition to those listed in (a) above, can be located on the feed circle. These locations could be used for 10.2-11.2 GHz ,86 GHz or other feeds in the future.One of the spare locations will be close to the elevation axis on the feed circle, making it suitable for a high frequency feed.

(g) Feeds will be positioned so that dual-band operation (as in (c) above) can be provided for the frequency pairs 4.8/23 GHz; 4.8/15GHz and 15/43GHz at some time in the future. If possible, the 2.3/8.4 GHz dual frequency feed pair will be arranged so that dual frequency operation can be initiated without any manual intervention on the antenna.

5.2 Description

The requirement to provide a large number of feeds covering a wide range of frequencies led to the selection of an offset Cassegrain geometry of the type used on the VLA for the antenna optics. Because of the limited space at the secondary focus, the two lowest frequency bands will be placed at the primary focus. The subreflector focussing mechanism will retract the subreflector to expose the prime focus of the main reflector. The prime focus feeds will be mounted on the subreflector. The main and sub reflectors are shaped for high efficiency. The geometry is optimized so that the areas blocked by the subreflector and feed system are approximately the same.

The subreflector is asymmetric so that the secondary focal point lies off of the main reflector axis and is above the main reflector vertex. When the subreflector is rotated around the main reflector axis the secondary focus describes a circle about the main reflector axis. This circle is called the feed circle and the phase centers of all feeds lie on it.

Locations for the up to nine secondary focus feeds will be provided around the feed circle at the top of the feed support cone. All Cassegrain feeds will have their phase centers close to their apertures and be as short as possible. The cryogenically cooled receivers will be attached directly to the feed outputs at varying heights above and below the main reflector vertex. Some of the important dimensions of the Cassegrain geometry are shown in Figure 5.1 and are listed below:

Primary reflector diameter = 2500 cm
F/D of best fit parabola for main reflector = 0.354
Distance from main vertex to subreflector vertex = 819 cm
Best fit prime focus behind subreflector vertex = 66 cm
Maximum radius of asymmetric subreflector = 175 cm
Depth of subreflector at maximum radius = 56 cm
Radius of feed circle = 85 cm
Radius of top of feed cone = 135 cm
Radius of bottom of feed cone = 175 cm
Plane of feed circle above main vertex = 209 cm
Angle subtended by subref. from sec. focus = +-13.3 deg
Angle between main reflector axis and feed axis = 7.9 deg
Feed pattern taper at edge of subreflector = -14 db

The arrangement of feeds around the feed circle is shown in Figure 5.2.

5.3 Component Design

5.3.1 Main Reflector Profile

The shaped main reflector is designed to give uniform phase in the antenna aperture when combined with the shaped subreflector. Although the subreflector is asymmetric, the geometry is such that the main reflector remains a surface of revolution. The maximum deviations of the shaped profile above and below the best fit parabola are 1.7 cm and 1.8 cm respectively occurring at radii of 909 cm and 1250cm respectively. The deviation of the shaped surface from a parabola results in a gain loss of 0.95 when the prime focus is used at a frequency of 0.6 GHz.

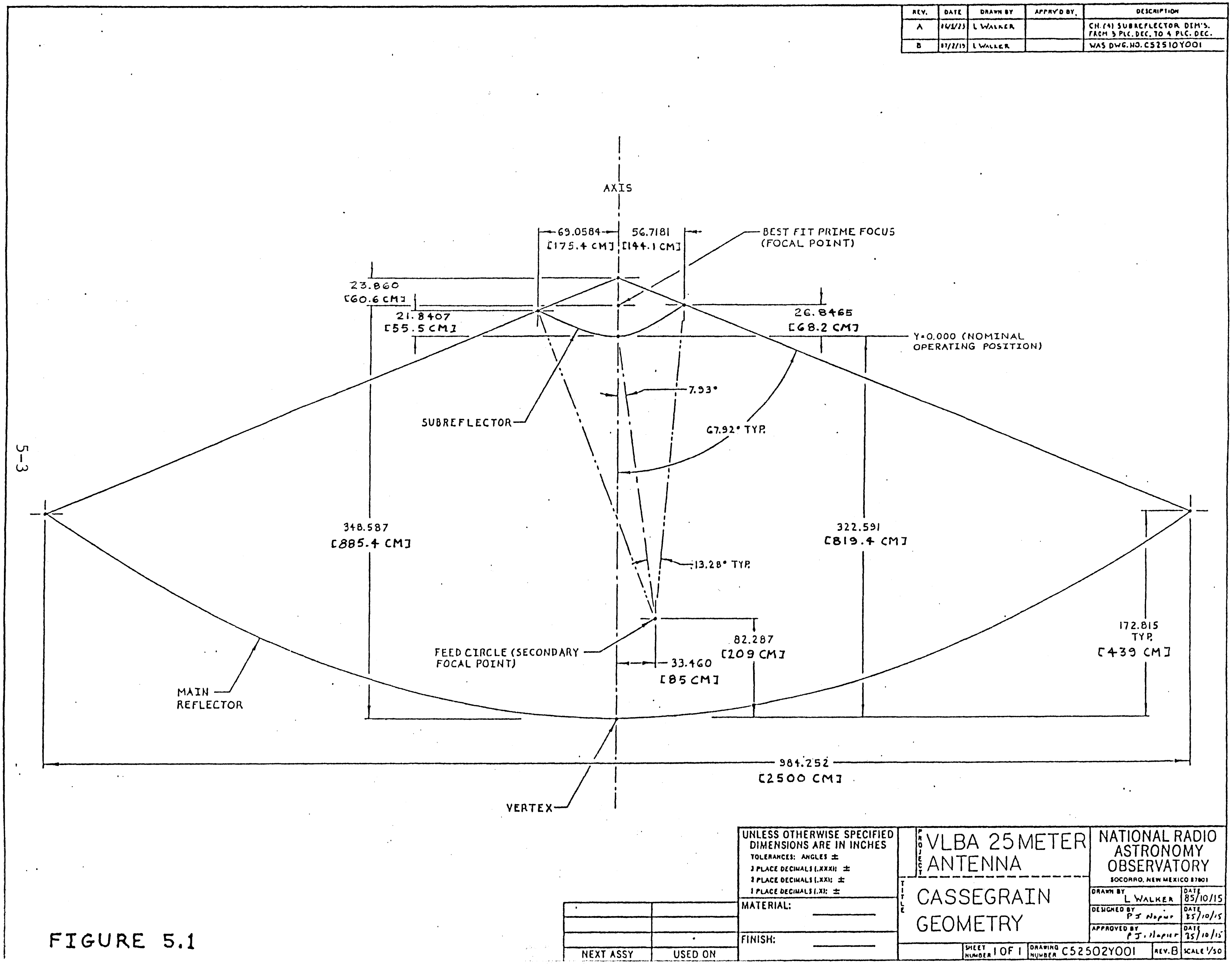

REV. | DATE | DRAWN BY | APPRV'D BY. | DESCRIPTION
A | 11/1/23 | L WALKER | | CH. (4) SUBREFLECTOR DIM'S. FROM 3 PLC. DEC. TO 4 PLC. DEC.
B | 11/2/15 | L WALKER | | WAS DWG. NO. C52510Y001
AXIS
69.0584
[175.4 CM]
56.7181
[144.1 CM]
BEST FIT PRIME FOCUS
(FOCAL POINT)
23.860
[60.6 CM]
21.8407
[55.5 CM]
26.8465
[68.2 CM]
Y=0.000 (NOMINAL
OPERATING POSITION)
7.93°
SUBREFLECTOR
67.92° TYP.
348.587
[885.4 CM]
322.591
[819.4 CM]
13.28° TYP.
172.815
TYP.
[439 CM]
82.287
[209 CM]
FEED CIRCLE (SECONDARY
FOCAL POINT)
33.460
[85 CM]
MAIN
REFLECTOR
984.252
[2500 CM]
VERTEX
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±
3 PLACE DECIMALS (.XXX): ±
2 PLACE DECIMALS (.XX): ±
1 PLACE DECIMALS (.X): ±
MATERIAL:
FINISH:
NEXT ASSY
USED ON
PROJECT
VLBA 25 METER
ANTENNA
TITLE
CASSEGRAIN
GEOMETRY
NATIONAL RADIO
ASTRONOMY
OBSERVATORY
SOCORRO, NEW MEXICO 87801
DRAWN BY L WALKER
DATE 85/10/15
DESIGNED BY P J Napier
DATE 85/10/15
APPROVED BY P J. Napier
DATE 85/10/15
SHEET NUMBER 1 OF 1
DRAWING NUMBER C52502Y001
REV. B
SCALE 1/50

FIGURE 5.1

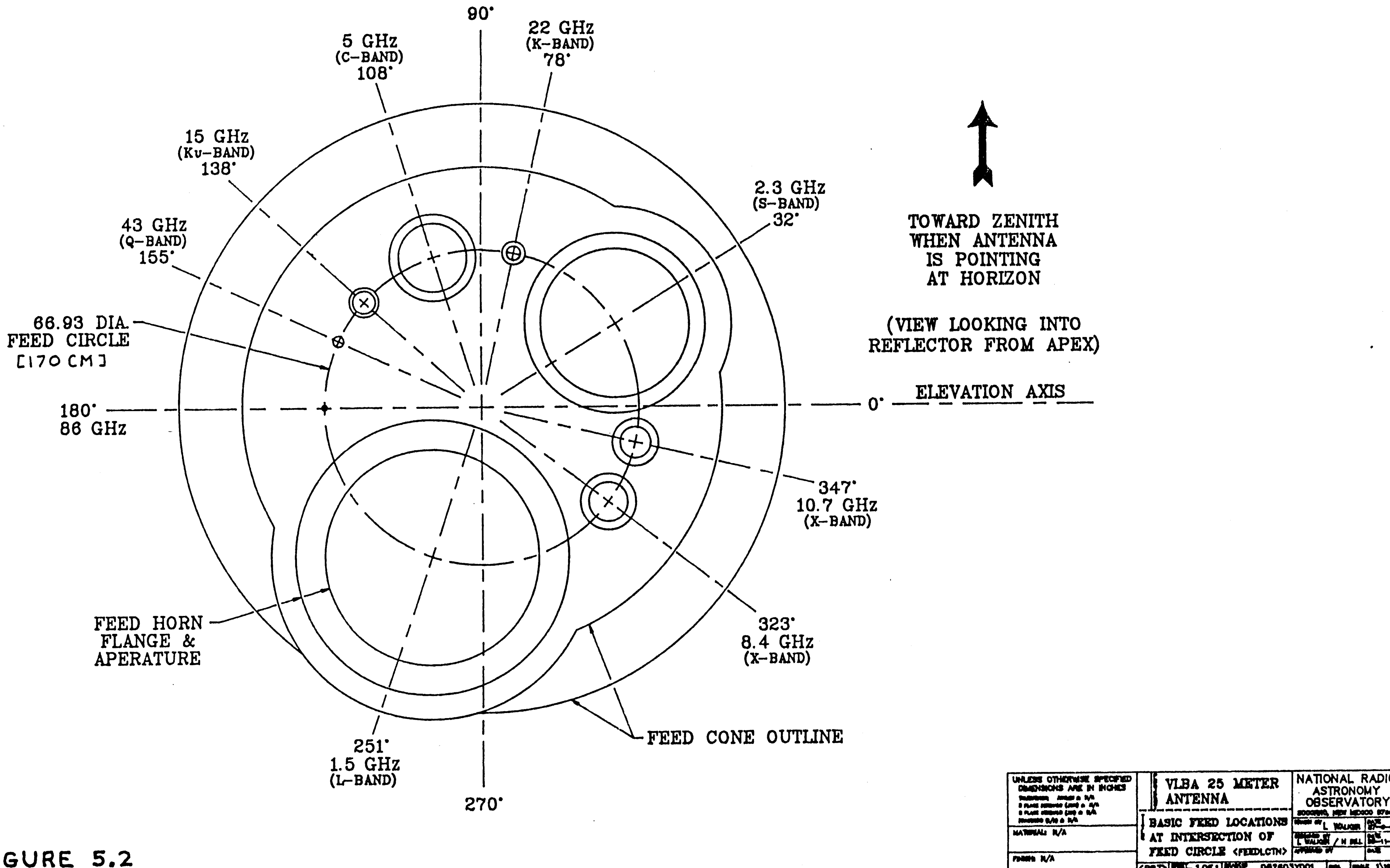

90°
5 GHz
(C-BAND)
108°
22 GHz
(K-BAND)
78°
15 GHz
(Ku-BAND)
138°
43 GHz
(Q-BAND)
155°
2.3 GHz
(S-BAND)
32°
TOWARD ZENITH
WHEN ANTENNA
IS POINTING
AT HORIZON
(VIEW LOOKING INTO
REFLECTOR FROM APEX)
ELEVATION AXIS
0°
66.93 DIA.
FEED CIRCLE
[170 CM]
180°
86 GHz
347°
10.7 GHz
(X-BAND)
323°
8.4 GHz
(X-BAND)
FEED HORN
FLANGE &
APERATURE
FEED CONE OUTLINE
251°
1.5 GHz
(L-BAND)
270°
VLBA 25 METER
ANTENNA
BASIC FEED LOCATIONS
AT INTERSECTION OF
FEED CIRCLE <FEEDLCTN>
NATIONAL RADIO
ASTRONOMY
OBSERVATORY
D62603Y001

FIGURE 5.2

5.3.2 Asymmetric Subreflector

The shaped subreflector is designed to give uniform aperture illumination out to 90 percent of the radius. The illumination over the outer 10 percent of radius rolls off to give a taper of -15 db at the edge of the aperture. This roll off is very important in reducing subreflector spillover to the ground and therefore maximizing G/T in the 1.5 GHz and 2.3 GHz bands. In the frequency range 1.5 to 4.8 GHz the reduced edge illumination results in G/T improvements of 20 to 30% compared to full uniform illumination. At 43 and 86 GHz, where spillover noise is less important, the reduced edge illumination causes a 6% loss in G/T.

Frequency changes for Cassegrain feeds are accomplished by rotating the subreflector about the main reflector axis so that the secondary focal point lies on the phase center of the desired feed. A computer controlable focus-rotation mount (FRM) holds the subreflector in position and provides the necessary focus and rotation movements as follows:

Subreflector rotation about main refl axis = +-205 deg.
Subreflector focus towards main reflector = 5 cm minimum
Subreflector focus away from main reflector = 64 cm minimum

The antenna quadrupod and FRM provides positional stability of the subreflector adequate to maintain gain and pointing performance at 86 GHz as follows:

Repeatable lateral offset between subreflector vertex and main axis = 3 mm max
Repeatable angle between subreflector axis and main axis = 4 arc.min. maximum
Stability of rotation about main refl axis= 2 arc.min. max

The asymmetric subreflector, which is not a surface of revolution, is a metal coated carbon-fiber/fiberglass reinforced aluminum honeycomb design. The specification on the subreflector surface accuracy is 150 mic rms with a design goal of 100 mic rms. These accuracies are only marginally adequate for 86 GHz operation, but it is difficult and very expensive to manufacture a subreflector which is both accurate and light enough to allow very fast changes in observing frequency and large enough to support low frequency observing. For the prototype subreflector, currently installed at Pie Town, the subreflector surface was measured in the factory and completely independently on the Large Optical Generator (LOG) at the University of Arizona. The following results were obtained.

Surface accuracy in factory	143 mic rms
Surface accuracy on LOG at same points as factory	190 mic rms
Surface accuracy on LOG at twice number of points	248 mic rms

For the production run of subreflectors the accuracy of the mold will be improved and the subreflectors will be measured at twice the number of points to improve surface accuracy. The effect of subreflector accuracy on high frequency performance is quantified in section 5.4 below.

A circular area 25 cm in diameter in the middle of the subreflector is in the shadow of the feed cone and is available for mounting a low frequency feed.

5.3.3 0.31-0.34/0.58-0.64 GHz Feed

This feed is a simple crossed dipole permanently located in the middle of the subreflector. There is a tuned circuit half way along the arms of the dipoles so that their electrical length is a half wavelength in both frequency bands. The distance between the dipoles and the subreflector is 3/8 wavelength at 610MHz, corresponding to 3/16 wavelength at 327MHz. This separation gives usable radiation patterns at both frequencies. Experience with a similar feed at the VLA predicts that the effect of this feed on the performance of the Cassegrain receiver systems will be a degradation of less than 2% in Cassegrain G/T. A frequency diplexer splits the two frequency bands at the input to the receiver and circular polarization is formed using a quadrature hybrid coupler in front of the low noise amplifiers.

5.3.4 1.35-1.75 GHz Feed

This feed is a compact corrugated horn in which the horn is bell shaped, rather than the usual simple conical shape, to produce higher modes in the horn aperture. Compact horns are 10 to 20 percent smaller than conventional corrugated horns. Because of its large size it is essential that a low cost fabrication technique be used for the major portion of the horn.

