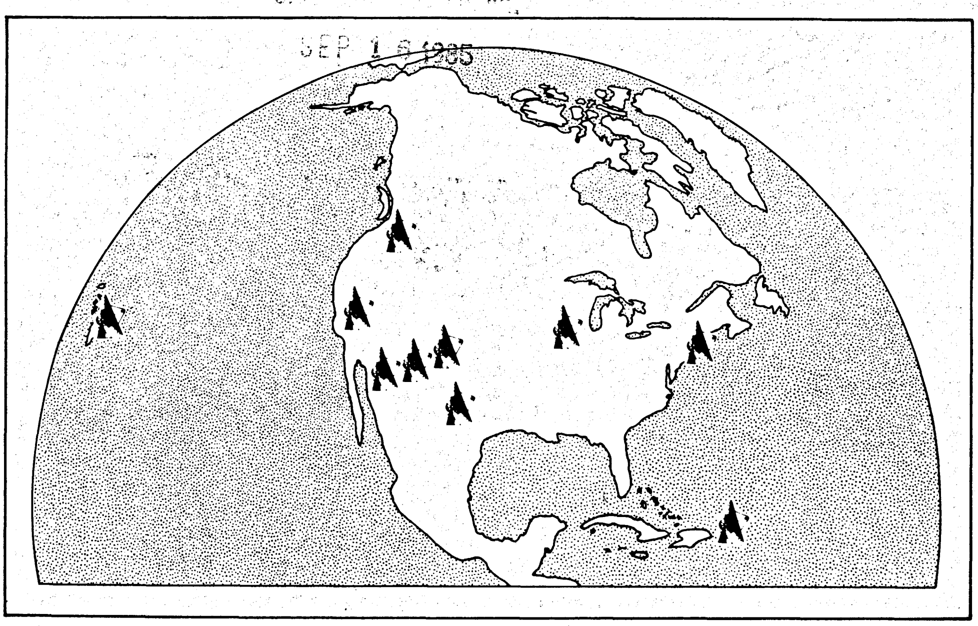
Very Long Baseline Array Project

VLBA PROJECT BOOK 840501



NATIONAL RADIO ASTRONOMY OBSERVATORY
Edgemont Road · Charlottesville, Virginia 22901

OPERATED BY ASSOCIATED UNIVERSITIES INC.,
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

VLBA
PROJECT BOOK
840501

VLBA PROJECT BOOK
1 May 1984

This printing of the VLBA project book is meant to describe the status of the technical design as of April 1984. The project book normally resides in the Charlottesville VAX and is used both as a reference document for the project staff and as a status report of the technical design and specifications. Each chapter is maintained by an author who is responsible for its content. Since the book is generally a dynamic document, with frequent updates of the various chapters, there are some inconsistencies, particularly among different chapters. Nevertheless we believe the project book gives a fairly accurate description of the current VLBA design.

This is a first printing of the project book, limited to 25 copies. We intend to repeat the printing of the current version from time to time for the benfit of those who are not engaged in the project on a daily basis.

Please let me (or the author of a particular chapter) know if you find any gross mistakes, inconsistencies or omissions that ought to be corrected.

Hein Hvatum

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLBA PROJECT BOOK

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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 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 make maps of 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 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. Each antenna should be near a major transportation center.

1.1.2.5 U.S. Territory. The initial 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 10. With fewer than 10, 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 10 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 Figure 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.

The sites of the antennas of the VLBA are:

1. HAWAII: A high altitude site will be needed to avoid the high atmospheric water vapor levels that occur in tropical, maritime regions such as Hawaii. The best sites are probably on Mauna Kea, perhaps near the mid level facilities. The summit is subject to weather conditions and costs that may be too extreme for the VLBA. The two other high mountains in Hawaii are subject

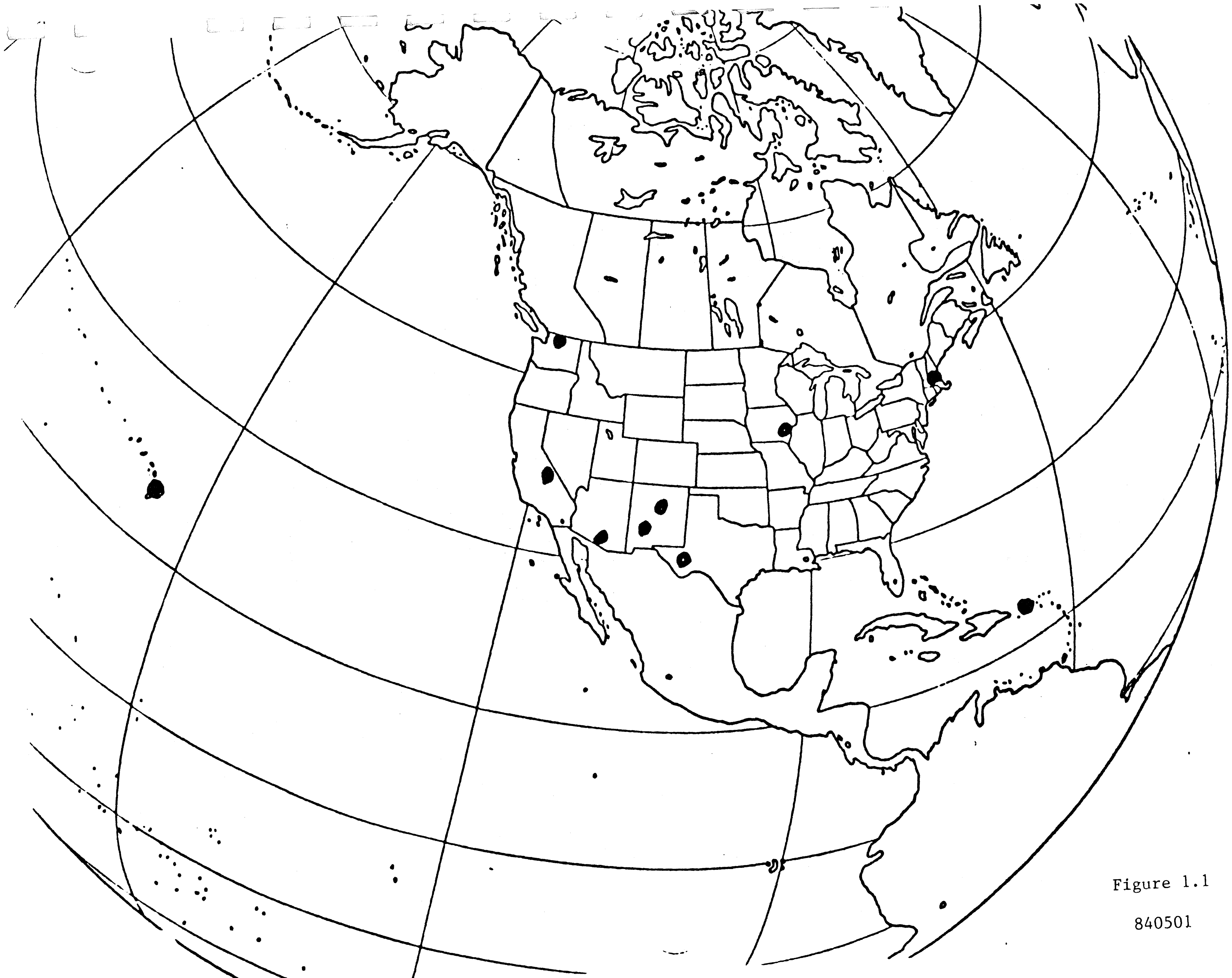

Figure 1.1

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14

Scale in km
(kilometers x 10^3)

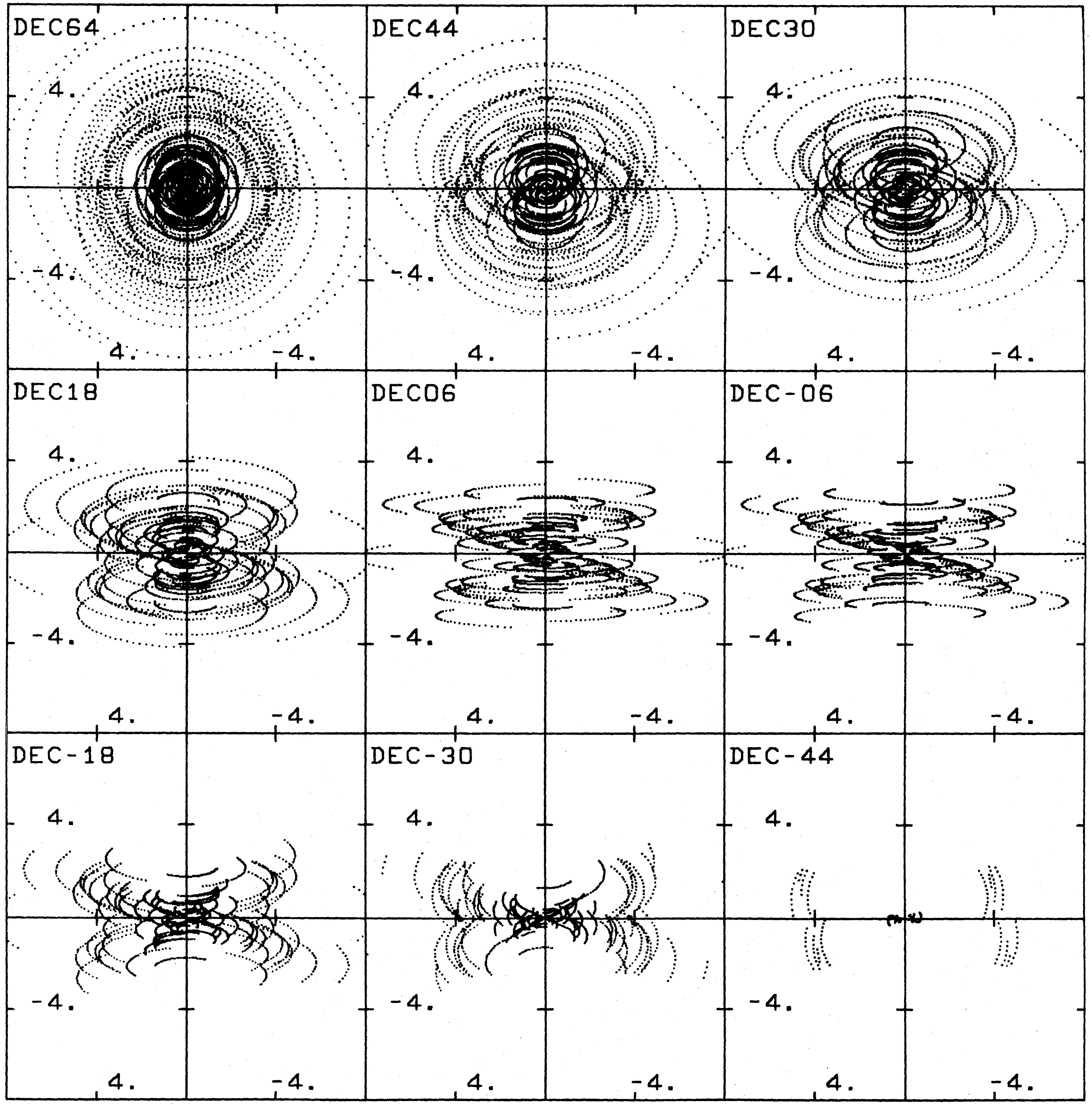

Figure 1.2a
8000 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14

Scale in km
(kilometers x 10^3)

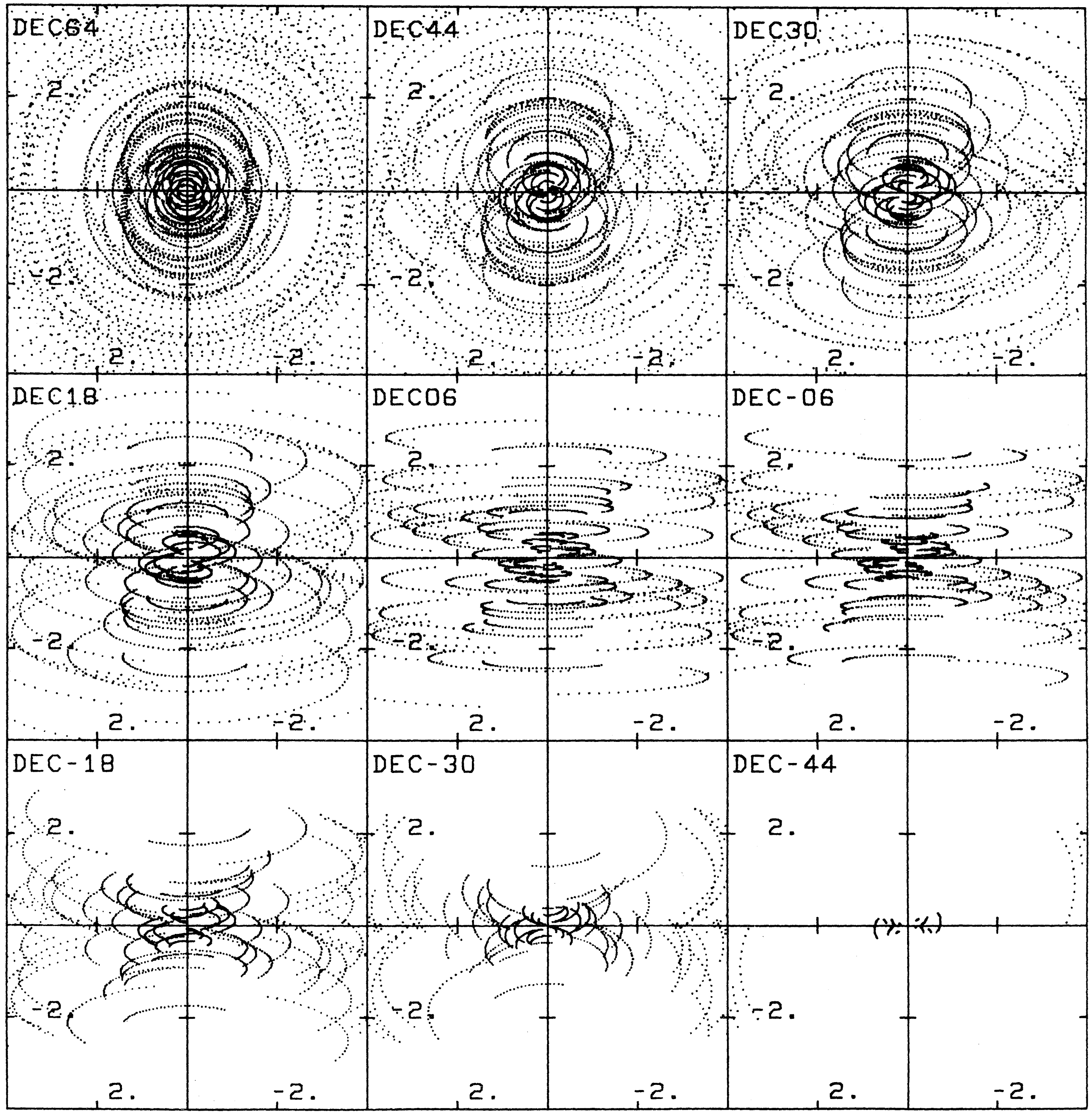

Figure 1.2b
4000 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14

Scale in km
(kilometers x 10^2)

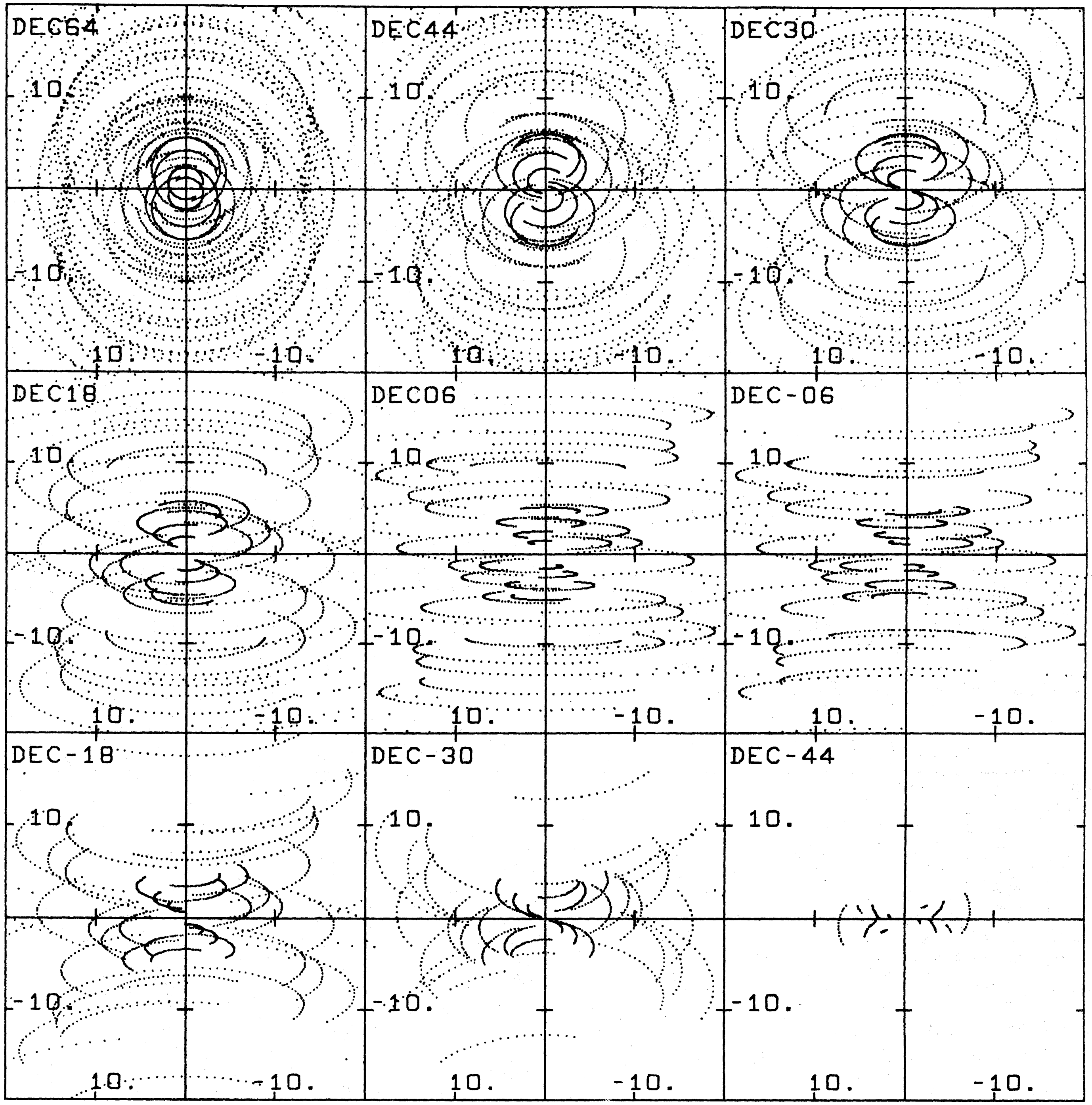

Figure 1.2c
2000 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14
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)