Sheet metal coated with fiberglass, as developed by CSIRO for the Australia Telescope low frequency horns is used. Circular polarization over the large bandwidth is obtained by using a VLA style room temperature dielectric-in-waveguide quarter wave plate in front of the Green Bank style cooled quad-ridged orthomode junction. Tests on the prototype feed predict a rather low spillover efficiency of 83%. This is because there is insufficient space on the feed circle to make the feed as large as is needed for full efficiency. The horn weighs approximately 150 Kg. A machined aluminum horn would weigh approximately 900 Kg.

5.3.5 2.15-2.35 GHz, 4.6-5.1 GHz, 8.0-8.8 GHz, 10.2-11.2, 14.4-15.4 GHz and 21.7-24.1 GHz Feeds

All these feeds are conventional corrugated horns using cryogenically cooled sloping septum circular polarizers. All feeds are scaled from the same design.

The 4.6-5.1 GHz horn has sufficiently good performance at 6.1 GHz that it can be used for that frequency, if desired, with only a few percent loss in gain. The transition section at the horn throat would need to be changed for 6.1 GHz.

The prototype 2.15-2.35 GHz feed installed at Pie Town is machined from aluminum and weighs approximately 180 Kg. The production run of horns will be of lightweight construction similar to the 1.5 GHz horn, or of machined aluminum, depending on cost. It will be usable at 2.7 GHz with negligible gain loss.

5.3.6 42.3-43.5 GHz, 86 GHz Feeds.

These feeds will be conventional corrugated horns. Circular polarization will be formed either using a cooled quarter-wave phase shift waveguide polarizer or quarter-wave phase shift vanes over the feed aperture. The feeds will be placed close to the elevation axis on the feed circle so that subreflector rotation can be used to correct for the effect of quadrupod gravitational deformation, if necessary. The feeds will be designed for a little less than 14 dB taper at the edge of the subreflector to correct for the effect of the aperture edge illumination roll-off that is needed at lower frequencies.

5.3.7 Dual Frequency Reflectors.

The feeds have been arranged around the feed circle so that the frequency pairings described in section 5.1 (c) and (g) above are possible. To obtain dual frequency operation a flat dichroic reflector is placed above the lower frequency feed of the pair. This reflector allows the low frequency wave to pass through with low attenuation and reflects the high frequency wave over to an elliptical reflector mounted above the higher frequency feed of the pair.

With this type of dichroic plate the size of the reflectors is determined by the size of the higher frequency feed of the pair and so results in the smallest possible reflectors. The requirement that the dual frequency reflectors be able to be left permanently in position is difficult to achieve. The ellipsoid tends to block the feed located on the feed circle next to it. If the ellipsoid cannot be made small enough to prevent this blockage, a computer controlled mechanism will be used to swing it in and out of position.

The principal dimensions of the feeds are given in the following table.

Frequency (GHz)	Feed Input ID (cm)	Feed Aperture Outside Diameter (cm)	Feed Length To Recvr (cm)
0.31-0.34	N-Coax	48	50
0.58-0.64	N-Coax	48	50
1.35-1.75	16.33	140	360
2.15-2.35	9.75	90	256
4.6-5.1	4.490	41	119
8.0-8.8	2.602	24	71
10.2-11.2	2.045	19	56
14.4-15.4	1.487	14	41
21.7-24.1	0.931	9	27
42.3-43.5	0.526	5	16
86	0.263	3	8

5.4 Performance Estimates

The VLBA offset shaped Cassegrain geometry was designed by first generating a prototype symmetrical shaped geometry. The main reflector of this prototype is retained and the subreflector is discarded. The asymmetrical subreflector is then generated such that uniform phase in the aperture of the main reflector is obtained when the secondary focus is offset to the desired location.

Estimates of the performance of the VLBA feed system have been made by analyzing the prototype symmetrical geometry using the geometrical theory of diffraction (GTD). The program to generate the prototype geometry and to perform the analysis was provided by G. James of the CSIRO Division of Radiophysics. The full asymmetric geometry has also been analysed at the Jet Propulsion Lab using their new GTD code.

The table below gives estimates of aperture efficiency made from radiation patterns measured on the prototype feed horns. Esurf is the reflector surface efficiency assuming that the main reflector surface rms is 275 mic rms (the spec for precision operating conditions) and the subreflector rms is the spec value of 150 mic. Eillum is the combined effects of aperture taper and subreflector diffraction. Espil is feed spillover efficiency. Eblock is aperture blockage efficiency. Ephase is aperture phase efficiency, including the shaping of the main reflector for the prime focus feeds and the effect of subreflector missallignment due to quadrupod deformation for the high frequencies. Emisc represents miscellaneous losses due to VSWR, resistive and other losses. Etotal is total aperture efficiency.

Freq (GHz)	Esurf	Eillum	Espil	Eblock	Ephase	Emisc	Etotal
0.33	1.00	.80	.80	.86	.96	.95	.50
0.61	1.00	.80	.80	.86	.93	.95	.49
1.5	1.00	.94	.83	.86	.99	.95	.63
2.3	1.00	.95	.91	.86	.99	.95	.70
4.8	1.00	.97	.92	.86	.99	.95	.72
8.4	.99	.97	.92	.86	.99	.95	.71
10.7	.98	.97	.92	.86	.99	.95	.71
15	.96	.97	.92	.86	.99	.95	.69
23	.92	.97	.92	.86	.99	.95	.66
43	.72	.97	.92	.86	.98	.95	.51
86	.27	.97	.92	.86	.93	.95	.18

To indicate the range of efficiencies that result from variations in the main reflector surface rms due to gravity and environment, or due to a more or less accurate subreflector, six cases are examined in the table below. A main reflector rms of 275 mic is the spec for precision operating conditions and 175 mic occurs when no gravity, thermal or wind is acting on the reflector or the quadrupod (ie panel and setting accuracy only).

Subreflector accuracies of 100 mic, 159 mic and 248 mic rms correspond to the design goal, hard specification and prototype measurement respectively.

Main rms (mic)	Sub rms (mic)	Total Effic 43 GHz	Total Effic 86 GHz
175	100	0.64	0.42
175	150	0.61	0.36
175	248	0.53	0.21
275	100	0.53	0.21
275	150	0.51	0.18
275	248	0.44	0.11

A first sidelobe level of -15dB is expected for the Cassegrain frequencies and -20dB for the prime focus receivers.

Estimates of the noise contributions of the feed and antenna system are shown in the table below. Tloss is the noise contribution due to resistive losses in the feeds and on the reflector surfaces; for the 2.3 GHz and 8.4 GHz feeds an additional loss due to the dichroic reflector system is included. Tspill is the effect of subreflector diffraction or feed spillover to the ground. Tscatter is ground radiation entering the feed due to scattering off of the quadrupod or other structure on the antenna. Tsky is the total sky brightness due to zenith tropospheric emission, galactic emission in a direction well away from the galactic plane and the 3 degree microwave background. Tanttot is the sum of these four effects and is the total noise entering the receiver input when the antenna is pointed at the zenith with no source in the beam (ie. Tanttot = system temp - receiver temp). All contributions are in degrees Kelvin.

Freq (GHz)	Tloss	Tspill	Tscatter	Tsky	Tanttot
.33	6	15	3	50	74
.61	6	15	3	10	34
1.5	4	3	5	6	18
2.3	7	2	5	6	20
4.9	2	2	5	6	15
8.4	8	1	5	7	21
10.7	3	1	5	7	16
14.9	3	1	5	9	18
22	5	1	5	16	27
43	6	1	5	23	35
86	7	1	5	56	69

The off-set geometry will result in the left and right hand circularly polarized beams from the Cassegrain feeds being separated in the sky by 0.05 beamwidths. Experience at the VLA where the effect is slightly worse (0.06 beamwidths) indicates that this circular polarization beam squint will not degrade the quality of the linear polarization measurements made with the VLBA. Circular polarization measurements will be effected. For a source that is 15 arc seconds off axis (the antenna pointing specification is 8 arc seconds rms for short term variations) the beam squint will cause instrumental circular polarizations of 0.1% and 3% at frequencies of 1.5 and 43 GHz respectively. The instrumental circular polarization varies linearly with frequency and angle off axis.

SECTION 6

ELECTRONICS RECEIVING SYSTEM

A. R. Thompson

6.1 System Definition

This section is concerned with the receiving system from the feeds in the antenna vertex room to the inputs of the baseband system located in the equipment room of the antenna building. It includes the low-noise front ends, the frequency converters, the local oscillator system, the 500-1000 MHz IF amplifiers, and the cables that transmit the IF signals from the antenna to the antenna building. Also included are the system for monitoring the length of the local oscillator cable, and the monitor and control interfaces of the receiving electronics. Other items that fall within this section include the hydrogen maser frequency standards and the water vapor radiometers. For a block diagram of the electronic system, see VLBA drawing No.D58001K001.

6.2 Front Ends

Table 6.1 lists the eleven frequency bands that have been considered for the VLBA. Two of these, 6.1 GHz and 10.7 GHz, are considered to be optional. One receiving system for the 10.7 GHz band is being constructed for the Pie Town antenna, but otherwise equipment for the 6.1 and 10.7 GHz bands is not included in the budget. For a discussion of the frequency bands see VLBA Electronics Memo No. 15. The types of amplifiers, receiver noise temperatures, antenna temperatures and system temperatures are given in Table 6.1.

TABLE 6.1. Front-End Characteristics

Frequency Band	Frequency Coverage	Amplifier Type	Physical Temp	Receiver Temp	System Temp
330 MHz	312-342 MHz	GASFET	320K	30K	104K
610 MHz	580-640 MHz	GASFET	320K	30K	64K
1.5 GHz	1.35-1.75 GHz	HEMT	15K	7K	25K
2.3 GHz	2.15-2.35 GHz	HEMT	15K	8K	28K
4.8 GHz	4.6-5.1 GHz	HEMT	15K	10K	25K
6.1 GHz	5.9-6.4 GHz	HEMT	15K	12K	32K
8.4 GHz	8.0-8.8 GHz	HEMT	15K	16K	37K
10.7 GHz	10.2-11.2 GHz	HEMT	15K	20K	36K
15 GHz	14.4-15.4 GHz	HEMT	15K	30K	48K
23 GHz	21.7-24.1 GHz	HEMT	15K	60K	87K
43 GHz	42.3-43.5 GHz	HEMT	15K	90K	125K

System temperatures are approximate and correspond to high angles of elevation and good atmospheric conditions. For all bands the front ends will use GASFET OR HEMT amplifiers. Those for 330 and 610 MHz will operate at a stabilized temperature of approximately 320 K, and those for other bands at 15 K. In the original proposal masers were considered for the 23 and 43 GHz bands, but later rejected on consideration of the maintenance problems of the cryogenics involved. For a further discussion see VLBA Electronics Memo No. 32. SIS mixers have also been considered for the 43 GHz band, but HEMT amplifiers appear to be a more practical choice.

6.3 Cryogenics

The amplifiers of the 15 K front ends will be cooled by closed-cycle helium refrigerator systems. The polarizers, which produce outputs corresponding to signals of opposite circular polarization from the feeds, are also cooled to minimize the noise associated with resistive losses. For 8.4 GHz and higher bands, the polarizer will be cooled to 15 K, which is the second-stage temperature of the refrigerator. For 1.5, 2.3 and 4.8 GHz the polarizer is large and would load the second stage too heavily, so it will be cooled to the first-stage temperature of 60 K. For 2.3 GHz and higher bands the CTI model 22 refrigerator will be used. For 1.5 GHz the larger CTI model 350 refrigerator will be used: see VLBA Electronics Memo No. 33. Table 6.2 gives some details of these refrigerators, and for comparison includes the model 1020 which is used on the VLA but is not included in plans for the VLBA. There will be two CTI model 1020 compressors (plus one spare) at each antenna. One such compressor will nominally drive five model 22 refrigerators, or three model 22 and one model 350 refrigerators (or one model 1020 and two model 22 refrigerators).

TABLE 6.2. C.T.I. Refrigerators

Model No.	22	350	1020
Load 60K			35W
Load 15K	1W	2-3W	10W
He (cu ft per min)	9	17	28
Cycles per min	200	72	72
Weight (lbs)	15	22	30
Length of Cooling Section (inches)	7.1	11.2	13.2
Approximate Cost (excluding compressor)	$3.5k	$6k	$7.2k

6.4 Local Oscillator

6.4.1 Hydrogen Masers

The specifications for the hydrogen maser frequency standard are given in Specification No. A53308N001. The short term stability requirement states that the integrated effect in the range 1 Hz to 1 MHz shall correspond to no more than 0.60 ps rms at 100 MHz. This value is based upon a requirement of 90% correlation at 86 GHz. The long term stability is specified in terms of a curve of Allan variance for which the value at 1 s is 7×10^{-14}. A contract for 11 hydrogen masers was let with Sigma Tau Frequency Standards in November 1985.

All LO signals are ultimately derived from the hydrogen maser frequency standard. Most of them must be tunable, with coarse tuning (200 MHz and 300 MHz steps) in the vertex room and fine tuning (10 kHz) in the equipment room. The hydrogen maser provides two standard frequencies: 100 MHz and 5 MHz. Although we could transmit only the 100 MHz reference to the vertex room, this would require generation of many undesired harmonics of 100 MHz near the sensitive receivers, and would require a high order of frequency multiplication in a relatively poorly controlled environment. Also, in order to compensate for transmission line length variations, the line length must be monitored, and this can be done more precisely at a higher frequency. Therefore, the maser output is multiplied to 500 MHz in the equipment room and this frequency together with 100 MHz is transmitted to the vertex room. The 10 kHz reference for the baseband converters is derived by dividing down the 5 MHz from the maser.

6.4.2 Frequency Conversion

In the vertex room of the antenna, the received signal in each band is converted to an IF of 500 to 1000 MHz. For all but the 23 GHz and 43 GHz bands, this is done in a single mixing. For those bands where the input bandwidth exceeds 500 MHz (8.4 GHz and higher frequencies), the band is covered by two LO tuning frequencies. The LO frequency can be chosen to be above or below the signal band in any particular case, to avoid pickup of the LO signal in the skirts of the front-end response, or to maximize image rejection.

Because of the availability of wide-range, YIG tuned oscillators in the microwave region, it is feasible to design a single synthesizer to provide the required first LO signals for all bands through 15 GHz. To accommodate dual-band operation, two such synthesizers are needed. A transfer switch is provided to exchange the roles of the synthesizers, allowing single-band operation to continue on any band even if one synthesizer fails.

At 8.4 GHz, it is considered necessary to be able to observe both ends of the band simultaneously. To accomplish this, we provide a third synthesizer. The two highest frequency bands require an additional frequency conversion in order to maintain image rejection. At 23 GHz, the third 2 - 16 GHz synthesizer will also provide the first LO.

6.4.3 LO System Modules

The distribution and synthesis of local oscillator signals requires four principal units which are briefly described as follows.

(a) LO Transmitter Module

This unit takes the maser output signals at 100 MHz and 5 MHz and generates signals at 500 MHz. The 100 MHz and 500 MHz signals are combined and transmitted by coaxial cable to the antenna vertex room.

(b) Round Trip Monitor Module

A signal with a small frequency offset from 500 MHz is generated in a modulated reflector in the vertex room and returned back down the LO-reference cable. In the Round Trip Monitor Module the returned signal is used to monitor the electrical length of the cable, and this information goes to the computer and is used to correct the visibility phases after correlation.

(c) LO Receiver Module

The LO Receiver Module is at the vertex-room end of the local oscillator cable, and in it the 100 and 500 MHz signals are separated and made available to the frequency synthesizer units. This module also contains the modulated reflector for round-trip phase measurement of the cable length.

(d) 2-16 GHz Synthesizer Module

This unit takes the reference signals at 100 and 500 MHz and generates signals at (N X 500 +/- 100) MHz, where N is an integer in the range 4 to 32. Three of these units will be required at each antenna.

6.5 The IF System

In the frequency bands up to and including 15 GHz the signals are converted to a first IF band which extends from 500 MHz to 1000 MHz. The frequency conversion is by means of the signals from the 2-16 GHz Synthesizer Modules described under section 6.4.3. For the 23 and 43 GHz band a higher first IF will be used to improve the image rejection. The frequency conversion to 500-1000 MHz is performed in a frequency converter module of which there will be a separate one for most of the frequency bands. The two IF signals from the two polarizations are amplified within the converter module. The output signals go to a series of IF switches in which the signal bands required for a particular observation are selected and transmitted by cable to the equipment room of the station building. Four cables are used to accommodate both polarizations for two frequency bands simultaneously. Recommended power levels at various points in the signal path are given in VLBA Electronics Memos Nos. 30 and 62. The total gain (RF plus IF) at the antenna for each band is in the range 60 +/- 10 dB to produce a level of -42 dBm at the cable output.