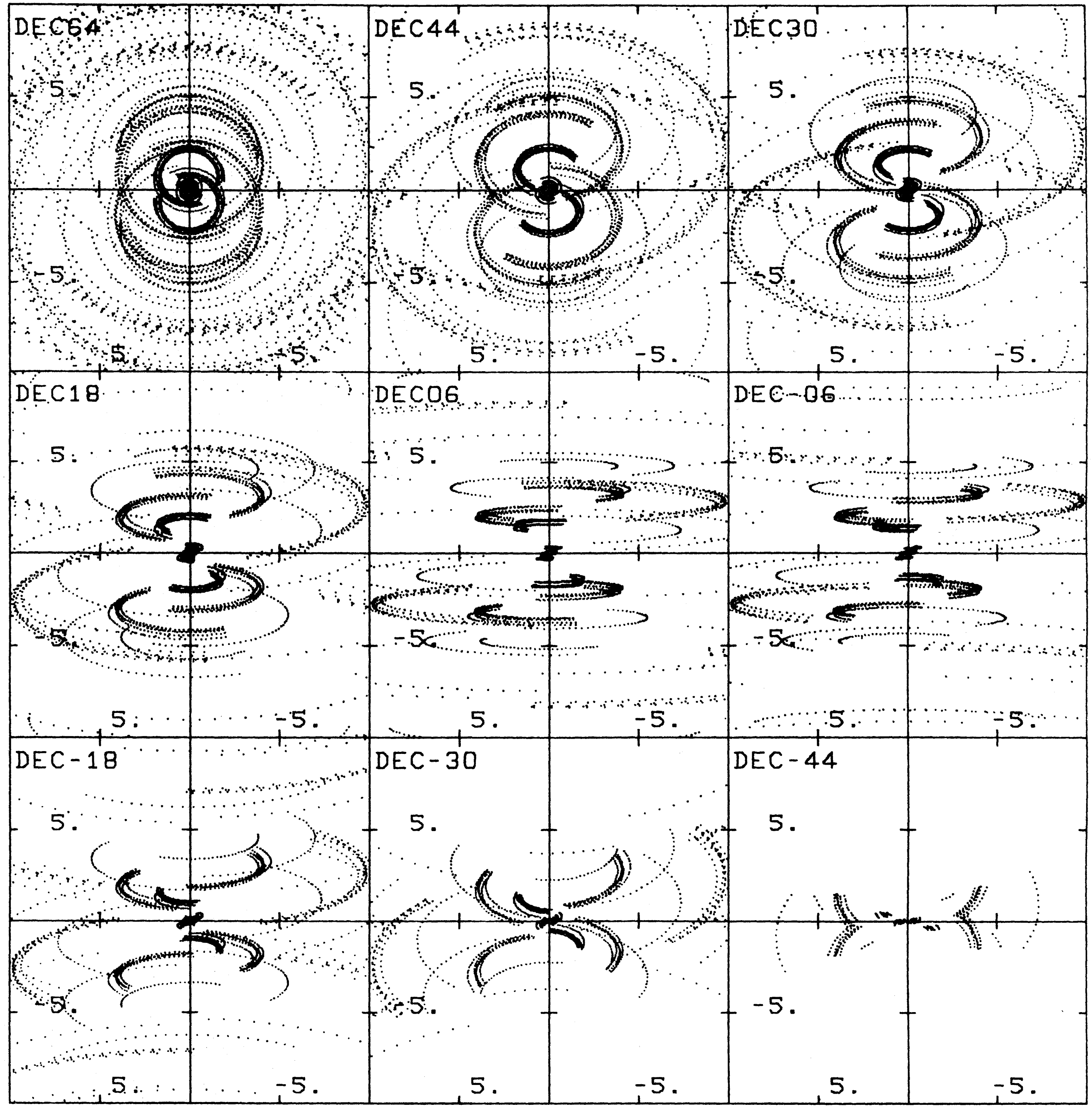

Figure 1.2d
1000 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
ORCVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14
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)

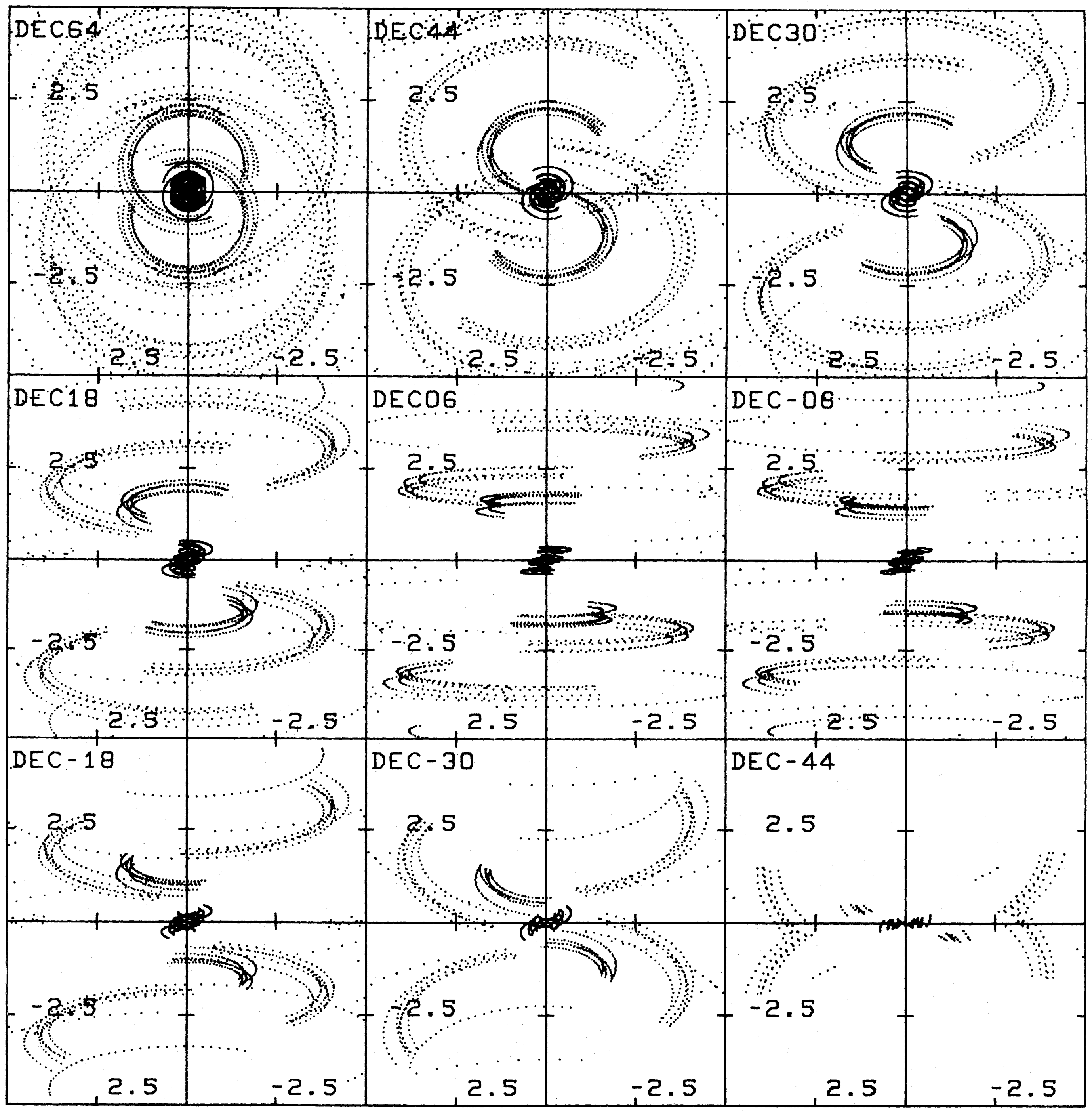

Figure 1.2e
500 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14
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)

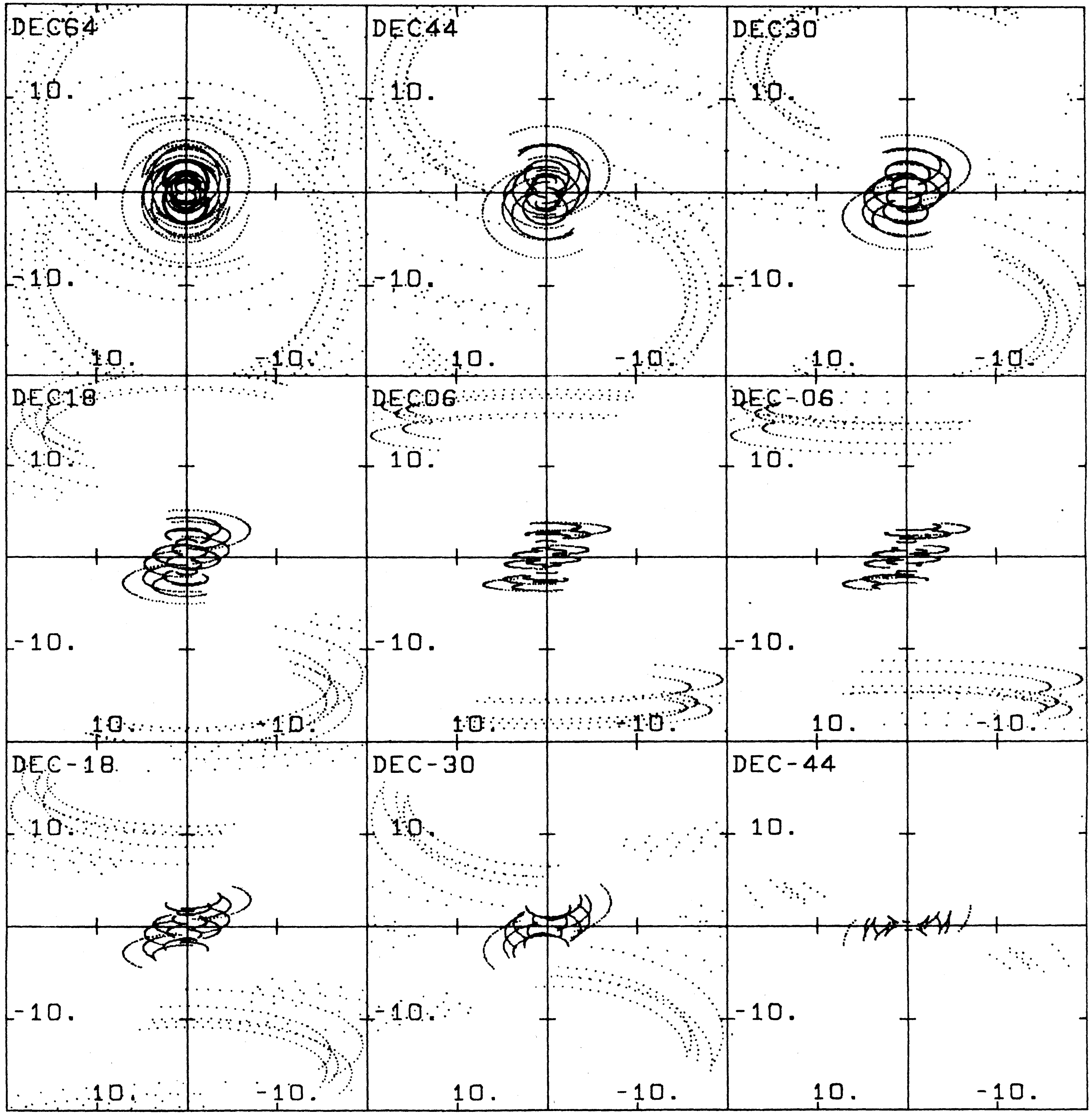

Figure 1.2f
200 km

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to serious problems. Haleakala on Maui is the site of many transmitters so the interference environment is extreme. Mauna Loa in an active volcano. Information is needed on the minimum tolerable altitude on Mauna Kea.

2. PUERTO RICO: (Listed as Arecibo on the Figures) The u-v coverage provided by a station in Puerto Rico is very attractive although the high water vapor content of the atmosphere over the island is a concern. Unlike Hawaii, Puerto Rico does not have high altitude sites. VLBI experiments 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. The search for a specific location will begin soon. The quality of the u-v coverage is sufficiently good that Puerto Rico 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 Puerto Rico 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.