For the 610 MHz frequency band the received signals lie within the required IF band, but because of the high levels of television signals in nearby bands at many of the sites, a double-conversion filtering system is included. Signals in the band 608-614 MHz are converted to 8-14 MHz using local oscillator frequencies of 500 MHz and 100 MHz. The signals then pass through a filter with a bandwidth of 4 MHz at the -3dB level and 7.2 MHz at -50 dB, and then are reconverted to the original input band. At other bands special filtering may be required to reduce particular interfering signals, and in most cases it should be possible to insert such filters in the 500-1000 MHz IF band. The concern here is with signals that would be rejected by the baseband filters, but would be strong enough to cause gain compression in the 500-1000 MHz IF amplifiers. Levels of signals that can be tolerated within the receiving bands are discussed in VLBA Memo No. 81.

6.6 Monitor and Control Interfaces

There will be a separate control module for each front end, with interface to the monitor and control bus. A Switch Control Module containing an interface and a series of switch drivers is used with the switching system that makes the local oscillator and IF interconnections required for any particular observation. The 2-16 GHz Synthesizer Modules will each contain an interface with the monitor and control bus to receive tuning commands.

6.7 VLBA Water Vapor Radiometers

The largest phase errors in the visibility data produced by the VLBA in the higher frequency bands will be those caused by fluctuations in the amount of water vapor along the line of site to each antenna. The size of these phase errors can be reduced by measuring the amount of water vapor above each antenna using water vapor radiometers and applying a phase correction based on these measurements. A water vapor radiometer consists of a pair of accurate microwave radiometers which measure the brightness temperature of the sky at frequencies of approximately 21.7 GHz and 30.7 GHz. It is planned to leave the construction of these radiometers until late in the program so that the project can benefit from the development efforts that are underway at various other laboratories.

6.8 Radio Link for VLA Area Antennas

It has been proposed that the antenna at Pie Town should be linked by microwave systems to the VLA site to allow real time correlation with the VLA, and possibly also tape recording of the Pie Town signals at the VLA site. To accommodate the signal bandwidth of 200 MHz required for maximum sensitivity in real time correlation with the VLA, the links would have to be in the 18 GHz or 25 GHz regions of the spectrum. Some preliminary considerations of the link requirements have been given in VLBA Memos No. 213, 240 and 246, and VLBA Electronics Memo No. 1. The radio link could also include transmission of LO reference frequencies from the hydrogen maser at the VLA site, and thus eliminate the need for a maser at the Pie Town site. The cost saving on the maser would partially offset the cost of the link. At this time a real-time link for the Pie Town or other antennas in the VLA vicinity is not included in the VLBA plan. If such a link is implemented in the future, fiber optics may provide the most economic medium.

6.9 Construction Plan

Construction of the receiving electronics is spread between the Green Bank, Charlottesville and VLA electronics groups, as best fits the available manpower. Progress in the various areas of the electronics is discussed at the monthly electronics teleconference meetings, the proceedings of which are summarized in the VLBA Electronics Memoranda series.

As a result of funding limitations, only a subset of the full electronic receiving system can be included in the initial installation on each antenna. The remaining equipment will be added later in the array-construction period. For the Pie Town antenna, however, the plan did allow a near-complete set of electronics installed as soon as possible. Thus the Pie Town installation includes equipment for the 0.33, 0.61, 1.5, 2.3, 4.8, 10.7, 15, and 23 GHz bands.

The initial outfitting of electronics on each antenna after the one at Pie Town will be limited to the feeds, front ends and converter modules for 1.5, 4.8 and 23 GHz. The local oscillator system and racks, cables, power supplies, etc. required for operation in these bands will also be included. Hydrogen masers will be added as they are received and tested. The three initial frequency bands were chosen because of their importance in astronomy, including usage on the VLA. The 23 GHz facility allows the use of the strong water maser sources for testing of the antennas.

SECTION 7

I.F. PROCESSING

A.E.E. Rogers

7.1 Specifications

7.1.1 General

Number of I.F. inputs:	4
I.F. frequency range :	500 - 1000 MHz
Number of baseband channels:	16 (8 upper and lower sideband pairs) expandable to 32
Baseband L.O. coverage:	500-1000 MHz in 10 KHz steps
Baseband bandwidths:	16,8,4,2,1,0.5,0.25,0.125,0.0625 MHz

7.1.2 Interfaces

7.1.2.1 I.F. Input From Receivers

Signals:	4 I.F.s in the range 500 - 1000 MHz
Levels:	-34 dBm nominal in 500 MHz bandwidth
Cables:	RG-9 or equivalent
Connectors:	Type N (male on cable ends from receivers)

7.1.2.2 Frequency and Time

FREQ:

Signals:	5 MHz at +13 dBm (nominal)
Cable:	RG-9 or RG-142 or equiv
Connector:	Type N

TIME:

Signal:	1 pps (used to define the 5 MHz transition coincident with the second mark)
Cable:	RG-142 or equiv
Connector:	BNC

7.1.2.3 Communications

Communication is via the Monitor and Control Bus. See SECTION 4., Control and Monitoring.

7.1.3 I.F. Distributors

Input frequency range:	500-1000 MHz
Gain:	4 dB at 750 MHz
Input atten range:	0, -20 +/-1.5 dB, infinity
Max phase change with gain:	<0.6 deg peak to peak
Square law linearity:	< 1% from 5% to full scale
Isolation between outputs:	> 20 dB
Noise temperature:	< 100,000 deg K

7.1.4 Baseband Converters

Input range:	492-1008 MHz
Gain through conv(2 MHz BW):	64 +- 1 dB maximum gain
Level control max atten:	30 dB
Level control phase shift:	< 0.5 deg over full range of atten
Gain for other bandwidths:	-3 dB/ octave increase in bandwidth
Image rejection:	>26 dB over video range 10 kHz to 8 MHz
Output power:	0 +-0.5 dBm
L.O. range:	500-1000 MHz in 10 KHz steps
Energy in 10 KHz sidebands:	< -40 dBc
L.O. phase noise:	< 2 deg. rms
L.O. leakage into video	< -50 dB
Gain compression:	< 0.05 dB (1%)
SNR(noise from converter):	> 25 dB
Noise temperature:	< 100,000 deg K when combined with IFD
Dynamic range:	> 30 dB
Temperature coeff of phase:	< 1 deg/ deg C/ GHz
L.O. settling time:	< 1 sec
L.O. repeatability:	< 0.1 deg upon return to same frequency
L.O. leakage into input:	< -60 dBm
Temperature coeff. of gain:	< 0.1 dB/ deg C
Temperature coeff. of differential phase:	< 0.1 deg/ deg C
Temperature coeff. of baseband delay:	< 0.1 ns/ deg C at 8 MHz BW
4-way input switch isolation:	> 60 dB
Bandpass response:	

1) >10 dB down at bandedge x 1.08
2) <0.5 dB ripple across lower 80%
3) <1 dB between units across upper 20%
4) <5 deg phase ripple between units across lower 80% of band
5) <10 deg between units across upper 20%
6) <0.1 deg/deg C temperature coefficient of phase over 80% of band
7) <0.1 dB/deg C temperature coefficient of amplitude over 80% of band

(The above should ensure that closure errors are < 0.1 degrees)

Bandwidths:	16,8,4,2,1,0.5,0.25,0.125,0.0625 MHz
Data processing:	1) Total power integration and synchronous detection with periods of an integral number of 80 Hz half-cycles (6.25msec) 2) Auto-leveling of output power

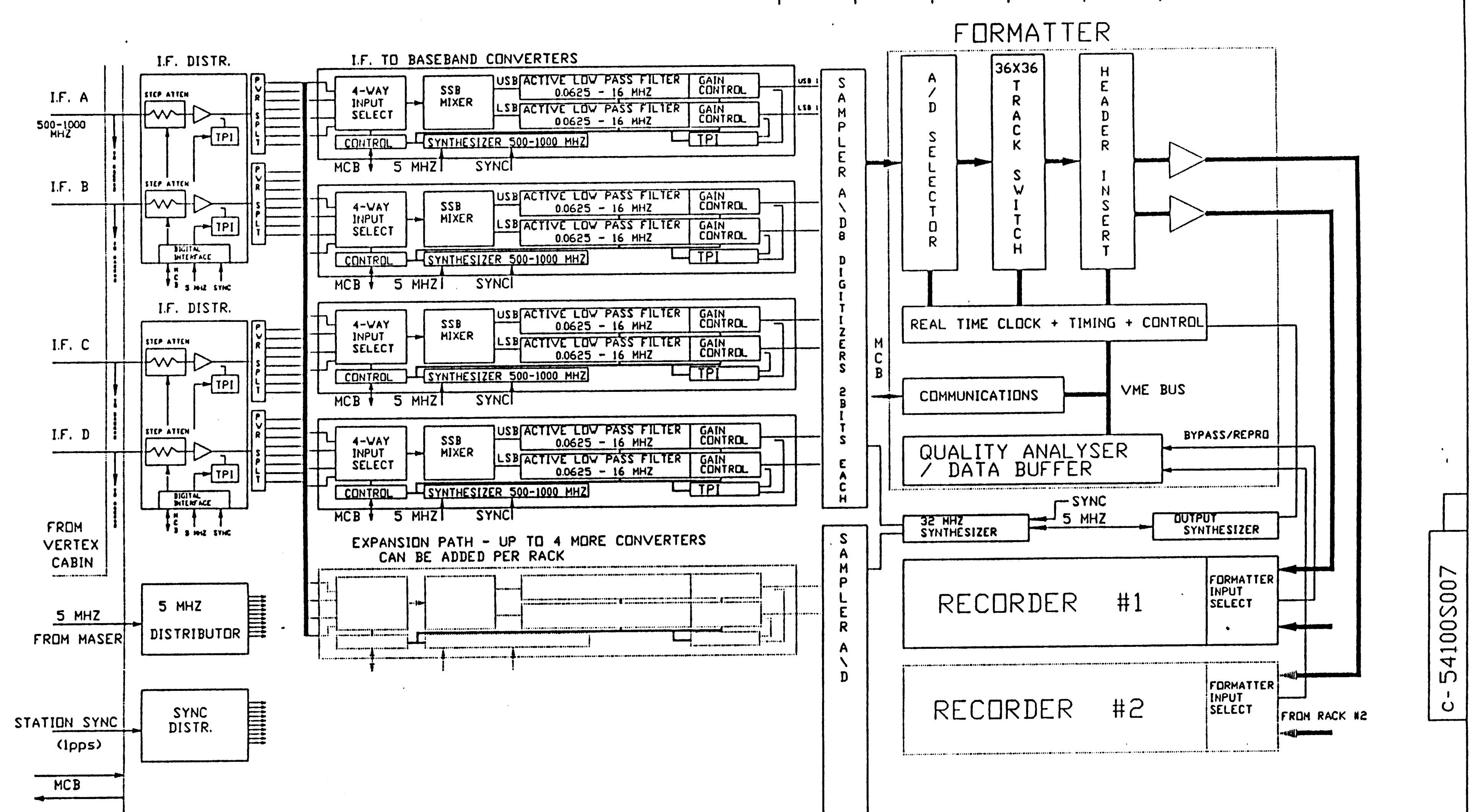
Monitor and control:

FUNCTION	#bits	control	monitor
IF input select	2	Y	Y
L.O. frequency	20	Y	Y
L.O. unlock	1	N	Y
USB bandwidth	16	Y	Y
LSB bandwidth	16	Y	Y
USB gain	8	Y	Y
LSB gain	8	Y	Y
USB TPI for last ref period	16	N	Y
LSB TPI for last ref period	16	N	Y
Radiometry mode	8	Y	Y
serial number	12	N	Y

7.2 Description

The data acquisition system uses VLBI techniques similar to those used in the Mk I, Mk II and Mk III systems with fixed-phase sampling and no fringe rotation - other than that which might be provided by offsetting the local oscillators in fixed steps. The system is modular with multiple baseband converters for multiple polarizations, frequency bands, bandwidth synthesis and pulsar dispersion. Sampling can be either 2 or 4-level, 4-level being provided to provide higher SNR for spectral line observations and to achieve the same SNR in continuum with a narrower bandwidth (for interference avoidance).

The I.F. processing is similar to Mk III and uses VLA packaging. New features include a higher I.F. range to achieve more bandwidth and active filters to reduce cost. A single data acquisition rack (DAR) contains 4 baseband converters (expandable to 8) , 2 dual I.F. distributors, a sampler module (expandable to 2) , a formatter and support modules (power supplies, 5 MHz distributor etc.). Two DARs and two recorders will be needed at each site to meet all requirements. Figure 7.1 shows a block diagram of the DAR, and Figure 7.2 shows the rack layout. Figure 7.3 shows the nominal signal levels from the sky, through the receiver, I.F. distributors and converters to baseband output.



CHANGE LETTER	DWN BY	CHK'D BY	APP'D BY	DATE	D.C.N. & DESCRIPTION

NOTES:

MCB = MONITOR AND CONTROL BUS.
SYNC = STATION SYNC (1pps)

IN FULL VLBA SYSTEM THERE ARE 2 RACKS,
AND 2 RECORDERS PER STATION.
EACH RACK HAS 4 CONVERTERS AND 1 FORMATTER.
IN THIS CONFIGURATION:
MAX # IF CHANNELS = 4(EACH 500-1000MHz)
MAX # BASEBAND CHANNELS = 16(8 USB + 8 USB)
MAX DATA OUTPUT RATE = 512MB/S

ELECTRONIC NOTES:
UNLESS OTHERWISE NOTED:
RESISTORS:
CAPACITORS:
INDUCTORS:

USED ON

SCALE NONE
CLASSIFICATION

DRAWN FOR: A.E.ROGERS — DATE: 7-87
DRAWN BY: A.E.ROGERS — 7-87
CHECKED BY:
APPROVAL — PROJECT ENGINEER:

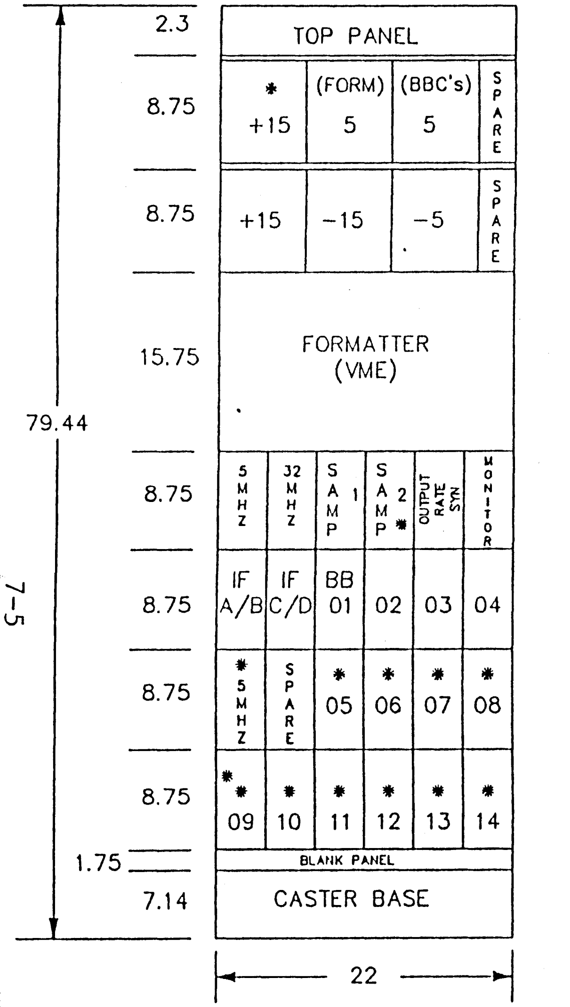
NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS

VLBA DATA ACQUISITION SYSTEM

AER\ACQRACK — C — 54100S007

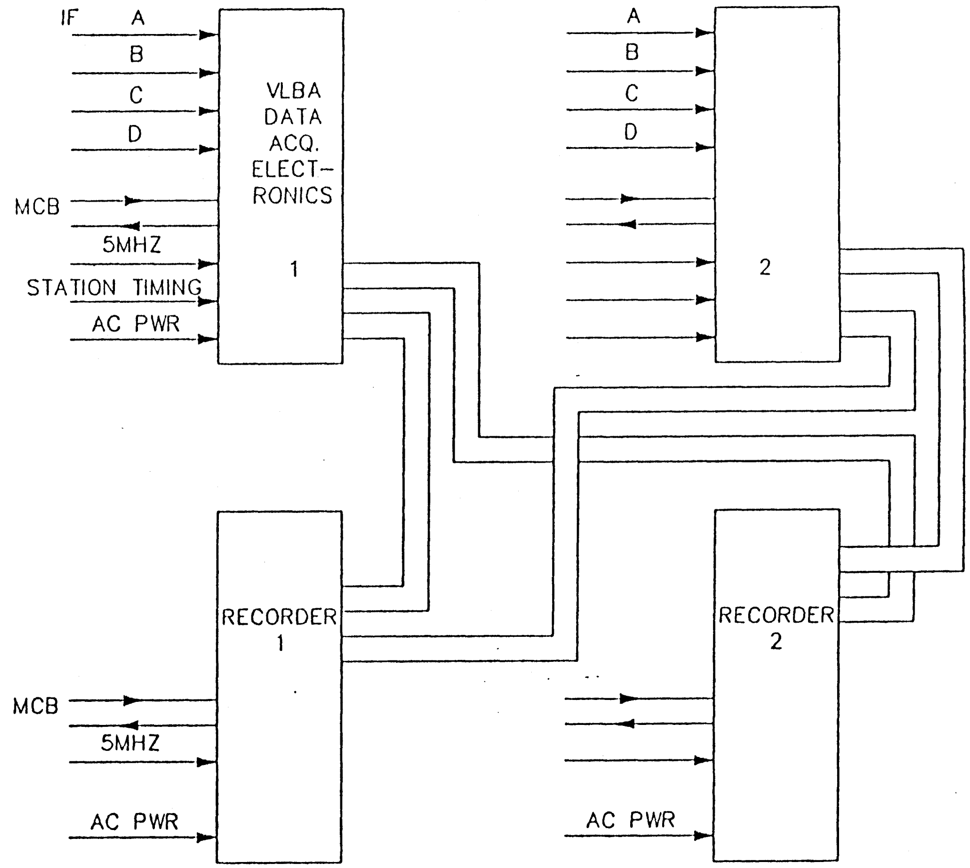
Figure 7.1

CHANGE LETTER	DWN BY	CHK'D BY	APP'D BY	DATE	D.C.N. & DESCRIPTION
A	APH			9/87	SEE MARKED UP PRINT



* FOR EXPANSION

DATA ACQUISITION RACK LAYOUT



FULL VLBA CONFIGURATION

1. EACH ELECTRONICS RACK HAS 4 BB CONV. EXPANDABLE TO 8.
2. EACH FORMATTER HAS 32 DATA OUTPUTS BUFFERED TO EACH RECORDER MAX OUTPUT DATA RATE 256 MB/S PER FORMATTER (EXPANDABLE TO 512 MB/S PER FORMATTER).
3. RACKS ARE INDEPENDANT.