3. HAYSTACK: (Listed as HSTK) This site in Massachusetts is at the existing radio astronomy facilities of the Haystack Observatory and has very good local support. Possible problems with interference need to be investigated. An attractive alternative is the Five College Radio Observatory. The u-v coverage would be similar to that provided by Haystack and the proximity to a mm telescope would facilitate possible millimeter wavelength VLBI experiments (Note that the OVRO and Kitt Peak sites are also at existing mm facilities).

4. WASHINGTON: (Listed as OROVILE) This site is very near the Canadian border in central Washington State. This is the only site in the configuration that is not near known local support. There is considerable freedom to move the site around in central Washington so logistical factors can determine which specific site is chosen. Note that this site is very near Penticton.

5. OVRO: The Owens Valley Radio Observatory in California is an existing VLBI site with good local support.

6. IOWA: The North Liberty Radio Observatory is an existing facility with local support and strong interest in VLBI. The obvious, although probably not serious, hole in the coverage at Dec 64 at a little over 2000 km can be 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 is considerable freedom in the choice of the location of this site so local factors can be considered seriously.

7. FORT DAVIS: (Listed as FDVSNEW) The Fort Davis, Texas, site could be at the existing radio observatory (George R. Agassiz Station - Harvard) that is active in VLBI or at the University of Texas facilities at McDonald Observatory.

8. KITT PEAK: Kitt Peak, Arizona, is an existing NRAO site with good local support.

9. LOS ALAMOS: (Listed as LASL2) Several sites on property belonging to the scientific labs at Los Alamos are being investigated for this antenna. This is the second closest antenna to the VLA and it is hoped that eventually it will be linked to the VLA so that it can be used as a VLA outrigger. However the link will be sufficiently difficult that it will not be part of the original construction. The site should be easy to maintain from headquarters in Socorro.

10. PIE TOWN: This site is west of the VLA on Rt. 60. Access from the VLA is good and power and phones are nearby. The site is the closest to the VLA and will be equipped with a link to the VLA so that it can be used as a VLA outrigger and so that the VLBA recordings can be made at the VLA, reducing the need for staff at the site. Maintanence from the VLA or from the VLBA headquarters will be relatively easy.

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 3 additional stations in New Mexico are needed to 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. In such an 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 additional sites of the 13 station configuration are:

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

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

3. ROSWELL: Roswell, New Mexico is east and a bit south of the VLA. There is some freedom in finding a specific site.

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 Figure 1.3. The 3 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.

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 Figure 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 using 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

HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14
BERNARDO	34.35	106.90
DUSTY	33.62	107.65
ROSWELL	33.40	104.55
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)

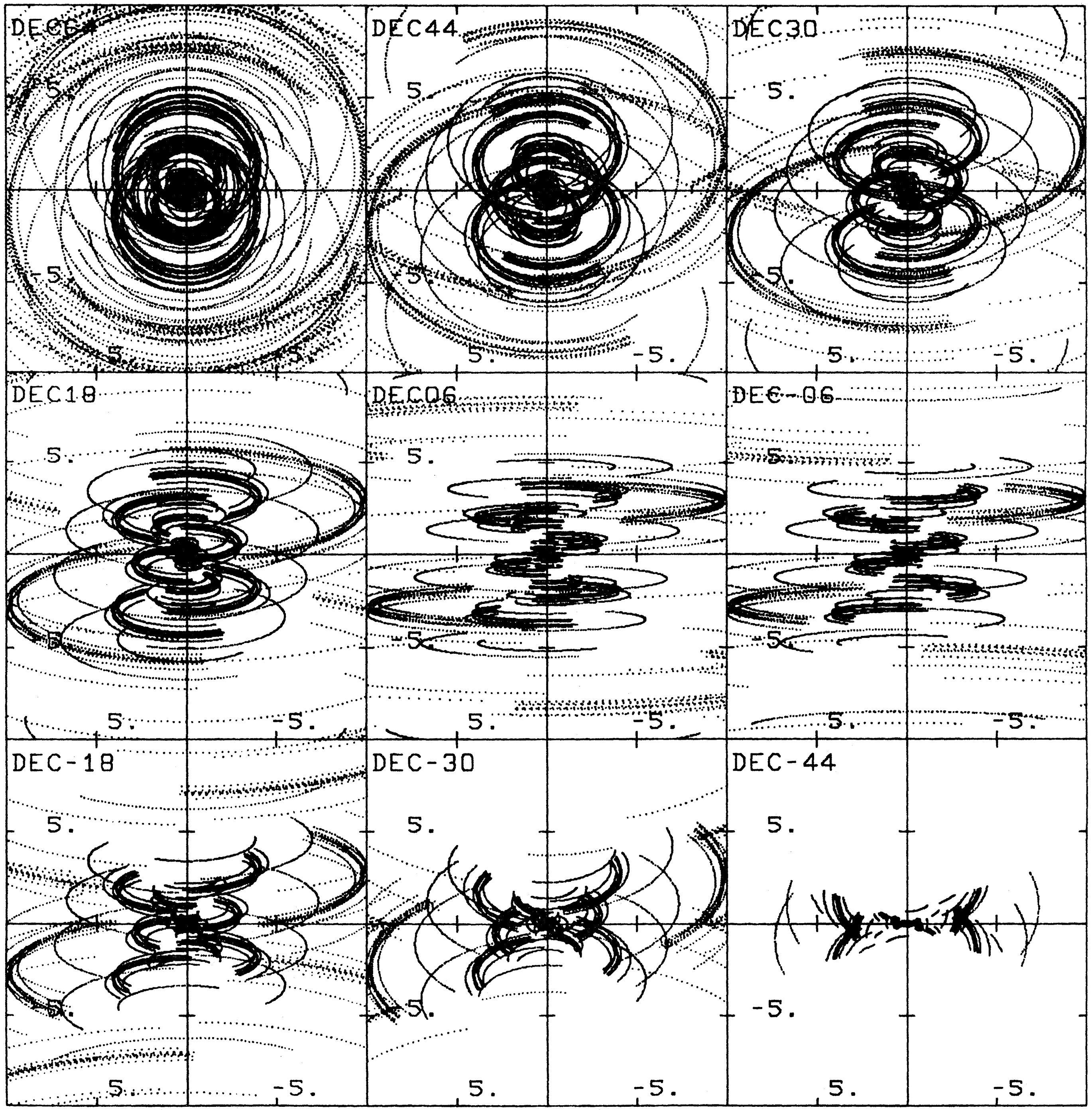

Figure 1.3a
1000 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
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AW3	34.06	107.64

Scale in km
(kilometers x 10^2)

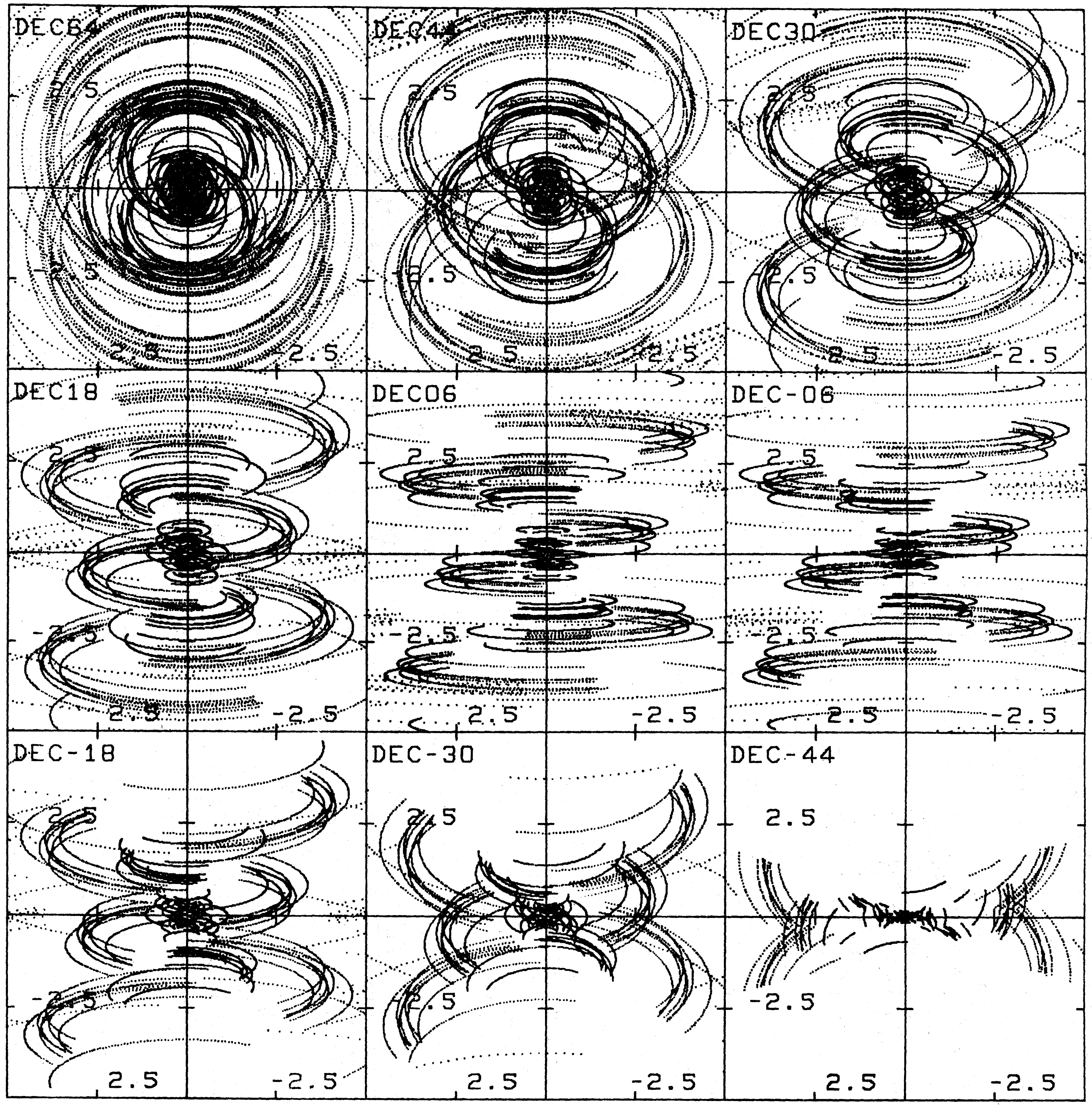

Figure 1.3b
500 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
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AWS	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64