C—54100D006 A

FIGURE 7.2

NOTES

MATERIAL

FINISH AND/OR HEAT TREATMENT

SHOP NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS ARE IN INCHES
2. TOLERANCE ON DIMENSIONS
FRACTIONAL ± 1/64
DECIMAL .XX ± .01
DECIMAL .XXX ± .005
ANGULAR ± 0°30'
3. SURFACE ROUGHNESS PER MIL-STD-10
4. REMOVE BURRS AND BREAK SHARP EDGES 1/64 MAX.
5. SCREW THREADS PER MIL-STD-9
6. ALL DIMENSIONS TO APPLY BEFORE PLATING OR CONVERSION COATING.

USED ON

NEXT ASSEMBLY

WEIGHT

SCALE NONE

CLASSIFICATION

DRAWN FOR A.E.ROGERS | DATE 3/87

DRAWN BY A.PHILBROOK | 3/87

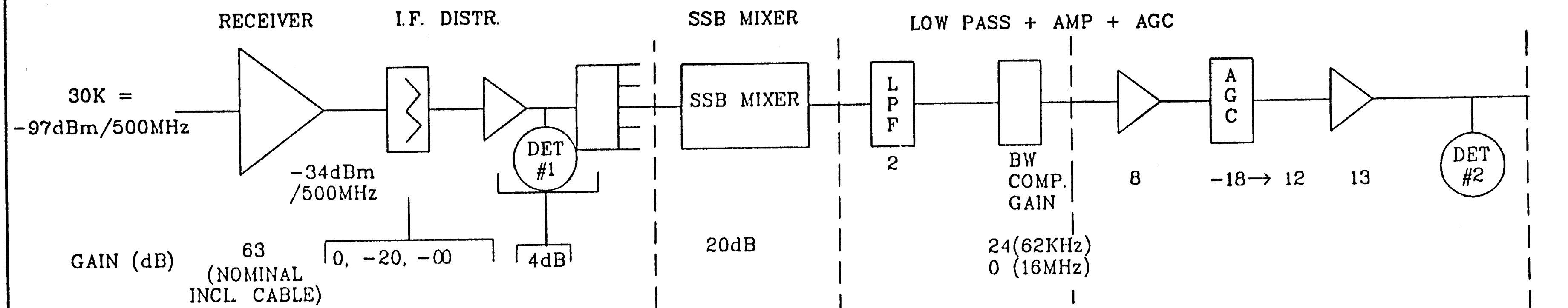
CHECKED BY

APPROVALS: PROJECT / ENGINEER / MATL. & PROCESS / STRUCTURES / THERMAL / MECH. ANALYSIS

NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS

DAR RACK
CONFIGURATION

AER\RACK | DWG. SIZE C | DWG. NO. 54100D006 | REV. A



NORMAL POWER LEVELS(30°K INPUT-0dB ATTEN SETTING) (3,000 K -20dB ATTEN SETTING)	-30dBm/500MHz	-20dBm/50MHz	-23dBm	AGC = 2dB	0dBm
3,000 K LINE IN 62.5KHz CHANNEL[1]	-30dBm/500MHz	-20dBm	-3dBm	AGC= -18 dB	0dBm
1dB GAIN COMPRESSION LEVELS	6dBm	16dBm			+13dBm
INTERNAL NOISE LEVELS	-62dBm/500MHz (100,000K INCLUDING MIXER)				

DERIVED FROM ABOVE:

BASEBAND SNR BETTER THAN 32dB
WORST CASE SENSITIVITY INTERFERENCE WITHIN I.F. - BUT OUTSIDE BASEBAND CHANNEL -71dBm AT FRONT - END INPUT.
DETECTOR #1 READS 1 VOLT AT -34dBm INPUT LEVEL FROM RECEIVER
DETECTOR #2 READS 1 VOLT AT 0dBm BASEBAND OUTPUT
(-10 dBm ON FRONT PANEL BNC MONITOR OUTPUT)

NOTES

1. FOR STRONGER LINES THE BW COMP. GAIN CAN BE DECREASED TO AVOID RUNNING AGC BELOW -18dB

CHANGE LETTER	D'WN BY	CHK'D BY	APP'D BY	DATE	D.C.N. & DESCRIPTION			

MATERIAL

FINISH AND/OR HEAT TREATMENT

SHOP NOTES: UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS ARE IN INCHES
2. TOLERANCE ON DIMENSIONS FRACTIONAL ± 1/64 DECIMAL .XX ± .01 DECIMAL .XXX ± .005 ANGULAR ± 0°30'
3. SURFACE ROUGHNESS PER MIL-STD-10
4. REMOVE BURRS AND BREAK SHARP EDGES 1/64 MAX.
5. SCREW THREADS PER MIL-STD-9
6. ALL DIMENSIONS TO APPLY BEFORE PLATING OR CONVERSION COATING.

USED ON | NEXT ASSEMBLY | WEIGHT | SCALE | CLASSIFICATION

DRAWN FOR A.E. ROGERS 1-87
DRAWN BY A. PHILBROOK 1-87
CHECKED BY
APPROVALS: PROJECT | ENGINEER | MAT'L & PROCESS | STRUCTURES | THERMAL | MECH. ANALYSIS

NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS

SIGNAL LEVELS IN VLBA RECEIVING SYSTEM

AER\SIGREC | DWG. SIZE C | DWG. NO. 54120K007 | REV. A

C—54120K007 A

FIGURE 7.3

SECTION 8

DIGITIZER

A. E. E. Rogers and J. I. Levine

8.1 Specifications

8.1.1 General Specification

Sample Quantization:	(-W=00, -1=01, +1=10, +W=11) or 2-level coded in 1 bit (sign)
Data format:	flexible: including MK III
Flexibility:	1) Any formatted output can be assigned to any digitizer output (within the restrictions given below)
Restrictions:	1) All channels must be sampled at the same rate 2) Maximum digitization throughput(in 2 units - see sect 8.1.5) 2x32x8=512 Mbits/s expandable to 2x64x8=1024 Mbits/s 3) All outputs must be used in same formatter mode (see section on formatter) 4) Output rate x21 must be an integral number of kHz (as supplied by special output rate synthesizer)

8.1.2 Interface Specifications

8.1.2.2 Frequency and Time

FREQ:
Signals: 5 MHz at +13 dBm (nominal)

TIME:
Signal: 1 pps (used to define the 5 MHz transition coincident with the second mark)
Cable: RG-142 or equiv
Connector: BNC

8.1.2.3 Communications

Communication is via MONITOR/CONTROL bus, see SECTION 4.

8.1.2.4 Output to Recorder

Signals: 2 independently buffered sets of 36 RS422 signals from each formatter expandable to 72 signals from each formatter.

8.1.3 Formatter Specifications

Number of video inputs:	16 (8 USB plus 8 LSB) in each of 2 identical formatters
Number of formatter outputs:	36 (expandable to 72) in each formatter
Sample rates:	32,16,8,4,2 MHz (data always sampled at 32 MHz every nth sample used at lower rates)
Output format:	Serial data format with programmable time code, auxillary data, CRC error detection, sync word, parity and programmable data block and frame length. Data is not replaced by time code,CRC, etc. unless a MKIII compatible format is being generated in which case data will be replaced by overhead bits (except parity).
Video input level:	0+-0.5 dBm
Input impedance:	50 ohms unbalanced
Threshold equivalent DC offset and hysteresis:	< 50 microvolts
Threshold level:	200 mv (for magnitude) 0 mv (for sign)
Sampling epoch accuracy:	< 2 ns (between channels)
Sampling jitter and drift:	< 0.2 ns
Sampling modes:	2-level (1 bit) and 4-level (2 bits) (4-level coding -w=00,-1=01,+1=10,+w=11 with MSB (sign) bit and LSB bit on separate tracks)
Formatter modes:	1X (output rate/track = sample rate) 2X (output rate/track = sample rate/2) 4X (output rate/track = sample rate/4) 1/2X (output rate/track= sample rate*2) 1/4X (output rate/track= sample rate*4)

Notes: In 1X mode adjacent time samples are on the same track
In 2X mode odd and even samples are on separate tracks
In 4X mode there is a 4-way split i.e. 1st. sample to trk w, 2nd. to trk x, 3rd. to trk y, 4th. to trk z
In 1/2X mode two sampler outputs are on one track
In 1/4X mode 4 sampler outputs are on one track

tracks/video signal (or video signals/track):

SAMPLING	FORMATTER MODE 1X	2X	4X	1/2X	1/4X
2-LEVEL	1	2	4	(2)	(4)
4-LEVEL	2	4	8	(1)	(2)

Track switch: 36x36 switch to allow arbitrary reassignment of data samples to recorder tracks

Barrel switch: switch to allow reassignment of data to recorder tracks in a "barrel" shifting scheme which "rolls" every frame - programmable from 0(no roll) to 16 positions

Output Signals: 2 independently buffered sets of 36 RS422 signals from each formatter - expandable to 72 signals

8.1.3.4. Data Quality Analyser/Data Buffer (submodule of Formatter)

Data Memory: 4 Mbits

Counters for: Parity errors, Sync Errors, CRC errors, Phase cal extraction.

Tracks : 2 tracks can be simultaneously analysed and buffered

8.2 Description

The formatter is modular in design and uses VME packaging. The sampling clock synthesizer and A/D converters are in 2-wide VLA modules. A special purpose synthesizer is used to clock the data out of the formatter (189 MHz for MKIIIA or 190.072 MHz for VLBA format divided by 21 and then divided by the appropriate power of two for lower tape speeds). Figure 8.1 shows a block diagram of the formatter.

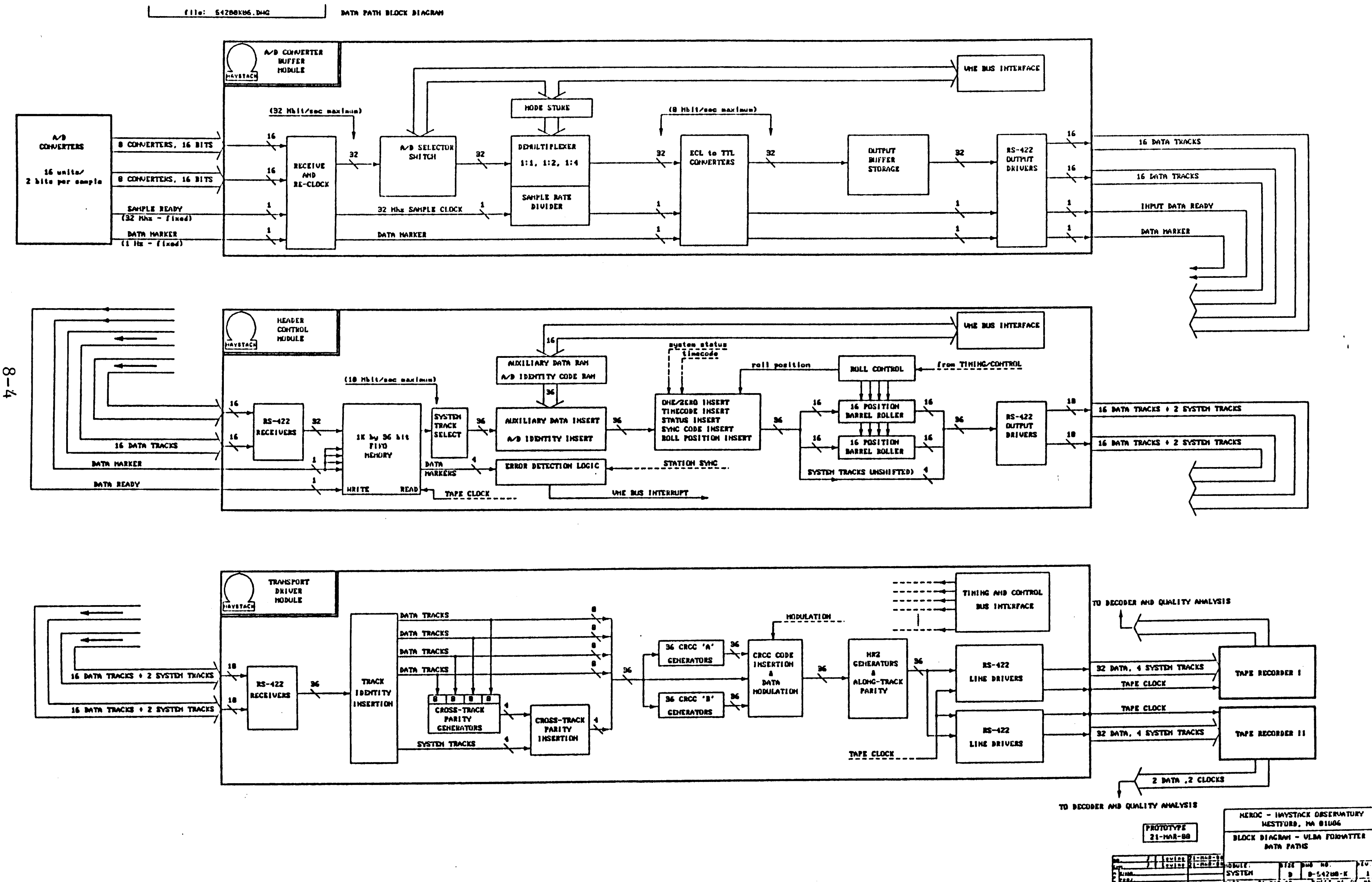

file: 54200KB6.DWG
DATA PATH BLOCK DIAGRAM
A/D CONVERTER BUFFER MODULE
A/D CONVERTERS
16 units/ 2 bits per sample
8 CONVERTERS, 16 BITS
8 CONVERTERS, 16 BITS
SAMPLE READY (32 Mhz - fixed)
DATA MARKER (1 Hz - fixed)
(32 Mbit/sec maximum)
RECEIVE AND RE-CLOCK
A/D SELECTOR SWITCH
MODE STORE
DEMULTIPLEXER 1:1, 1:2, 1:4
SAMPLE RATE DIVIDER
32 Mhz SAMPLE CLOCK
DATA MARKER
(8 Mbit/sec maximum)
ECL to TTL CONVERTERS
OUTPUT BUFFER STORAGE
RS-422 OUTPUT DRIVERS
VME BUS INTERFACE
16 DATA TRACKS
16 DATA TRACKS
INPUT DATA READY
DATA MARKER
HEADER CONTROL MODULE
16 DATA TRACKS
DATA MARKER
DATA READY
RS-422 RECEIVERS
(18 Mbit/sec maximum)
1K by 36 bit FIFO MEMORY
WRITE
READ
SYSTEM TRACK SELECT
DATA MARKERS
TAPE CLOCK
AUXILIARY DATA RAM
A/D IDENTITY CODE RAM
AUXILIARY DATA INSERT
A/D IDENTITY INSERT
ERROR DETECTION LOGIC
VME BUS INTERRUPT
STATION SYNC
system status
timecode
ONE/ZERO INSERT
TIMECODE INSERT
STATUS INSERT
SYNC CODE INSERT
ROLL POSITION INSERT
roll position
ROLL CONTROL
from TIMING/CONTROL
16 POSITION BARREL ROLLER
16 POSITION BARREL ROLLER
SYSTEM TRACKS UNSHIFTED)
RS-422 OUTPUT DRIVERS
VME BUS INTERFACE
16 DATA TRACKS + 2 SYSTEM TRACKS
16 DATA TRACKS + 2 SYSTEM TRACKS
TRANSPORT DRIVER MODULE
16 DATA TRACKS + 2 SYSTEM TRACKS
16 DATA TRACKS + 2 SYSTEM TRACKS
RS-422 RECEIVERS
TRACK IDENTITY INSERTION
DATA TRACKS
DATA TRACKS
DATA TRACKS
DATA TRACKS
SYSTEM TRACKS
CROSS-TRACK PARITY GENERATORS
CROSS-TRACK PARITY INSERTION
36 CRCC 'A' GENERATORS
36 CRCC 'B' GENERATORS
MODULATION
CRCC CODE INSERTION & DATA MODULATION
NRZ GENERATORS & ALONG-TRACK PARITY
TIMING AND CONTROL BUS INTERFACE
RS-422 LINE DRIVERS
RS-422 LINE DRIVERS
TAPE CLOCK
TO DECODER AND QUALITY ANALYSIS
32 DATA, 4 SYSTEM TRACKS
TAPE CLOCK
TAPE CLOCK
32 DATA, 4 SYSTEM TRACKS
TAPE RECORDER I
TAPE RECORDER II
2 DATA ,2 CLOCKS
TO DECODER AND QUALITY ANALYSIS
PROTOTYPE 21-MAR-88
NEROC - HAYSTACK OBSERVATORY WESTFORD, MA 01886
BLOCK DIAGRAM - VLBA FORMATTER DATA PATHS
MODULE: SYSTEM
SIZE D
DWG NO. D-54200-K

FIGURE 8.1

SECTION 9

RECORDERS AND PLAYBACK SYSTEM

A.E.E. Rogers and J.C. Webber

9.1 Specifications

9.1.1 General Specifications

Longitudinal recording will be used in which a narrow track headstack is physically moved between passes of the tape

Average recording rate: 100 Mb/s for 24 hours unattended

High data rate (HDR): 200 Mb/s or greater

For each channel and for an averaging time of 1 minute (real time)
Fraction of bits out of sync but flagged valid: $<10^{-5}$

Fraction of bits which are incorrect and flagged valid (excluding bits out of sync): $<3 \times 10^{-4}$

Fraction of bits flagged invalid: <0.01

If the above specs are met for the prescribed averaging time of 1 minute then there can be no loss of data (dropout) longer than 600 msec.

In no circumstances, even when performance degrades, should data which fail to meet error specs 1 (fraction of bits out of sync but flagged valid) or 2 (fraction of incorrect bits flagged valid) be passed to the correlator.

Weight of tape/day/station approx. 25 lbs at 100 Mb/s

Redundancy: The system will continue to ensure that observations can continue without maintenance in the event of single failures, provided unrecorded tape is available on at least one working transport.

9.1.2 Interface Specifications

The playback recorders (PBD) will provide "bit synchronized" data and clock on differential ECL lines capable of driving cables up to 100 feet. Each PBD will provide 36 parallel (but not deskewed) data and clocks. Recorder control will be essentially the same as in the acquisition recorder with augmented features in firmware for playback slewing and synchronizing.

9.1.3 Recorders

Write speeds: 180, 90, or 45 inches/sec for 8, 4, or 2 Mbit/sec standard data rates/track, assuming 50 kfci with 12.5% format overhead.

Read speed: 180 inches/sec for 8 Mbit/sec fixed rate. Transport is capable of playback at up to twice this rate, but further development would be required since this has not been tested.

Recording medium: D1-equivalent tape, thickness 13 microns, packaged on special "self-packing" 14-inch reels (12 hours at 128 Mbit/sec) or 16-inch reels (16 hours); alternate metal particle or evaporated metal tape possibly usable for higher volume densities (neither available yet as a commercial product).

9.2. Description

The VLBA recording system uses the same longitudinal tape transport (Honeywell model 96) as Mark III, equipped with: 1) a newly-devloped narrow-track recording headstack; 2) a new integrated controller using the VME architecture; and 3) new analog electronics to minimize noise and interference. The narrow-track recording headstack exhibits individual head performance equivalent to VHS cassette heads, and uses a positioning mechanism capable of better than 1 micron precision.

An initial implementation, a stack of heads each 38 microns wide will be used, permitting 16 passes with 32 data tracks plus up to 4 "system" tracks, using 4 micron guard bands; this permits writing 588 tracks across the 1-inch-wide tape. The system tracks may be used to record across-track parity or to systematically replace a failed data head; they may also be used to aid long-term track following. Depending on headstack position, only 3 system tracks may be in contact with the tape on some passes. Standard 27-micron-thick video tape (such as FUJI H621) will be used initially to produce Mark IIIA compatible recordings at tape speeds of 270 or 135 inches/sec at 33,000 kfci.

Although D1-equivalent tape (available now from Ampex and soon from Sony and 3M) has been shown to satisfy the VLBA requirements in limited laboratory tests, field testing under operational conditions is needed to confirm this choice of recording medium. Also, more evaluation of possibly superior media should be done prior to the time when major tape purchases must begin.

The head positioning system is completely analog and can place the headstack at any position within a 3000-micron-wide range, to a precision better than 1 micron. This makes it possible to accommodate future improvements in volume density by using narrower heads, since the positioner has no constraints. Placement of tracks (defined as the magnetized strips on the tape) is thus entirely defined in software.

SECTION 10

CORRELATOR

J. D. Romney

10.1 Specifications

This section summarizes the fundamental correlator specifications in a concise list; descriptive explanations and further details can be found in Section 10.2, Description, which is organized in parallel for convenience. Specifications marked with the # symbol are still preliminary, generally those carried over from earlier concepts and not yet subjected to detailed design for incorporation into the FX correlator.

10.1.1 Capabilities

10.1.1.1 Basic Dimensions

Stations	s = (10), (15), 20
Channels per station	c = 1, 2, 4, 8
Spectral Points per channel per station	l = 32, 64, 128, 256, 512, 1024

10.1.1.2 Additional Features

Oversampled Input Data	f = 1, 2, 4, ...
Interleaving	n = 1, 2 ($n \le f$)
Overlapping	v = 1, 2, 4, ...
Interpolation	z = 1, 2
Polarization	p = 1 (Normal), 2 (Polarized)
Polarized Spectroscopy	y = 1, EXCEPT when p = 2 AND: $l = 256 \longrightarrow y = 2$; $l = 512 \longrightarrow y = 4$ (where y is Polarized Resol'n Factor)

10.1.1.3 Modes and Restrictions

F Mode Limit	$s\ c\ n\ v\ z\ y\ /\ f \le 160$
X Mode Limit	$s\ (s+1)\ c\ p\ l\ /2 \le 262{,}144$

10.1.2 Data Interfaces

10.1.2.1 Input

Playback Drives (PBDs)	24
Playback Input Ports	20
Tracks, per station	36
Playback Speed, per track	8 Mbit/s (nominal), fixed
Speedup Factor, w.r.t. recording	1, 2, 4
Sample Rate	32, 16, 8, 4, 2 Msmp/s
Sample Quantization	2 bits

10.1.2.2 Output

Integration Time Quantum	100 ms
Integration Time, max.	# 102.4 s
Archive Data Rate, max.	0.5 Mbyte/s
Archive Format & Medium	"FITS-like", medium TBD
Distribution Format & Medium	FITS on 9-track tape @ 6250bpi.

10.1.3 Interferometer Model

10.1.3.1 Delay Tracking

Delay Range	Unlimited, via offset in PBD
Delay Switching Range	6000 samples
Coarse Delay Rate Range	# +/- 50 sample/s
Fine Delay Range	+/- 1/2 sample
Fine Delay Accuracy	0.001 sample

10.1.3.2 Phase Tracking

Phase Accuracy	0.002 turn
Fringe Rate Range	Unlimited (+/- full bandwidth)
Fringe Acceleration Range	# +/- 10.4 Hz/s

10.1.4 Other Features

10.1.4.1 Simultaneous Correlation

Subarrays	10
Switched Models	> 8
Switching Interval Quantum	100 ms

10.1.4.2 Pulsar Gating

Gate Profile	Arbitrary
Pulse Phase Resolution	1024 points/period
Pulse Timing Resolution	Equal to FFT length

10.2 Description

The following paragraphs provide explanatory descriptions and further details relating to the specifications in the parallel-numbered subsections 10.1.*.* above. Numerical values which are still preliminary are again flagged with the (#) symbol.

10.2.1 Capabilities

10.2.1.1 Basic Dimensions

The 20-station capability allows the correlator to support either global observations involving the VLBA plus up to 10 "foreign" stations, or the simultaneous correlation of any set of subarrays totalling as many as 20 stations. Eight channels per station is half the total number which can be recorded, but suffices to correlate in real time (possibly in several faster-than-real-time passes) any observations recorded at up to twice the maximum sustainable rate of 128 Mbit/s. The maximum frequency resolution, 1024 points, exceeds the nominal VLBA specifications by a factor of 2, but is provided to accommodate the FX channel profile. Resolution can be reduced from the FFT output by binary factors up to 32(#) through averaging of adjacent spectral points in the long-term integrator.

The specific values shown, generally binary submultiples of the maximum dimensions, are those supported by the mode switching which implements the tradeoffs among these dimensions and the other capabilities. Modes are described in Sections 10.*.1.3.

10.2.1.2 Additional Features

Optional facilities are provided to enhance sensitivity and resolution, and to support cross-polarized correlation. The first group involves resequencing and/or reprocessing of input samples in the FFT section. `Oversampled input data' (at factor $f$ times the Nyquist rate) must be decimated to maintain full spectral resolution. This may be done simply by processing only every $f$'th sample and discarding the rest; alternatively, the `interleaving' option $n = 2$ retains two Nyquist-sampled, interleaved streams which are then processed independently. This is only possible when $f >= 2$, of course.

In the `overlapping' option a single Nyquist-sampled stream (possibly interleaved) is processed several times with successive offsets of $1/v$ of the FFT length. And `interpolation' (or "zero-padding") with $z = 2$ breaks the input stream into groups of half the nominal FFT length, forcing the remainder of the input array to zero. All these options imply additional tradeoffs with the number of stations and/or channels which can be processed, as described under the "F Mode Limit" below. Spectra resulting from two or more separate FFT operations in the latter three options are combined in the integrator.

Cross-polarized correlation, $p = 2$, requires pairing channels in the multiplier/accumulator section where baseline correlations are formed. Each channel's station spectra are cross-multiplied not only among themselves but against those from the oppositely-polarized partner channel. This again influences the mode tradeoffs, in this case among stations, channels, and spectral resolution, under the "X Mode Limit". Finally, polarized spectroscopy represents an extreme of correlator performance, and the factor y incorporates the cost of supporting the highest resolutions.

10.2.1.3 Modes and Restrictions

Modes in the FX correlator arise in two distinct areas. The "F Modes" represent tradeoffs among stations, channels, and the various optional features implemented in the FFT section. The correlator comprises 160 FFT engines, enough to process 8 channels from each of 20 stations, for Nyquist-sampled data with no overlapping or interpolation. Additional processing required to implement the options -- as well as the capacity freed by decimating oversampled data -- is incorporated into the F Mode equation. With respect to the F Modes, a single binary submultiple of the station parameter s itself is available: $s = 10, 20$ only.

In general, spectral resolution is irrelevant to the F Modes; the FFT engines receive one input sample, and return one-half spectral point, per clock cycle, for any length FFT. The exception applies only to the special switching required to support high-resolution polarized correlation. Polarized correlation requires that two differently-polarized cross-power spectra be accumulated simultaneously in a single "FX chip", where the limited local storage restricts the resolution to 128 spectral points each.

To support higher resolutions it is necessary to process each channel two or four times and use different sets of output points, each one-half or one-fourth of the total.

The "X Modes" are imposed by the multiplier/accumulator section of the correlator, and in fact by the accumulator alone (so that "X" is rather a misnomer despite its appealing symmetry). Here the tradeoffs involve baselines and channels, as well as spectral resolution and polarization. Accumulator storage is provided for 256k = 262,144 complex values, which can accommodate a range of 20-station observations, from single-channel, high resolution spectroscopy to low-resolution, wideband cross-polarization measurements. The X Mode equation computes $s(s+1)/2$ "baselines" to include the self or single-dish power spectra; here the binary sub-multiple applies to the baseline rather than the station dimension, and $s = 15, 20$ only. The factor p represents the required double storage to support cross-polarization.

10.2.2 Data Interfaces

10.2.2.1 Input

The number of data playback drives (PBDs) connected to the correlator must exceed the 20 station input ports to allow efficient tape changing as well as repairs. While not yet fully defined, the inter-connection will allow each PBD to provide data to a different group of 4-5 station ports, and each port to receive data from a different group of 4 PBDs.

All these elements must support the full 36 track (32 data and 4 system) capacity which can be recorded. A fixed PBD playback speed is specified to simplify the equalization of reproduced signals; the nominal rate of 8 Mbit/s refers only to data bits and ignores parity bits and slack time for test cycles. A proportional speedup is induced when data recorded at, nominally, 4 and 2 Mbit/s are processed.

The playback sample rates are all those recordable, after application of any speedup factor, which will always raise recorded rates of 0.5 and 1 to a minimum of 2 Mbit/s. Output samples from the playback interface (PBI) are always transmitted with 2-bit precision; data recorded in 1-bit mode are reconstructed as unit-magnitude samples.

10.2.2.2 Output

The multiplier/accumulator is dumped every 100 ms; one or more, up to 1024(#), of these dumps can be averaged in the long-term integrator. Data transmission to the correlator archive -- and thus into subsequent processing -- is deliberately throttled to 0.5 Mbyte/s, and very short integrations therefore imply restrictions in baselines and/or channels.

Data recorded in the archive generally contains results from correlation of multiple observations, made at different times, by different users. An encoding scheme capable of correcting the errors which may arise over long time spans is also essential. These and other considerations make the FITS data format inappropriate for the archive, although the basic structures and number representation should be as close as possible to FITS to minimize the translation effort in producing the distribution tape. It is anticipated that a revised FITS standard will accommodate floating-point numbers by the time routine correlator operation begins.

10.2.3 Interferometer Model

10.2.3.1 Delay Tracking

Delay tracking is applied to individual station data streams, and all specifications refer to station delay with respect to the center of the Earth -- and to motion of terrestrial stations only. Tracking is implemented in two very distinct processes: Coarse tracking is maintained in units of data-sampling time quanta, and is achieved by modification of the readout pointer from the reclocking and frame-editing buffer in the PBI. Fine tracking corrects the remaining, fractional sample-time error by applying a phase ramp in the spectral domain at the output of the FFT section. The accuracy of fine tracking is determined by the 8-bit phase register used for this purpose; shown is the corresponding worst-case delay error for an individual FFT.

Delay switching is an aspect of model switching between different phase centers. Its range must be restricted to cover only a fraction of the coarse-delay buffer.

10.2.3.2 Phase Tracking

In the FX correlator, phase tracking is also applied on a station basis, and again the specifications refer to a station wavefront phase with respect to the center of the Earth, for terrestrial stations. Accuracy of phase tracking is determined by the 9-bit phase register which applies the required phase shift at the input to the FFT section; the accuracy shown thus applies to an individual sample.

10.2.4 Other Features

10.2.4.1 Simultaneous Correlation

Two different aspects of "simultaneous correlation" are extensively supported. Subarraying is essential for a variety of purposes, including dual 10-station correlation, efficient transition between temporally adjacent observing programs, and fringe searching. The extreme case of 10 subarrays is only useful for multiple single baselines, of course, but is taken as a convenient general upper limit. Stations and channels can be allocated to subarrays with complete generality. There is only one limitation in the selection of modes within each subarray: the long-term integrator will only support a maximum of 4(#) distinct dump intervals across all subarrays.

Model switching is a distinct capability which permits near-simultaneous correlation of different phase centers, etc., within a single processing pass. Since the correlated data arising from different models are not compatible, model switches must coincide with integrator readouts.