Scale in km
(kilometers x 10^1)

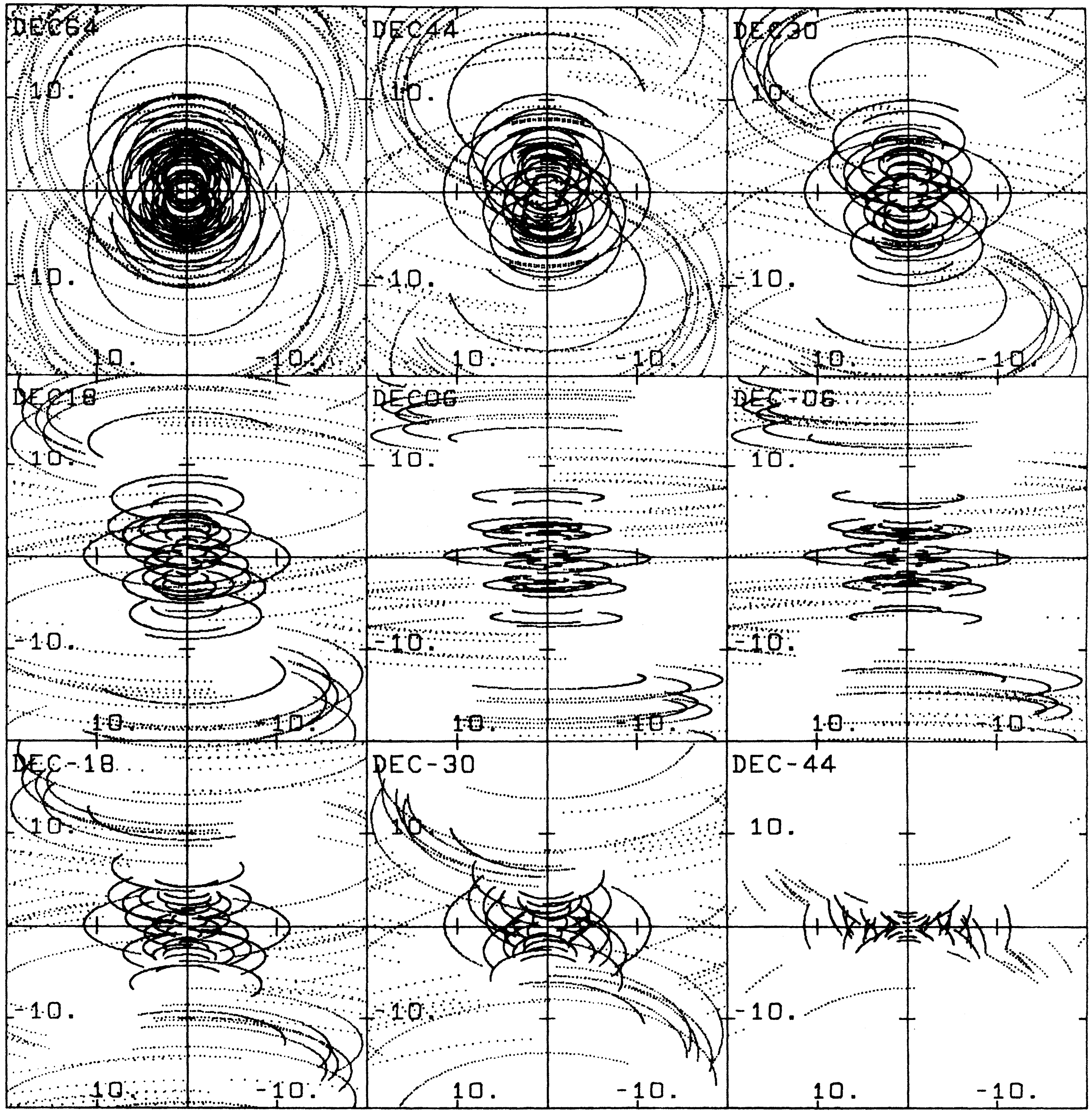

Figure 1.3c
200 km

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HAWAII	19.80	155.50
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75
OVRO	37.05	118.28
IOWA	41.58	91.57
FDVSNEW	30.47	103.95
KITT	31.96	111.60
LASL2	35.81	106.27
PIETOWN	34.33	108.14
QUITO	-0.20	77.00

Scale in km
(kilometers x 10^3)

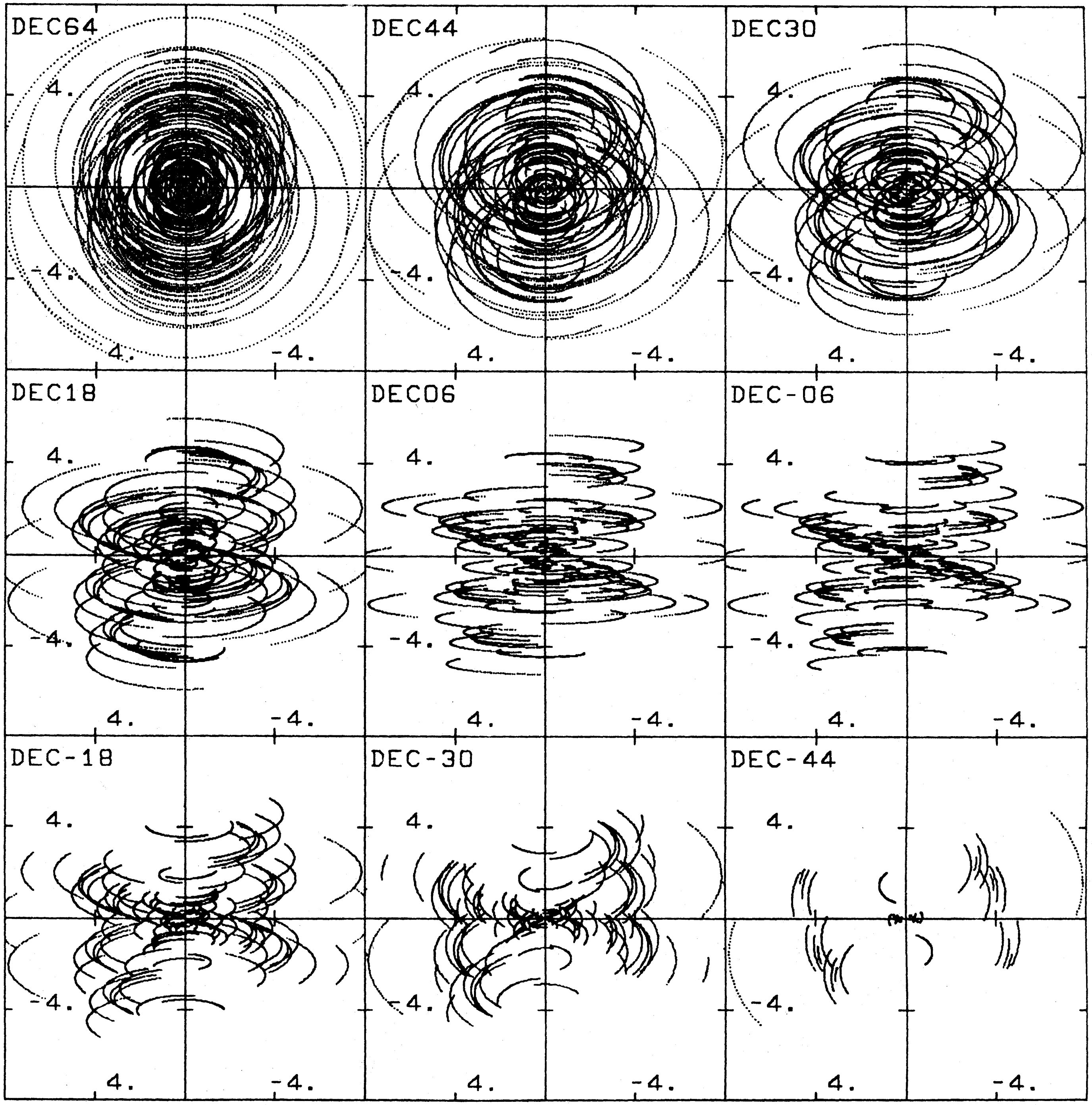

Figure 1.4
VLBA and QUITO

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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 eastwest 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. 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 Cramer-von 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 nearly complete. The important job that needs to be done is to identify the exact sites to be used within the small regions specified for each of the stations. For several of the sites, the task should be easy since the new telescope will presumably be built somewhere on the grounds of an existing facility. For other sites, such as Hawaii, Puerto Rico, and Washington, much work needs to be done to identify a good plot of land. This work must be complete in time for site testing to be done and administrative details (eg. environmental impact statements etc.) to be completed before construction begins. The detailed time schedules will be dealt with in the sections of this report on the sites. If no site can be found near the position of some element of configuration presented here, the configuration search may need to be resumed to find alternatives, or at least to check that a relatively large move can be tolerated.

SECTION 2

SITES

B. PEERY

2.1 Specifications

2.1.1 Number of Sites

The VLB Array will consist of ten radio telescopes at separate sites and an Operation Center strategically located to serve all ten telescopes and to interface with other existing radio astronomy facilities that might support or occasionally function in conjunction with the VLBA. The number of sites needed to achieve the scientific goals of the instrument was determined in an extensive study of configurations of the array, as described in the chapter on configurations and in Volume I, dated May 1982.

2.1.2 General Location

All ten radio telescopes and the operation center will be located inside United States territory. Eight radio telescopes and the operation center will be located on the continent with the other two located on islands. The spacings and general locations were determined by optimizing the UV coverage while giving consideration to utilizing existing radio telescope sites and to local weather conditions. These decisions are explained in the configuration section of this volume. The radio telescopes will be located in the states of Arizona, California, Hawaii, Iowa, Massachusetts, New Mexico (two sites), Texas, Washington and the Commonwealth of Puerto Rico. Exact locations, on the ground, will be determined by checking for conformity with the criteria set forth below. The operation center will be located at Socorro, New Mexico. There will be a single service facility to provide maintenance and service support for the entire array which is the VLA site near Socorro, New Mexico.

2.1.2.1 Specific Site Locations in Proposed Order of Developing

Pie Town, New Mexico
Kitt Peak, Arizona
Los Alamos, New Mexico
North Liberty, Iowa
Puerto Rico
Oroville, Washington

Owens Valley (Big Pine), California
Fort Davis, Texas
Westford, Massachusetts
Hawaii

2.1.3 Requirements of a Typical Radio Telescope Site

The following general requirements will help establish the exact location of the site within the tolerances allowed by the configuration study. Areas, dimensions, arrangements, relative locations on the site and in the building will be refined or changed to meet local requirements, conditions and equipment sizes as the design and program develops.