10.2.4.2 Pulsar Gating

A frequency-dependent pulsar gate is applied between the FFT section and the multiplier/accumulator. An arbitrary, binary-valued gating function can be specified for 1024 steps of pulsar phase, for each point in the spectrum. Timing resolution depends on the FFT length, which should be short enough that the entire group of samples transformed can be attributed sensibly to the same pulse phase.

10.3 Overview

The VLBA Correlator incorporates a spectral-domain or `FX' architecture. This differs from the conventional lag correlator essentially in the sequence of operations performed to calculate baseline cross-power spectra from the input station sample streams. The FX scheme first transforms the input data into the spectral domain, exploiting the efficient FFT algorithm and organizing as much other processing as possible on a station basis to minimize the number of operations required.

"Correlation" is then reduced to pairwise complex cross-multiplication of the station spectra rather than a multi-lag cross-correlation. FX and lag correlators thus represent opposite sides of the convolution theorem of Fourier transforms. For a many-station, high-spectral-resolution system as is required for the VLBA, elementary calculations as well as comparative design studies show that the FX architecture offers significant hardware economies.

10.2.1.2 Additional Features

Optional facilities are provided to enhance sensitivity and resolution, and to support cross-polarized correlation. The first group involves resequencing and/or reprocessing of input samples in the FFT section. `Oversampled input data' (at factor $f$ times the Nyquist rate) must be decimated to maintain full spectral resolution. This may be done simply by processing only every $f$'th sample and discarding the rest; alternatively, the `interleaving' option $n = 2$ retains two Nyquist-sampled, interleaved streams which are then processed independently. This is only possible when $f >= 2$, of course.

In the `overlapping' option a single Nyquist-sampled stream (possibly interleaved) is processed several times with successive offsets of $1/v$ of the FFT length. And `interpolation' (or "zero-padding") with $z = 2$ breaks the input stream into groups of half the nominal FFT length, forcing the remainder of the input array to zero. All these options imply additional tradeoffs with the number of stations and/or channels which can be processed, as described under the "F Mode Limit" below. Spectra resulting from two or more separate FFT operations in the latter three options are combined in the integrator.

Cross-polarized correlation, $p = 2$, requires pairing channels in the multiplier/accumulator section where baseline correlations are formed. Each channel's station spectra are cross-multiplied not only among themselves but against those from the oppositely-polarized partner channel. This again influences the mode tradeoffs, in this case among stations, channels, and spectral resolution, under the "X Mode Limit". Finally, polarized spectroscopy represents an extreme of correlator performance, and the factor y incorporates the cost of supporting the highest resolutions.

10.2.1.3 Modes and Restrictions

Modes in the FX correlator arise in two distinct areas. The "F Modes" represent tradeoffs among stations, channels, and the various optional features implemented in the FFT section. The correlator comprises 160 FFT engines, enough to process 8 channels from each of 20 stations, for Nyquist-sampled data with no overlapping or interpolation. Additional processing required to implement the options -- as well as the capacity freed by decimating oversampled data -- is incorporated into the F Mode equation. With respect to the F Modes, a single binary submultiple of the station parameter s itself is available: $s = 10, 20$ only.

In general, spectral resolution is irrelevant to the F Modes; the FFT engines receive one input sample, and return one-half spectral point, per clock cycle, for any length FFT. The exception applies only to the special switching required to support high-resolution polarized correlation. Polarized correlation requires that two differently-polarized cross-power spectra be accumulated simultaneously in a single "FX chip", where the limited local storage restricts the resolution to 128 spectral points each.

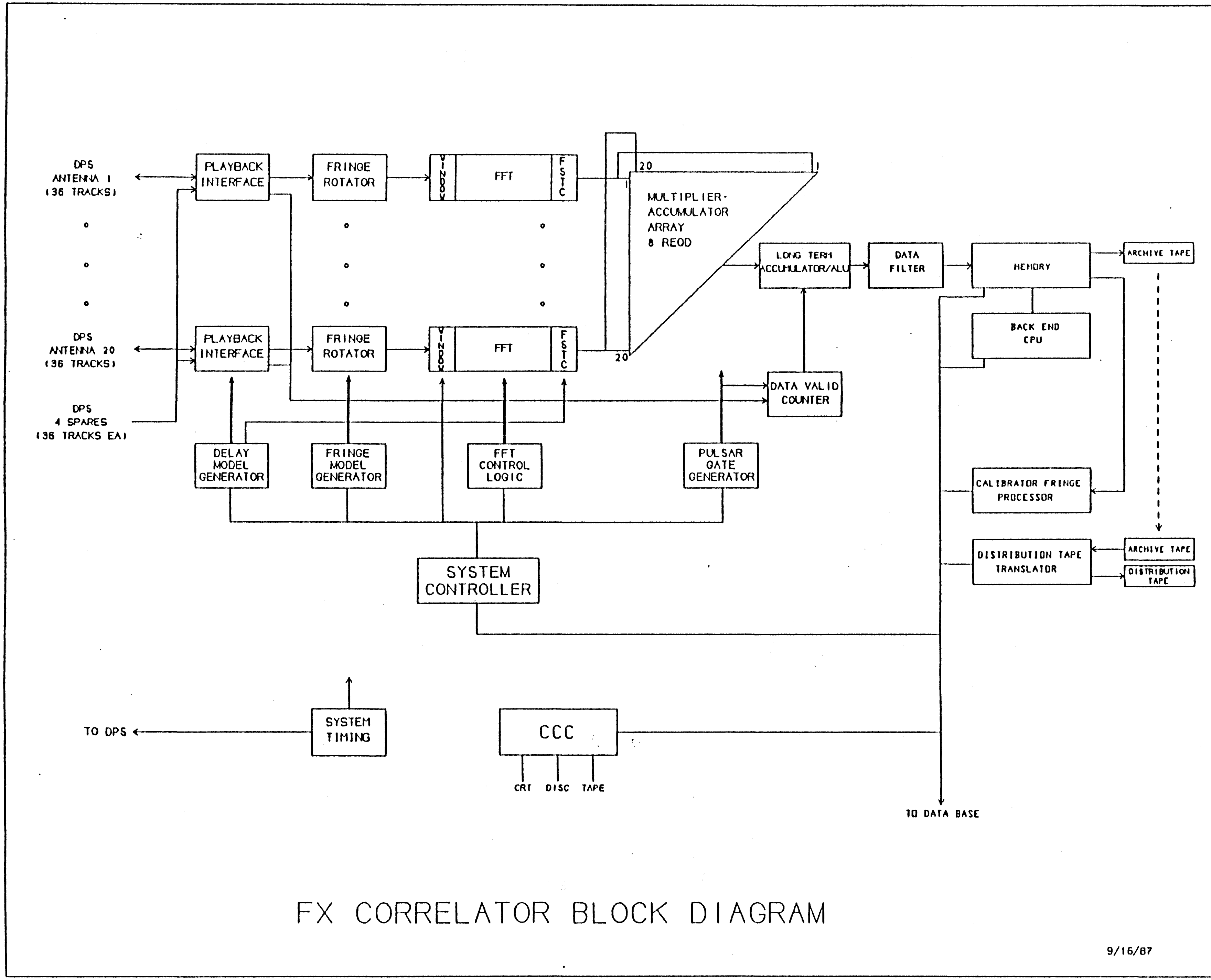

DPS ANTENNA 1 (36 TRACKS)
DPS ANTENNA 20 (36 TRACKS)
DPS 4 SPARES (36 TRACKS EA)
PLAYBACK INTERFACE
FRINGE ROTATOR
WINDOW
FFT
FSTC
MULTIPLIER-ACCUMULATOR ARRAY 8 REQD
20
1
LONG TERM ACCUMULATOR/ALU
DATA FILTER
MEMORY
ARCHIVE TAPE
BACK END CPU
DATA VALID COUNTER
DELAY MODEL GENERATOR
FRINGE MODEL GENERATOR
FFT CONTROL LOGIC
PULSAR GATE GENERATOR
CALIBRATOR FRINGE PROCESSOR
DISTRIBUTION TAPE TRANSLATOR
ARCHIVE TAPE
DISTRIBUTION TAPE
SYSTEM CONTROLLER
TO DPS
SYSTEM TIMING
CCC
CRT
DISC
TAPE
TO DATA BASE
FX CORRELATOR BLOCK DIAGRAM
9/16/87

Figure 10.1

The computer system includes the following functional elements, although they have not yet all been allocated to particular processors:

- Supervising the correlator's operation and supporting interfaces to the operator and the VLBA database is the correlator control computer, CCC. (This may, additionally, serve as the host to the database itself.)

- The system controller establishes mode configurations, and computes intermediate parameters required by the hardware model generators for delay, phase, and the pulsar gate.

- The archive writer receives correlated spectra, merges related global parameters from the CCC and calibration information from the database, and supervises the recording of all these data on specialized archive media.

- Two tasks loosely coupled to the rest of computer system provide further processing of correlated data: The distribution translator sorts and translates archived data into a standard format (FITS) on 9-track computer tape. And the calibrator fringe processor applies a fringe-fitting algorithm to selected observations of appropriate sources to track station clock performance.

SECTION 11

POST PROCESSING

W. D. Cotton

11.1 Specifications

11.1.1 What Post Processing Is Supposed To Do.

The purpose of the post processing hardware and software is to allow the user of the VLBA to extract physically meaningful information from his data.

11.1.2 Correlator Interface (Distribution Tape)

The distribution format for VLBA data will be FITS (Wells, Greisen and Harten 1981, A. & A. Suppl. vol 44, p 363.; Greisen and Harten 1981, A. & A. Suppl. vol 44, p 371. and Harten et. al. 1985, Mem. S. A. It., 56, p 437). The principle features of these files are 1) multiple sources are kept in the same file and 2) much auxillary information is carried in extention files on the FITS tape. The intent is to have relatively raw data with calibration and editing information mostly unapplied but given in an extention table.

11.1.2.1 Use Of FITS

The VLBA distribution tapes will follow standard AIPS conventions for FITS tapes. FITS table useage was deemed unacceptable to use for several of the files and a more flexible 3 dimensional table format using binary data is being formulated.

11.1.2.2 Items Incompletely Determined

There are several details of the VLBA distribution tapes which have not yet been completely determined. Other details are likely to be determined to be inadequate as this format goes into use and may be changed. One of these items is how weather data will be passed.

11.1.2.2.1 Observing And Correlation Logs

The observing and correlation logs will be carried with the data. It has not yet been decided whether to put this information in the AIPS history file or as a separate file. The latter choice is probable but the details have not been worked out.

11.1.2.2.2 Scaled Integer Vs. Floating Point.

VLBA data will probably use 32 bits for data in the main data file (the example shown later uses mostly 16 bits). It is not yet clear if scaled integers or floating format is preferable. We assume that the FITS standards will include a floating format convention, probably IEEE, by the time the VLBA goes into production. IEEE floating format will be used in the tables.

11.1.2.3 Tables Associated With UV Data.

Much auxillary information about the data is carried in tables associated with the file. A number of these are necessary for the proper interpretation of the data and others may be generated later. The necessary tables are: the antenna table, the source table (for multisource files), and the channel table (if more than 1 IF is included). The following are highly desirable but not required: Cal table and Flag table.

The following lists the tables currently associated with a FITS uv file:

- Antenna file (required) - this file contains antenna locations, time information and other antenna specific and array geometric information. The file described in this document contains only a subset of the information contained in the AIPS antenna file. This information will eventually be included.

- Channel table (required if more than one channel used) - this file gives the frequency offsets for the IFs in the data. An IF in this sense consists of a group of one or more equally spaced frequency channels; these groups may be unequally spaced in frequency. The frequency offset of the referency channel in each IF is given in the channel table. IF is a regular axis in the data but the units are IF number.

- Source table (required if more than one source is given) - a given data file may contain data from several sources; the source number is carried as a random parameter. The source number points to an entry in the source table which gives the source specific information, e.g. position.

- Cal table (optional) - this table contains the geometric and atmospheric model used and other calibration information such as system temperatures.

- Gain table (optional) - this table contains information about amplitude, phase, delay etc. corrections to be applied to the data. The data itself is in relatively raw form with only sufficient phase calibration to allow averaging of the data to the time and frequency resolution in the file. The details of the gain table are likely to change as the calibration needs become better defined. Other calibration tables for purposes such as bandpass calibration may be added.

- Flag table (optional) - this table will contain descriptions of data to be ignored. This may be modified somewhat in that some data may be flagged in the visibilities (weights non positive) with a corresponding table describing the data which has been flagged. This allows selective unflagging of data flagged at correlation time.

11.2 Description

11.2.1 General

The processing path, as the data progresses from the correlator through the mapping stage, is divided into two parts, correlation processing (on-line) and post-processing (off-line).

Correlation processing is defined as those programs which are run automatically on the raw correlator output in dedicated computers that are directly linked to the correlator. The "standard VLBA correlator output" that is archived and supplied to the astronomer will be the output of the correlator.

Post-processing is defined as those programs which operate on the data thereafter. These are run by the astronomer on demand. Post-processing includes all further processing including analysis. No attempt is made to differentiate between the post-processing that is done for the original map set (if appropriate) and that done at the observers home institution.

11.2.2 Correlator Interface And Synchronous Processing

There is a certain set of operations that must be performed on almost all VLBA visibility records and need only be done once. These tasks will be done in several dedicated computer systems that accept the raw correlator output. To maintain accountability, the correlator model delays, delay rates and phases will be carried along in the calibration table. Thus each archive visibility record (residual values) can be rapidly converted to interferometric observables.

11.2.3 Post-Processing

11.2.3.1 Architectural Overview And Philosophy

The various types of observations to be made on the VLBA should use the same software to the greatest extent possible. Specifically, the data format should be flexible enough to handle continuum, spectral line, and astrometric / geodetic data. This insures that, for example, source maps can be made from astrometric data or that astrometric source positions can be found from mapping data (within the limitations imposed by observing style).

Much of the science that can be done with the VLBA will concern changes in the source and/or baseline parameters over long periods of time. Therefore the data archive system must preserve all of the information needed to reconstruct any amplitude, phase, and delay modifications made to the data and must preserve all information needed for full geodetic and astrometric analysis of the data. Such a reconstruction should not require reference to the original software since that software will probably change with time. To satisfy this requirment, the total interferometer model values with suffucuent derivatives will be kept in the gain table to compute with sufficient accuracy the model at an arbitrary time. Any calibration of the data which modifies this model will modify the values and the derivatives in the gain table.

11.2.3.2 Hardware

11.2.3.2.1 Current Hardware Thinking

The hardware of a sort that would be used in post-processing involves a technology which is undergoing extremely rapid evolution. Component selection changes on a time scale of as little as six months; some components become uneconomical to operate after a lifetime of only 5 to 7 years. Because of this rapid technological evolution, significant effort was not put toward optimizing the detailed hardware configuration. Nor was effort spent cross comparing various manufacturers' products. Above the NRAO's general, ongoing efforts in this area. Developement of the post-processing software may proceed using existing computer hardware at NRAO. The VLBA post-processing computer hardware need not be purchased until late in the project schedule.

11.2.3.2.2 Size Of Problem And Comparison To VLA

The computing capability now (Apr. 1988) available for the VLA seriously limits the science that can be done with that instrument. This is the conclusion of studies that have led to a proposal that NRAO acquire a network of minisupercomputers for the reduction of VLA data. The problems that drive this need are those for which it is desirable to image the entire field of view of the primary antenna beams at high resolution. The size of the images needed is very large. Many of the experiments that need the large images are spectral line observations where there are many images to make.

A study of the computing needs of the VLBA has also been done, although the needs of an instrument that will not be on line for several years cannot be known as well as those of an instrument already in operation. The conclusions are that, for most observations, the wide fields that drive the large VLA needs are not needed for VLBI. The brightness temperature sensitivity of the VLBA is very much worse (because of the resolution) than for the VLA so typically only very compact sources can be observed. Also, delay and fringe rate offsets insure that confusing sources in the primary beams will not affect data from the program source in most cases. Therefore the image sizes are driven by the source structure only and should generally be manageable with the class of minisupercomputers currently in use for VLA data reduction.

There are some extreme cases for the VLBA however. The worst that is forseen would be an effort to image the water masers in an extended source such as Orion by brute force methods. Maps with over 40,000 pixels on a side, for each of 512 channels might be desired. These extreme cases are so bad that they could not be done even if several supercomputers were available. Therefore more clever techniques such as making low resolution images, or fringe rate maps, of the whole field, followed by small images of the region of each maser cluster, must be used in any case. If such techniques are used, and if the extreme case experiments are a small fraction of the total (few percent, at the most) then these observations can be reduced on the super-minicomputers. The conclusion of the study of the computing needs of the VLBA is that a computing power about equivalent to several Convex C1's.

This conclusion only applies to the VLBA used as a stand alone instrument or used with other VLBI stations. When the VLBA stations near the VLA are used as outriggers to the VLA, they make the problems for the VLA worse. They increase the resolution without either reducing the brightness sensitivity or providing delay and rate discrimination sufficient to overcome the need to image wide fields. Therefore, for many experiments, the size of the images needed, in pixels, will be even larger than for the VLA alone. This will further increase the already very large computing needs of the VLA. The current budget of the VLBA does not support the additional needs of the VLA caused by the nearby VLBA stations.

11.2.3.3 Software

11.2.3.3.1 Decision To Use Common Software For Processing VLBA And VLA Data.

The techniques used and the software needed for all kinds of interferometry are sufficiently similar that there is no need for specific software packages for every instrument. In particular, the software needed for the VLBA will be so similar to that needed for the VLA that the VLA software package, which represents many man-years of work, should be used. Until the late 1970's, the techniques used for linked interferometers and for VLBI were very different, largely because the linked interferometers were able to measure the visibility phase while VLBI was not able to obtain any phase information. Since then, the VLA has been operating at high frequencies on baselines that are sufficiently long that the phase measurements are poor. Techniques have been developed to use closure phases and "self-calibrated" amplitudes. As a result, the techniques used for both kinds of instruments are now very similar.

11.2.3.3.2 Need For Transportability.

Much of the software developed in support of the VLBA will be run at various university facilities as well as at NRAO processing centers. This both allows the user to make late changes to the displays and analysis and relieves NRAO facilities of some of the computing burden generated by the observations. Software involved in observation preparation and post-processing may be very common at these other facilities. This is certainly the case in VLA support software, where the main post-processing package is run at more than 25 institutions. As such it is important that the software be as transportable as possible.

11.2.3.3.3 Use Of AIPS For All Software Involving User Interactions

The primary data analysis system for the VLA is now the AIPS (Astronomical Image Processing System) package. This package already has most of the functions needed for processing astronomical data from the VLBA and is routinely used for VLBI data reduction. There are a few functions that are still needed (e.g., astrometric calibration) for complete VLBA data reduction but those should be available sometime in the near future.

Using AIPS makes a large body of data analysis and display capabilities available that would require a tremendous effort to duplicate in a VLBA specific package. To avoid requiring users to learn two systems, AIPS should contain all user routines used on the VLBA data after correlation, including all editing and calibration routines that are now outside of AIPS for the VLA.

An advantage of the AIPS system as it is now coded is that it is designed to be easy to move from one type of computer to another. This allows users that have a reasonably powerful computer at their home institution to take their data home and analyze it at their leisure.

It is not yet clear where the geometric (geodetic and astrometric) analysis will be made. The capability should be provided within the standard package but the Geodetic community may also want to be able to use their own software. The VLBA software should be able to provide an output data set that contains all of the necessary data to extract geodetic information. This means that all alterations made to the data by the correlator and reduction software should be undone or at least documented to the extent that they can be undone easily.

11.2.3.3.4 AIPS

Most of the astronomical data obtained with the VLBA will be processed through the AIPS system or its successor so it is desirable to have a post-correlation database compatible with that used in AIPS.

Distribution Tape format. The uv-FITS format will be used whenever data is passed to the post processing system. The uv-FITS format is sufficiently compact and flexible that it should be a rather efficient means of storing data.

Database structure. AIPS data files are structures very much like FITS files on tape. There are two basic types of data sets: 1) regularly spaced arrays (i.e., images) and 2) irregularly spaced arrays (i.e., uv data). Additional types may be added if necessary. Since VLBA data will be predominantly of the second type, most of the following comments will be directed towards this type of dataset. There are three distinguishable parts of the AIPS database structure: the catalog header, the main data file and extention files.

- Catalog. The catalog header contains information about a database such as source name, observing date, the amount of data, details of the structure of the main data file and the existence of and number of any extention files. The catalog header record currently has a fixed structure which, although more general than those of previous data reduction systems, is the least flexible portion of the AIPS database.

- Main data files. The form of the uv data files in AIPS is a sequence of logical records containing a regular, rectangular array of data (e.g., correlator lags, spectral channels, time, etc.) and a number of \`random' parameters describing the array (u, v, w, time, baseline, etc.). The number and order of the random parameters is given in the catalog header. At the present time there is no limit on the number of random parameters but there is space in the catalog header for the labels for only the first seven. The data array in each record is also described in the catalog header which gives the number of axes, the axis type, the dimension of each axis, the axis value increment, a reference pixel (needs be neither integer nor in the bounds of the array given) and the axis value at the reference pixel. The format of the current catalog header allows up to seven dimensions. The current convention is to have RA, Dec, Stokes type and Frequency as an axis even if that axis is degenerate. This allows a convenient way to specify position, frequency, etc. This structure requires that there be a uniform spacing along each axis which may present problems for the VLBA (e.g., when observations are made in the bandwidth synthesis mode). This limitation can be circumvented by use of channel number instead of frequency.

- Extention files. Extention files are used to store information not contained in the catalog header or the main data file. An example of an extention file is the History file which is carried along with all AIPS data files. This file contains ASCII records describing all processing which has been done on the data in the file. Other current extention files are the antenna files, calibration and editing files. Extention files contain a header record containing general information; for instance Antenna file headers carry time information like the Greenwich Sidereal Time at IAT midnight for the reference date. Extention file entries consist of fixed length logical records which may be complex data structures. VLBA data bases will use extention files to store antenna logs, correlator logs, calibration tables, correlator models, etc.

Database access. AIPS programs generally access the main data files sequentially which allows reading large blocks of data at a time and overlapping I/O and computation by means of double buffering. In order to increase I/O speed, DMA transfer requests are sent directly to system utilities rather than using FORTRAN I/O. This allows programs to directly access the I/O buffer removing one memory-to-memory copy of the data. The I/O routines are quite fast and are probably comparable in speed with mapping virtual memory onto the data base. The AIPS I/O routines have been designed to maximize speed and flexibility at the cost of increasing the complexity of their use.

I/O to extention files is generally sequential but the routines which handle the I/O are capable of random access and mixed reads and writes. This increased flexibility comes at a cost of reduced speed. However, since the extention files are generally much smaller than the main data file the reduced I/O speed is usually not serious.

11.2.3.4 Special Considerations For Astrometry And Geodesy

The primary observables of interest for astrometry and geodesy are the group delay (from bandwidth synthesis), the phase, and the phase delay rate. It is felt that the values of these quantities should be given as totals, not as residuals from the correlator model. If total values are kept, there is no need ever to remember the details of the correlator model. If residuals and/or geocentric values are being kept, the correlator model should be carried along for all further stages of reduction, to very high accuracy. We will be able to carry along the delays and phases used during correlation in the calibration/gain table. Thus the VLBA data sets would be similar to the current Mk III data sets in that observables can be recovered essentially as fast as data sets can be read in.

Calibration data include weather measurements (temperature, pressure, and humidity or dew point), water vapor radiometer measurements (reduced off-line), perhaps with algorithms that are the in the correlator. Provisions for deriving dual-frequency ionospheric corrections must be available. This procedure requires knowledge of all the frequencies used for bandwidth synthesis in order to determine the effective frequency at each band. Source image information may be used to correct the measured delays.

In the first stage of analysis, a model for station position and earth orientation (tides, precession, nutation, polar motion, etc.), source positions, the Solar System barycenter, general relativity, antenna geometry, etc is used to calculate a priori values of group delay, delay rate and phase. Changes to the model are found by a least-squares procedure that compares a priori's with the observables. During the analysis stage, the investigator should be able to turn on or off the various parameters to be solved for. It should be possible to analyze single, short experiments as well as large ensembles of data from several observing sessions. It should be possible to classify some parameters as "global" (having the same value for many experiments), such as source and station positions; and some as "arc" (having values that change from experiment to experiment, or even within an experiment) such as clock or atmospheric parameters.

11.2.4 Miscellaneous Computing Support

The VLBA like other similar instrumentation will require ongoing support and continued development. This work will utilize computer resources over and above those required for the normal data processing operations. Similarly, astronomers located at the center will also require additional facilities.

It is important that these auxiliary aspects and the normal data processing operations do not interfere with each other. If common resources are used for both data processing and development this implies liberal overall capacity. This is the approach that has been taken here. It may not be best, however, because the necessary data processing load is very inelastic and difficult to predict. The question of separating the operational and other computer facilities is perhaps best faced after we have some early operational experience.

11.3 Manpower Requirements

We estimate that 10 man-years of programming effort are required to upgrade the AIPS software for VLBA data analysis. A fairly large effort has already gone into writing new AIPS tasks for VLBI and many VLBI experiments are now being reduced through AIPS. Ten man-years over and above the current level of VLBI programming effort in AIPS will allow creating the special calibration and editing programs for VLBA data. The greatest uncertainty in the manpower estimate concerns the special software required to support astrometry and geodesy. We may choose to integrate an existing non-NRAO, non-AIPS geodetic software package into AIPS. The 10 year manpower estimate excludes creating an entirely new and duplicate geodetic software system.

11.4 Cost Estimates

Currently $3.5 M is budgeted for post ppprocessing computing hardware; the systems to be acquired will be a standard AIPS configuration at the time of purchase. This hardware need not be purchased prior to 1989. It is hoped that advances in computer technology over this period will improve the performance/cost ratio. Post-processing software will depend largely on procedures already developed for the VLA and existing specialized VLBI software.

SECTION 12

OPERATIONS

C. Bignell

12.1 Introduction

The current operational needs for the VLBA are presented in several subsections and cover specifically: manpower requirements, antenna site workload requirements, array operations center, operating budget and the plan for phasing into operations and the operation budget.

12.2 VLBA Manpower

The manpower estimates are predicated on the assumption that the VLA and VLBA will operated as one entity, sharing where possible, all resources including personnel. The central location for most of the manpower will be Socorro, New Mexico. Table 12.1 lists the current VLA manpower levels as well as the estimated levels for the combined VLA and VLBA operations.

12.3 Antenna Site Work Load

The original estimates of the average amount of work required at each of the antenna stations has not changed and is listed in Table 12.2. It should be noted that these times do not include any unusual maintenance which may be site specific such as snow removal, etc. More discussion of potential site differences are presented in sub section 12.4.2.

12.4 Operating Budget

These estimates listed in Table 12.3 are based on assumptions presented in the next the next sub section.

12.4.1 Budget Assumptions

Some of the operating budget estimates were based directly on VLA experience where most appropriate. These include:

1. The increase in the number of personnel for the combined operations compared to the VLA operations is about 94. The operating cost for wages and benefits includes costs for these 94 personnel. These numbers are calculated using current salary levels appropriate for each of the 94 positions and a benefit rate of 27.5 percent.

2. Travel for antenna maintenance is based on assuming a need for at least 12 trips per antenna per year by an average of 1.5 people per trip and that for sites (a) more than 500 miles from the AOC a stay of 4 days and three nights is required, (b) between 100 and 500 miles from the AOC a stay of 3 days and 2 nights is necessary and no over night stays are necessary for sites less than 100 miles away. This amounts to about \$130 K. In addition it is assumed that 2 vehicles are required for visitor and general transforation needs at an annual cost of about \$8.4K.

3. General travel is based on VLA experience and scaled approximately to the number of employees. Average cost per individual per year for VLA travel is 0.5K whereas the average annual cost per individual for the Computer, Scientific and Electronics is 1.1K, 1.4K and 2.1K respectively. Using these numbers and the appropriate personnel levels, the general travel costs for the VLBA were estimated at about \$85K.

4. Digital communications estimates are based on assuming four dedicated lines per site for both data and voice requirements. It may be possible to reduce these costs by as much as a factor of 2 by using other alternatives such as packet switched data networks for data transmission.

5. Regular telephone communications estimates are based directly on the most current estimates for what NMIMT would charge NRAO for use of their system in the new AOC building. Further assumptions include an average of one line and phone per individual.

6. Power requirements at the antennas are based on assuming each site will require about 50KW and using a cost rate appropriate for each site.

7. Power requirements for the Array Operations Center are based on a load of 100KW for computers and 150KW for other equipment and a final usable building size of 57000 sq. ft. The VLBA contribution is determined by scaling by the ratio of the number of VLBA to total personnel in the building (67/150).

8. Antenna M&S is based directly on VLA costs scaled by the number of antennas (approximately 3.9K per antenna).

9. Electronics M&S is based on VLA experience where the estimated "system" cost is \$3K per receiver (a total of 28 x 4 systems. For the VLBA there are 10 antennas each with 10 systems giving an approximate cost of \$300K. There is in addition \$45K for tape head replacement and \$22K for tape transport replacement.

10. Operations requirements include \$45K for tape replacement and \$15K for miscellaneous materials.

11. Computer M&S consists of the following contributions: contract maintenance for 6 computers (4 Post Processing, 1 Array control and 1 correlator control) $230K, non-contract maintenance $45K, General M&S is taken as $112K and is based directly on VLA experience.

12. Plant maintenance for each site is calculated to include costs for vehicle, site leases (where appropriate), other equipment rental, janitorial, as well as site, road, building and equipment maintenance and water. This is an average of $15.9K per antenna site. Maintenance for the AOC is based on NMIMT's initial estimates of about $2.89 per sq. ft.. This translates into about 91K per year for a 67000 sq. ft. building and an employee ratio of 67/150.

13. Other M&S includes all the necessary administrative supplies ($95K) and is based on VLA experience.

14. The shipping costs are based on assuming: (a) a 40 lb package being shipped each way between each site and the AOC for 300 days/yr, (b) shipment is by UPS for continental US and Blue Label overseas to give a total of $157K, (c) regular freight, postage and data for $35K and (d) shipping costs for modules which is expected to be $37K and $30K in the first and second year periods of operation respectively and $18K in subsequent years. This shipping estimate do not include foreign telescopes.

15. The new equipment was taken as $500 K.

12.4.2 Operational Differences of the Antenna Sites

The current operating budget estimate more accurately reflects the operating differences between the different sites. These diferences mainly fall into the areas: communications, power, shipping, site and antenna maintenance and other utilities. In addition these estimates include providing seven of the ten sites with dedicated vehicles and appropriate mileage costs for the other sites.

12.5 Operational Buildup Plan and Budget

An very simple operational plan has been put together. It is based on the following assumptions:

1. An antennas initiating schedule of 1,4,2,3 antennas for the years 1988, 1989, 1990 and 1991 respectively.

2. A preliminary (7 antenna) correlator becoming operational at the end of 1990.

3. Apart from the considerations of 1. and 2. above a linear ramp-up of other personnel from construction into operations is assummed.

4. All costs (except RE equipment) were based on an average cost per person and per antenna.

Table 12.4 lists the number of antennas operational by year end and the number of operational personnel on board by year end for each year beginning 1987.