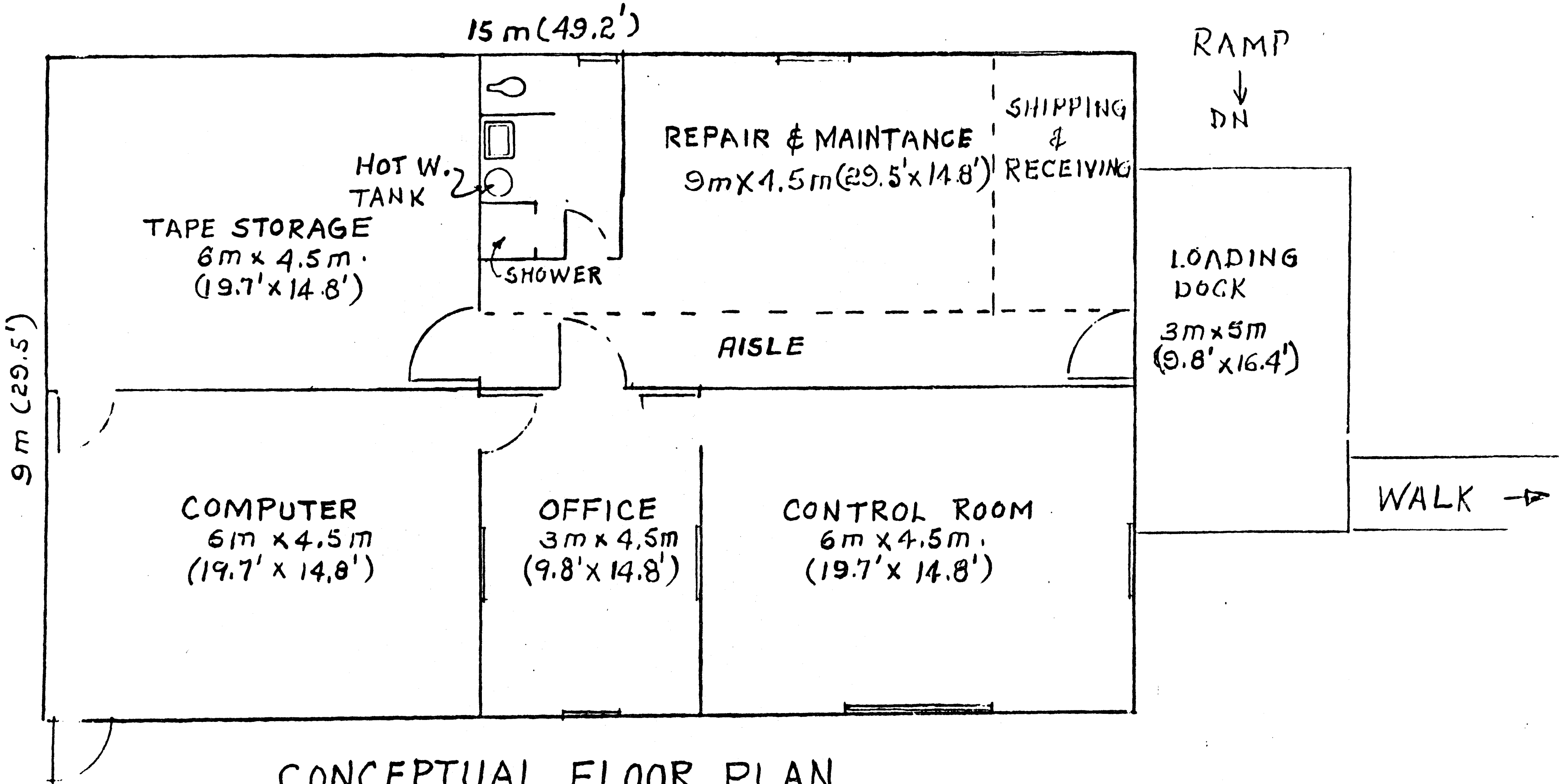
2.1.3.1 Land Area: Each radio telescope will require a fence enclosed land area of approximately 225 ft x 250 ft or 1.25 to 1.75 acres.

2.1.3.2 Control Building: Each radio telescope will require a control building on the site.

2.1.3.2.1 Function: The building will house the telescope control equipment, electronic equipment, a micro computer for operating the telescope, facilities for controlling and monitoring the antenna, radiometers, and recording system, magnetic tape storage space, hydrogen maser clock system, mechanical equipment (building environmental system and electrical power system), sanitary facilities, spare parts and components storage area, and a space for repair facilities. Only minor repairsand preventative maintenance will be performed at the individual sites. Components will be replaced and the defective ones shipped to the service facility or supplier for repair.

2.1.3.2.2 Area: A building approximately 49 ft x 29 ft or 1425 sq ft subdivided into six or more rooms would provide the space to perform the operations outlined above. A conceptual floor plan showing a general arrangement is included (Fig. 2.1). The size, number of, and arrangement of spaces will be refined to match the equipment installed and the specific site on which the building is located.

2.1.3.2.3 Conceptual Specifications: The telescope control building will be an energy efficient, masonry, single story building on grade with minimum windows and doors. Security doors and windows will be provided to protect against vandalism. The building will be equipped with an environmental control



CONCEPTUAL FLOOR PLAN

CONTROL BUILDING

SCALE: 1:80

135 m^2 (1451 ft^2)

Fig 2.1

system to maintain 25 deg C +_ 1 deg C continuously with 40% +_ 10% relative humidity. The building will be equipped with hot and cold water and a toilet. The exterior walls, ceiling and some interior walls will contain a grounded metal screen grid to serve as an electromagnetic shield against radio frequency interference (RFI). RF filters and shielding will be provided in electrical, telephone and telescope services as required. A loading dock will be provided at the shipping and receiving entrance. A special environmental controlled chamber will be installed as part of the control equipment for the hydrogen maser system. The building will be designed and constructed to meet all applicable building and safety codes. Automatic burglar and fire protection and alarms will be provided as required for the specific location.

2.1.3.3 Access

2.1.3.3.1 From a distance: The telescope site will be reasonably near a transportation center where daily flights are available for the rapid transporting of tapes, parts and personnel between the site and the operation center and the service facility.

2.1.3.3.2 Locally: The exact site will be chosen to be near a residential or similar non-industrial area close to a public highway of such quality and status that the site will be accessible 24 hours a day year round.

2.1.3.4 Weather: The operation of the radio telescope and the quality of the data obtained are materially affected by temperature, temperature changes, rain, snow, cloud cover, wind and precipitable water vapor. The exact site will be chosen where these factors are minimal.

2.1.3.5 Utilities: The site will require commercial electric power, water, sewer and telephone services. Equipment to provide clean power or instant power will be installed, if required. The estimated power demand is 90 kVA for a typical site. It is estimated three telephone lines of digital transmission grade will be required at each site. If public sewer and water systems are not accessible, a septic system and well will be installed on the site. An approach road from the highway, averaging approximately 400 feet (for estimating purpose), and a parking area on site will be provided. The approach road and parking area will be thoroughly compacted gravel with a light coat of asphalt topping as a wearing surface. Storm and surface drainage will be controlled by grading of the site and roadway. An auxiliary generator for emergency use during commercial power outages, estimated to be 45 kVA, an equipment storage building and snow removal equipment will be provided each site as required. An elevator for telescope maintenance and other required maintenance equipment will be provided each site.

2.1.3.6 <u>RFI Protection</u>: Radio frequency electromagnetic interference must be minimal. To meet these requirements, the exact site location will be chosen to be located as far as possible, within the tolerances allowed, from radio and TV transmitter antennas, industrial installations, busy roadways, electrical distribution lines, electrical generators, electrical substations, microwave equipment and radio navigation aids. Where potential sources of interference exist, the exact site will be chosen, so far as possible, to have distance, forest, wooded areas, hills or other forms of natural shielding between the radio telescope and the potential source of interference. Filters for and shielding of utility and telescope services will be installed as required.

2.1.3.7 <u>Terrain</u>: The actual site of the radio telescope will be chosen so as to have reasonably level ground with stable soil conditions at such an elevation that the horizon to the south, east and west of the telescope will generally not project higher than a 5 degree angle above the horizontal plane passing through the elevation axis of the telescope. Segments of the horizon (in azimuth) below 5 degrees will be considered, where practical, in locating the telescope.

2.1.3.8 <u>Seismic History</u>: The exact site will be chosen in an area as far as possible from any geological faults and having a history of minimal seismic activity. The soil conditions in the area must be stable and well drained and not subject to slides or major condition changes due to moisture content.

2.1.4 <u>Conceptual Site Plan</u>: A typical conceptual site plan is included (Fig. 2.2).

2.1.5 <u>Location of the Operation Center</u>

The operation center will be located in Socorro, New Mexico. Warehouses, shops, repair and maintenance facilities to serve as the service facility for the new Array will be those at the VLA site in New Mexico.