Table 12.1

VLA AND VLBA OPERATIONAL MANPOWER LEVEL

Division	Position	VLA Curr Level	VLA AND VLBA Personnel Soc	VLA AND VLBA Personnel Site	VLA+VLBA+SC Personnel Soc	VLA+VLBA+SC Personnel Site	Notes
Electronics	Head	1	1	0	1	0	
	System Technician	0	1	0	1	0	
	Systems Engineer	1	1	0	1	0	
	Visiting Engineer	1	1	0	1	0	
	Cryogenic Grp Ldr	1	0	1	0	1	
	Cryogenic Tech	2	0	5	0	5	E
	Low Noise Rcv Grp Ld	1	1	0	1	0	
	Low Noise Rcvr Engr	1	2	0	2	0	
	Low Noise Rcvr Tech	6	7	1	7	1	E
	IF/LO Grp Ldr	1	1	0	1	0	
	IF/LO Engr	0	1	0	1	0	
	Maser Engr	0	1	0	1	0	
	IF/LO Tech	4	5	1	5	1	
	Digital Grp Ldr	1	1	0	1	0	
	Digital Engr	0	1	0	1	0	
	Digital Tech	3	5	0	5	0	
	Correlator Engr	1	2	0	2	0	
	Correlator Tech	1	2	0	2	0	
	Recorder Engr	0	1	0	1	0	
	Recorder Tech	0	3	0	3	0	
	Communications Tech	0	1	0	1	0	
	Field Grp Ldr	0	1	0	1	0	
	Field Tech(at sites)	0	20	0	20	0	
	Waveguide Grp Ldr	1	0	1	0	1	
	Waveguide Tech	1	0	1	0	1	
	Draftsman	1	2	0	2	0	
	Total	28	61	10	61	10	

Table 12.1

VLA AND VLBA OPERATIONAL MANPOWER LEVEL

Division	Position	VLA Curr Level	VLA AND VLBA Personnel Soc	VLA AND VLBA Personnel Site	VLA+VLBA+SC Personnel Soc	VLA+VLBA+SC Personnel Site	Notes
E&S/Antennas	Head	1	0	1	0	1	C
	Vehicle Mechanic	1	0	1	0	1	
	Site Electrician	1	0	1	0	1	
	Aircondition,Plumbng	1	0	1	0	1	
	Carpenter	1	0	1	0	1	
	Antenna Mechanic	9	0	10	0	10	
	Antenna Servo Tech	4	0	6	0	6	
	Engineer/Supervisors	2	0	3	0	3	
	Machinist	2	0	3	0	3	
	Draftsman	1	0	2	0	2	
	Labourer	2	0	3	0	3	
	Total	25	0	32	0	32	
Array	Head	1	1	0	1	0	
	Chief Array Oper.	1	2	0	2	0	
	Array Oper.	7	11	1	11	1	
	Main. Coord.	1	1	0	1	0	
	Chief Corr. Oper.	0	1	0	1	0	
	Corr. Oper.	0	5	0	5	0	
	Data Analysts	3	5	0	5	0	
	Total	13	26	1	26	1	
Business	Head	1	1	0	1	0	
	Sr. Adm. Ass.	1	1	0	1	0	
	Admin. Aide-person.	1	1	0	1	0	
	Secr. Pool	3	4	1	6	1	
	Recep./Oper.	1	1	0	1	0	
	Ship Clerk	0	1	0	1	0	
	Librarian	0	1	0	1	0	B
	Guard/Janitor	4	0	4	0	4	
	Janitor	1	2	0	2	0	
	Warehouse/Bus	1	0	1	0	1	
	Receiving	1	1	0	1	0	
	Leadman/Shuttle Dr.	1	1	0	1	0	
	Shuttle Driver	0	1	0	1	0	
	Sr. Buyer	1	2	0	2	0	A
	Buyer	1	1	0	1	0	A
	Purch. Secr.	2	3	0	3	0	A
	Head Cook	1	0	1	0	1	
	Cook/Housekeeper	3	0	1	0	1	
	Total	23	21	8	23	8	

Table 12.1

VLA AND VLBA OPERATIONAL MANPOWER LEVEL

Division	Position	VLA Curr Level	VLA AND VLBA Personnel Soc	VLA AND VLBA Personnel Site	VLA+VLBA+SC Personnel Soc	VLA+VLBA+SC Personnel Site	Notes
Fiscal	Head	1	1	0	1	0	B
	Accountant	1	1	0	1	0	
	Bookeeper	0	2	0	2	0	
	Fiscal Clerks	3	3	0	3	0	
	Total	5	7	0	7	0	
Computer	Head	1	1	0	1	0	
	Ass. Div. Hd/Op.Man.	1	2	0	4	0	
	Systems Prog./Anal.	1	2	0	8	0	
	Senior Programmers	6	8	0	9	0	
	Programmers	2	5	0	13	0	
	Engineer	1	1	0	1	0	
	Technician	2	5	0	6	0	D
	Oper. Supp.(Libr.)	2	3	0	8	0	
	Computer Operators	1	1	0	9	0	
	Total	17	28	0	59	0	
Scientific Services/ Management	Director	1	1	0	1	0	
	Deputy Director	1	2	0	2	0	
	Scientists	6	8	0	10	0	
	Systems Scientists	5	9	0	9	0	
	Mathematical Anal.	0	0	0	3	0	
	Post Docs	2	4	0	6	0	
	Resident Cust./Sup.	0	0	1	0	1	
	Photographer	0	1	0	1	0	B
	Technical Illust.	0	1	0	1	0	B
	Secretaries	2	1	0	1	0	
	Total	17	27	1	34	1	
Grand total		128	170	52	210	52	

Notes:

A. Number of buyers and purchasing secretaries assume the use of a computer for inventory and purchasing.
B. Exact number of personel may depend on any particular redistribution of manpower within NRAO in the future.
C. Assumes grounds work and much of caretaking is contracted through NMIMT.
D. Assumes all equipment maintained by contract.
E. Assumes no support for 86 GHz system.

Table 12.2

WORK LOAD OF ANTENNA SITE TECHNICIANS

Equipment & Area	Work Description	Rate	Hours/ Year	Days/ Year
Antennas	Monthly inspection	4 hrs/mo	48	6.0
	Quarterly maintenance	16 hrs/3mo	64	8.0
	Semi-yearly maintenance	38 hrs/6mo	76	9.5
	Yearly inspection	58 hrs/yr	58	7.3
	Servo main./semi-annual	12 hrs/6mo	24	3.0
	Unscheduled repair/repl.	92 hrs/yr	92	11.5
Electronics	Prev. maintenance	4 hrs/wk	208	26.0
	Module replacement	16 hrs/wk	832	104.0
	Systems tests	18 hrs/mo	216	27.0
Computers	Preventative main.	2 hrs/wk	104	13.0
	Repairs, diagnostics	8 hrs/mo	96	12.0
Supervisory	Schedule,procure part time assistance	16 hrs/mo	192	24.0
	Keep track of module, tape and other shipments	3 hrs/wk	156	19.5
Tape Hndlng	Unpack/pack tapes and record inform.	1.5 hrs/day	540	67.5
Busisness	Travel for module, other equip. deliv. (tapes?)	14 hr/wk	728	91.0
	Janitorial duties	2.5 hrs/wk	130	16.3
Total			3564	445.5

Final manpower requirements: 1.9 employees.

Table 12.3

VLBA OPERATING COSTS (1987$)

Category	Costs ($1000)	NOTE #
Personnel (wages and benefits)	3115	1
Travel		
Service	139	2
Other (Sci.,etc)	85	3
Communications		
To antennas (10)	234	4
Other (reg. tele., etc)	175	5
Power		
At antennas (10)	282	6
At operations center	75	7
M & S		
Antennas	39	8
Electronics	367	9 *
Operations	60	10
Computer	388	11
Plant	250	12
Other (administrative)	95	13
Shipping	210	14
New Equipment	500	15
Total	6014	

See sub section 12.4.1 for details.

* These numbers should be increased for the first and second 2 year operating periods by $43K and $21K respectively.

See note 13 for details.

Table 12.4

VLBA OPERATIONAL BUILDUP

YEAR	NUM ANTS BY YEAR END	NUM PERS BY YEAR END	OPERATING COST (1988$)
1987	0	5	0.2
1988	1	9	0.5
1989	5	27	1.4
1990	7	53	2.7
1991	10	80	3.9
1992	10	91	5.0
1993	10	94	6.2

SECTION 13

ARRAY OPERATION CENTER

C. Bignell

The Array Operations Center will be located in Socorro New Mexico on the campus of the New Mexico Institute of Mining and Technology (NMIMT). The new building, which is under construction and nearing completion, will house both VLBA and VLA operations, plus associated scientific, electronics and computing activities. The building is partially funded by a $3 M grant from the State of New Mexico and partially out of VLBA construction funds.

The total floor area of the building is approximately 67,000 square feet of which about 47,000 is usable office and laboratory space. About 9000 sq. ft. will be left shelled and unused initially in order to save on operating costs. The shelled space will be needed in 1990 when the correlator is moved to Socorro.

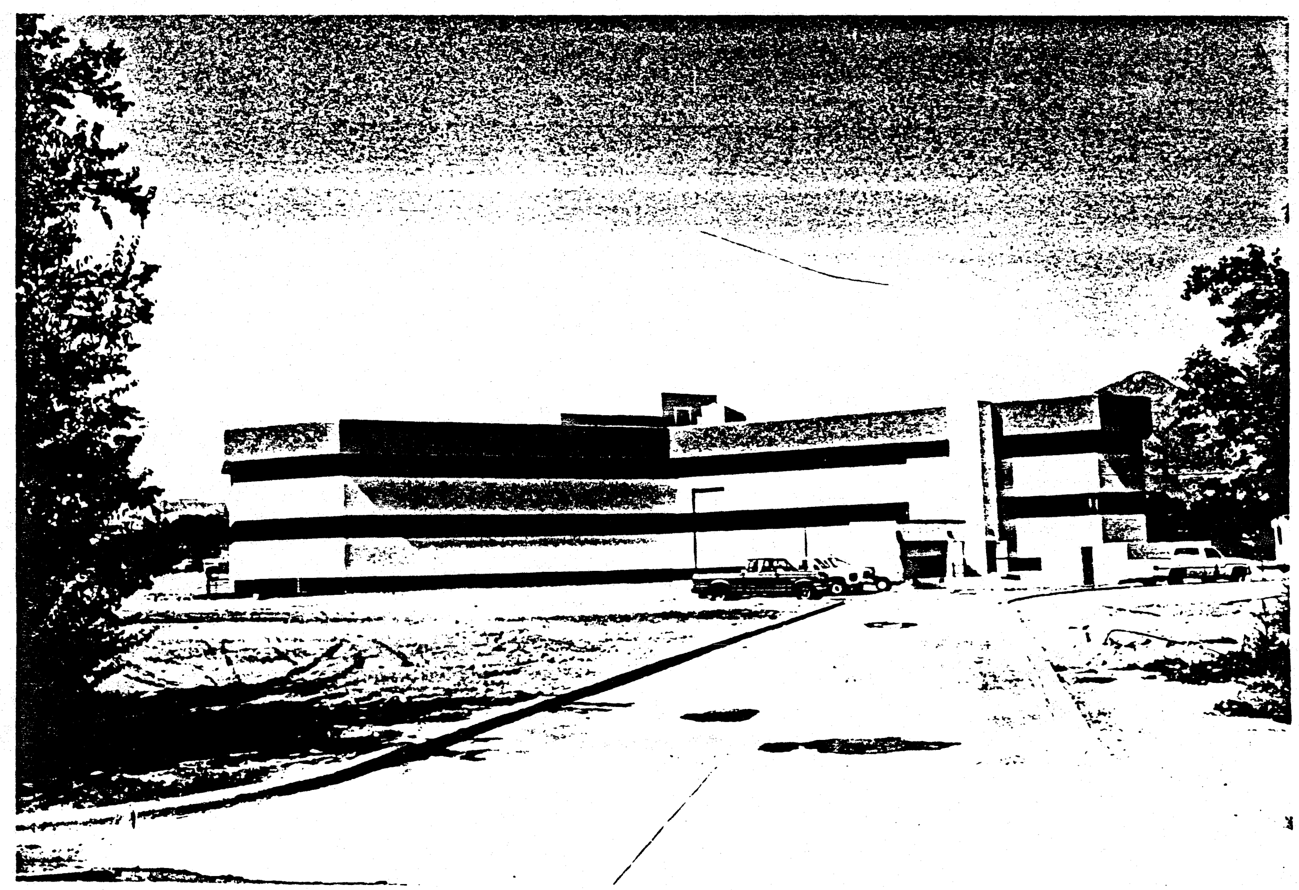


Figure 13.1 The Array Operations Center Building in Socorro, New Mexico

SECTION 14

OPTIONS LIST

J. D. Romney

The VLBA Options List was originally intended to facilitate selection among numerous possible cost-saving or performance-enhancing variations on Array specifications. As the VLBA project has developed from design to construction, most original options have either been incorporated into the Array, or rejected (implicitly or explicitly) and omitted from further planning. The Options List has thus evolved into a "wish list" of desirable upgrades to the basic VLBA currently foreseen in the construction plan.

In general, the nominal specifications from which the options depart are those presented in the current chapters of the "VLBA Project Book". I have attempted to include all options seriously considered at at the date of compilation, although this necessarily involves an exercise of judgement. Not included in the List are choices of a strictly technical nature which have a negligible impact on both cost and performance.

The options are grouped into major areas generally paralleling the group structure of the VLBA project with some exceptions to allow a more unified presentation. Each option is given a mnemonic name, briefly described, and its effect on Array performance outlined. The cost is estimated as precisely as possible, generally for the entire 10-station VLBA unless indicated as cost per station. Development costs are mentioned (but not estimated) only for those options where they may be substantial.

ANTENNAS

86-GHz Operation (see also 86-GHz Receiver) --

- Description: Improve pointing performance by grinding azimuth track and/or implementing circulating-coolant system.
- Effect: Satisfactory pointing for 86-GHz operation.
- Cost: To be determined from operating experience; probably less than 120 k$.

RECEIVERS & FEEDS

6.1-GHz Receivers --

- Description: Add 6.1-GHz receivers (sharing 4.8-GHz feeds) at some stations.
- Effect: Observations of 6.035-GHz OH line possible.
- Cost: 19 k$ per station, plus development cost.

10.7-GHz Receivers --
Description: Add 10.7-GHz receivers and feeds at some stations. (One such system already installed at Pie Town site.)
Effect: Additional X-band capability beyond planned 8.4 GHz (for continuity of ongoing observing programs, and compatibility with global array).
Cost: 20 k$ per station.

12.2-GHz Receivers (Uncooled) --
Description: Add uncooled 12.2-GHz receivers and feeds at some stations. (Would have to replace 10.7-GHz.)
Effect: Observations of 12.2-GHz methanol maser line possible.
Cost: 13 k$ per station, plus development cost.

12.2-GHz Receivers (Cooled) --
Description: Add cooled 12.2-GHz receivers and feeds at some stations. (Would have to replace 10.7-GHz.)
Effect: High-sensitivity observations of 12.2-GHz methanol line.
Cost: 20 k$ per station, plus development cost.

86-GHz Receivers (see also 86-GHz Operation) --
Description: Add 86-GHz receivers and feeds at some stations.
Effect: Observations at 86 GHz possible.
Cost: 50 k$ per station, plus development cost.

Additional Dual-Frequency Pair(s) --
Description: Implement additional dichroic reflector systems for, e.g., 4.8/23, 10.7/43, or 15/43-GHz pairs.
Effect: Improved atmospheric/ionospheric calibration, and extended coherence times at high frequencies.
Cost: ~80 k$ per pair.

Remote Dual-Frequency Operation --
Description: Equip dichroic reflectors for remotely commanded operation.
Effect: Improved sensitivity for single-band observations, and unimpeded observation using neighboring feeds.
Cost: ~100 k$ per pair equipment cost, plus development cost.

AUXILIARY STATION ELECTRONICS

Fewer Water-Vapor Radiometers --
Description: Delete 22/31-GHz radiometers for measuring atmospheric water vapor content at some stations.
Effect: Restricted calibration of atmospheric phase fluctuations for astrometric/geodetic observations, and mapping at high frequencies.
Saving: 50 k$ per station.

Dual-Frequency GPS Systems --

Description: Replace standard satellite timing receivers with advanced, dual-frequency systems at some stations.

Effect: Enhanced calibration of ionospheric propagation effects.

Cost: 40 k$ additional, per station.

BASEBAND ELECTRONICS, RECORD & PLAYBACK SYSTEMS

32 Channels --

Description: Double station complement of baseband converters (to 16) and sampler modules (to 4).

Effect: More channels (32) and tunable LO's (16) available for specialized observations; bandwidth per channel limited by standard peak recordable data rate (512 Mbit/s -- 4 times sustainable rate).

Cost: 420 k$.

128 Tracks --

Description: Double station complement of formatter data-path modules (to 4) and recorder headstacks (to 4 -- 2 per recorder).

Effect: Higher peak recordable data rate (1024 Mb/s -- 8 times sustainable rate) for high-sensitivity, short-coherence-time observations; matches capacity of standard baseband converter complement.

Cost: 320 k$.

EXTENDED ARRAY

These options represent extensions of the 10-station VLBA project to VLBA project to cover more uniformly the range of baselines available on the surface of the Earth and approach a "matched u-v filter" appropriate to any angular scale. The extensions provide facilities to integrate the VLA and VLBA apertures into a fully-capable joint instrument, and to broaden the aperture coverage more generally using additional stations.

Additional Acquisition/Recording System(s) --

Description: Provide complete or partial acquisition/recording systems for fixed sites (e.g., the VLA, Green Bank, ...) or as portable units.

Effect: Enhancement of the Array (in particular to include elements with large collecting areas or high-frequency performance).

Cost: 164 k$ per station for single DAR/REC system, plus control computer.

Pie Town VLA Station --

Description: Implement wideband digital data link from Pie Town site to the VLA; provide VLA electronics at Pie Town, and upgrade VLA correlator delay etc.

Effect: Pie Town usable as VLA "outrigger".

Cost: ~1 M$.

Additional Southwest VLBA Stations --

Description: Build additional fully-equipped stations at three or four sites close to the VLA: Dusty, Bernardo, and Roswell, NM; or Dusty, Bernardo, Vaughn, NM and Holbrook, AZ.

Effect: VLBA aperture extended inwards from 200 km towards 35 km outer envelope of VLA aperture.

Cost: ~5.6 M$ per station.

South American VLBA Station --

Description: Build an additional fully-equipped station in northern South America, probably in Ecuador.

Effect: Improved north-south aperture at equatorial and southern declinations.

Cost: ~7 M$.