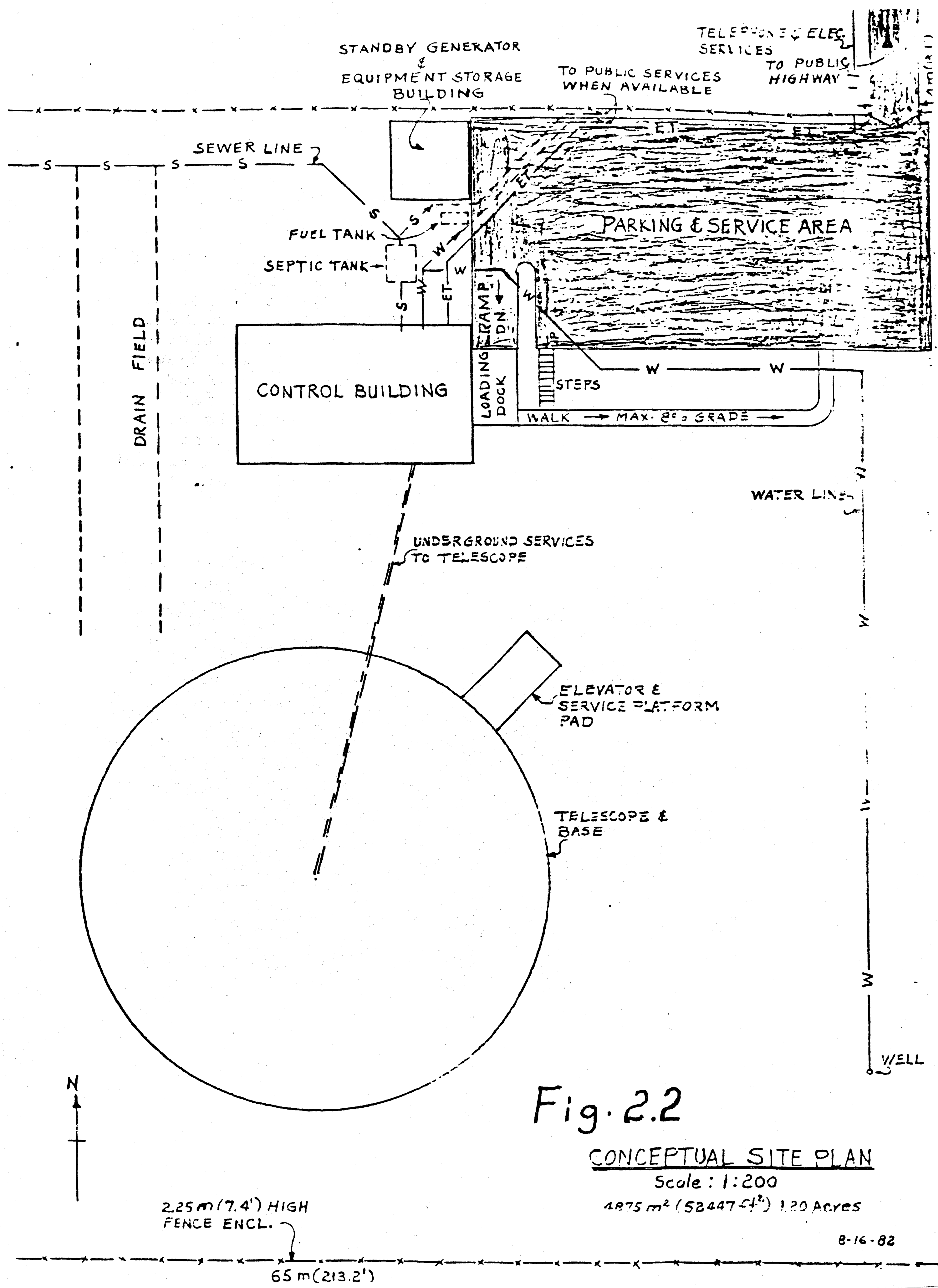


Fig. 2.2

CONCEPTUAL SITE PLAN

Scale : 1:200

4875 m² (52447 ft²) 1.20 Acres

8-16-82

2.1.6 Requirements of the Operation Center

2.1.6.1 Function: The operation center will provide housing and facilities to operate and monitor the ten remote radio telescopes, to receive from and ship to remote sites, parts, tapes, etc., to play back and analyze the data tapes received from the remote sites, and to combine the data from all remote telescopes to produce the end results, maps, image plots, etc. It will have space for scientific staff offices, electronics engineers offices, laboratories and shops for developing new electronic equipment, tape storage and control, computer programming and software development, visiting scientist offices, and administration and management of the complete operation.

2.1.6.2 Area: A two-story building approximately 203 ft x 49 ft or 19,900 sq ft subdivided into offices, laboratories, work areas, computer space, control room and shops will provide the space to perform the functions outlined above. A conceptual floor plan showing a general arrangement is included (Fig. 2.3). The size, number and arrangement of spaces will be refined to match the equipment installed and to meet known functional requirements as they develop and the overall program develops. The final floor plan will be limited to the area indicated but will be arranged for expansion to double (or more) the size shown. The site chosen for the building will be for the building actually built plus an equal amount or more for future expansion. The building plan will be adapted to the site chosen.

2.1.6.3 Conceptual Specifications: The operation center building will be an energy efficient, masonry, two-story building on grade. The building will be equipped with an environmental control system to maintain 25 deg C +_ 1 deg C continuously with 40% +_ 10% humidity in areas requiring humidity control. The building will be equipped with toilet facilities including a limited number of showers to meet the requirements for the number of people occupying the building. Hot and cold water distribution systems will be provided throughout the building. The required stairways and exits will be installed to meet applicable fire codes. Automatic fire protection and alarms will be provided. A loading dock will be provided at the shipping and receiving entrance. The building will be designed and constructed to meet all applicable safety and building codes including facilities and access for the handicapped. The architecture will be such as to conform to that existing on the site where the control center is finally located. The design will be such as to provide for a major expansion in the future.

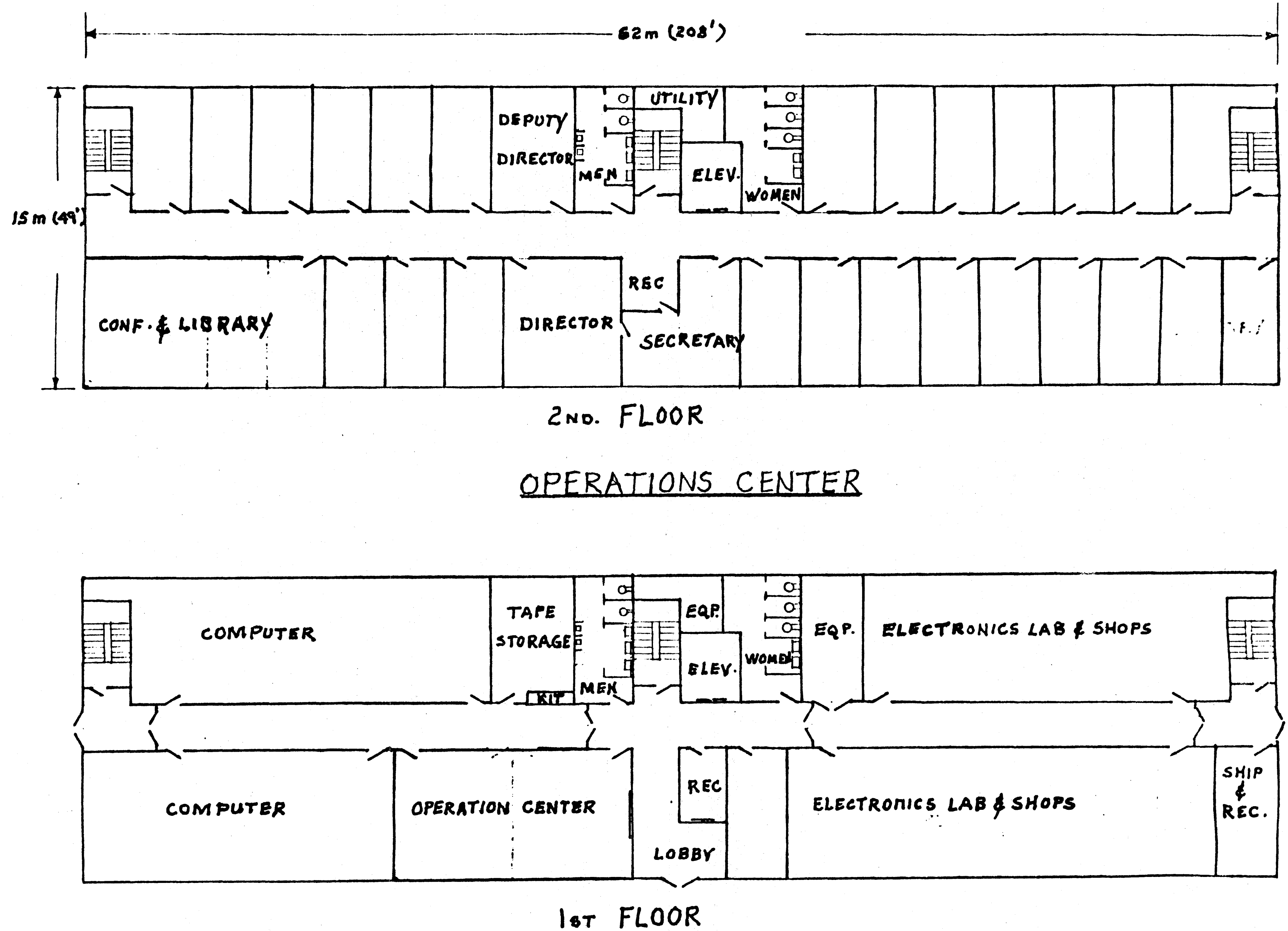

62m (208')
15m (49')
DEPUTY DIRECTOR
MEN
UTILITY
ELEV.
WOMEN
CONF. & LIBRARY
DIRECTOR
REC
SECRETARY
2ND. FLOOR
OPERATIONS CENTER
COMPUTER
TAPE STORAGE
KIT
MEN
EQP.
ELEV.
WOMEN
EQP.
ELECTRONICS LAB & SHOPS
COMPUTER
OPERATION CENTER
REC
LOBBY
ELECTRONICS LAB & SHOPS
SHIP & REC.
1ST FLOOR

Fig. 2.3

2.1.6.4 Access: The operation center is located near a major transportation center (Albuquerque, N.M.) where frequent flights are available for the rapid movement of tapes, parts, equipment and personnel to any of the remote telescope sites. Local access will be available 24 hours a day year round.

2.1.6.5 Utilities: The operation center will require commercial electric power, water, sewer and telephone services. The estimated power demand is 150 kVA. A minimum of 15 telephone lines of digital transmission grade will be needed. Water, sewer, storm drains, driveways, walks, parking security and landscaping will be incorporated into and be an extension of the existing site system. The land area required will be that on which the building rests plus an equal amount for future expansion. A 30 kVA auxiliary generator for emergency use during a commercial power failure will be provided.

2.2 Description

(This subsection not yet written.)

2.3 Cost Estimates

2.3.1 Typical Site:

	1984 Dollars
Land	3,500.00
Grading	3,750.00
Soils Investigation	7,000.00
Fence	20,000.00
Access Road	13,500.00
Water and Sewer	10,500.00
Electrical Service	7,000.00
Antenna Foundations	57,500.00
Building	108,000.00
Maser Enclosure	50,000.00
Furniture	6,750.00
Service Elevator & Maintenance Equipment	40,000.00
Standby Generator	22,000.00
Weather Equipment	10,000.00
UPS & Clean Power Protection	15,000.00
Design Fee (Engineer-Architect)	35,000.00
Total for 1 typical site	409,500.00

2.3.2 Operation Center:

Soils Investigation	7,000.00
Building	1,550,000.00
Elevator	50,000.00
Furniture	50,000.00
Utility Connections	7,500.00
Standby Generator	22,000.00
UPS & Clean Power Protection	30,000.00
Design Fee (Engineer-Architect)	150,000.00
Total for Operation Center	1,866,500.00

2.3.3 These estimates do not include a contingency fee (15%) or management fee (10%).

2.3.4 A suggested Design and Construction Schedule is included (Fig. 2.4).

Design and Construction Schedules

1/27/84

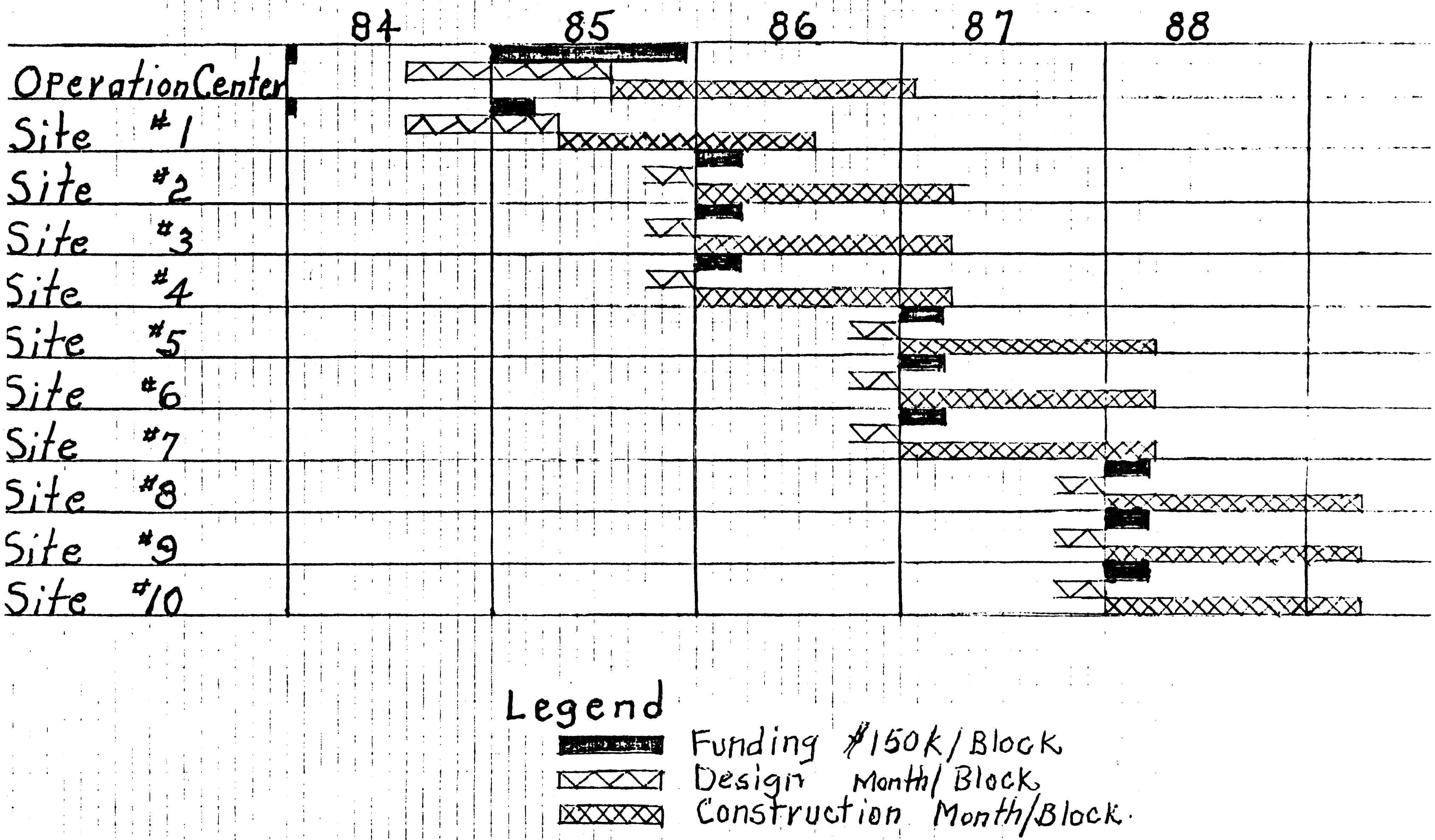


Fig. 2.4

SECTION 3

THE ANTENNA ELEMENTS

W. G. Horne

3.1 Operational Requirements

3.1.1 Size

Chapter IV-A of VLBA report dated May 1982 contains a discussion of the requirements of reflector size and the relative merit of different sizes possible. The considerations of cost and accuracy presented in that discussion are still relevant and the further development of the antenna element presented in this report has been based on the reflector diameter of 25 meters as proposed in that report. An effort has been made in the continuing design of the antenna element to develop an antenna structure which would allow a later addition of an operating frequency of 86 GHz even though, due to cost considerations, certain of the antenna features cannot be provided which would permit operation at the 86 GHz frequency. A larger reflector diameter than 25 meter size would not allow this feature to be incorporated in the design.

3.1.2 Observing Frequencies

The antenna system proposed for this project will operate at the following frequencies:

325 MHz (92 cm)
611 MHz (49 cm)
1.4/1.7 GHz (21.4/17.6 cm)
2.3 GHz (13.0 cm)
5 GHz (6 cm)
8.4 GHz (3.57 cm)
10.7 GHz (2.8 cm)
15 GHz (2 cm)
22 GHz (1.3 cm)
43 GHz (0.7 cm)

Since the highest observing frequency (43 GHz) determines the required surface manufacturing and installation accuracies and also the allowable gravity deformation of the reflector structure initial target designs were based on this frequency. As stated in previous reports and proposals this frequency requires an RMS surface accuracy of 0.45 mm (/16), and non-repeatable pointing errors of 8 arcseconds RMS. During the just completed review and development study a further design goal of possible later addition 86 GHz as an operating frequency was presented as a desirable feature which if possible, should be provided for in the antenna structural design.

3.1.3 Sky Cover Required

Sites for VLBA element location presently being considered vary from a latitude of 18.3 deg to 48.9 deg and a longitude of 66.7 deg to 156.2 deg. The presently proposed antennas will provide 540 deg (+_270 deg) of azimuth rotation; elevation motion will be from 5 deg above horizon to 35 deg beyond the vertical. This amount of azimuth travel will permit continuous tracking from horizon to horizon, will permit rapid calibration by traveling the minimum angular distance in azimuth and will permit in certain cases calibration by plunging the antenna in elevation over zenith.

3.1.4 Observational Configuration

Antennas are proposed to operate at prime focus for 325 MHz and 611 MHz and in a Cassegrain configuration for the remaining configurations. The primary reflector will be a shaped surface to increase efficiency.

Two approaches to basic antenna structural configuration were considered form the start of design studies (a) a yoke and alidade antenna similar to the VLA antennas and (b) a wheel and track antenna similar to the numerous existing communications antennas or the proposed 25 meter millimeter wave antenna. As will be discussed in Section 3.3 of the antenna report the most recent cycle of design studies has concentrated on a wheel and track configuration. One feature common to either configuration is the provision of a vertex room of approximately 150 sq. ft. area.

3.1.5 Weather Limitations on Operational Availability

The antenna elements of the VLBA will be exposed to a wide range of environmental conditions due to their locations which range from tropical (Puerto Rico and Hawaii) to northern United States (North Central Washington and New England). Disregarding the subject of water vapor in the air and cloud cover which are evaluated in another chapter of this report the weather environment impacts the antenna design and operational availability in the following manner.

3.1.5.1 Snow - The antenna specifications provide a strength requirement in the zenith position such that 20 lbs/ft2 of snow (approx. 3 ft.) could be supported without damage to panels or structure. The antenna may be moved to dump snow with a load of 4 lb/ft without overloading panels, structure or drive.

No provision has been made for snow or ice removal by melting as such systems are quite expensive. When conditions are such that snow accumulations occur which are greater than approximately 6 inches but which will not release from the panel surface the antennas affected will be left inoperative in the zenith position. Site selection should be such that these conditions are held to a minimum.

3.1.5.2 Ice - Antenna is capable of being driven with coating of 1 cm thickness of ice and winds of 60 MPH (26.8 m/sec) operational efficiency however will be limited to only the lower frequency due to beam displacement. Site selection should consider frequency of ice storm occurrence. Antenna is designed to survive in the stowed position with 1 cm radial ice on all exposed surfaces and with winds of 110 MPH.

3.1.5.3 Hail - Hail storms because of their very localized occurrence are difficult to predict. There are however certain areas of the United States which are subject to small, localized very damaging hail storms in the general area. An antenna subjected to one of these hail storms could suffer considerable damage to its reflecting surface. A study of weather records is being made by the configuration and site group to determine if desirable sites from a configuration standpoint are located in the higher risk areas.

3.1.5.4 Wind - These antennas will be designed for precision performance in winds to 6 meters/sec (13.4 MPH), for "normal" operation in winds to 18 meters/sec (40 MPH) with reduced precision. Since a desire has been expressed by the scientific and coordinating committees for the possible continuation in service of the antennas at somewhat higher wind speeds a special condition will be provided for which will permit operation in winds to 24 meters/sec (54 MPH) but in which winds we will permit the acceleration rate of the antenna to full speed to be a maximum of 4 secs of time and the maximum speed of the antenna to fall to 60 deg/min in azimuth for the most adverse wind direction and antenna attitude. While these requirements establish the antenna operational parameters they do not establish the operational availability. Site selection will determine the wind environment that antennas will be subjected to and hence the operational availability of the different frequencies. It has been suggested that a requirement that winds not exceed 15 MPH more than 35% of the time, not exceed 25 MPH more than 20% of the time, and not exceed 45 MPH more than 15% of the time would be a reasonable basis for site selection.

3.1.5.5 Temperature - Temperature effects on the antenna must be considered from 2 quite different aspects. The most important aspect (and the most difficult to compensate for) affects the surface accuracy and pointing accuracy of the antenna. Because of sun elevation, wind velocity and antenna altitude temperature differences occur across the antenna structure which can cause reflector distortion or deflection of the main beam of the antenna. We have specified that the precision pointing requirement shall be met when temperature differentials are not greater than 3.5 deg C(6.3 deg F) across the structure. Since this statement only sets up the conditions under which the antenna shall meet the precision pointing requirements we have required that the design assure that temperature differentials do not occur more than 5% of the time which places the antenna outside the precision operating condition. Section 3.2.4.2 of the specifications sets forth the measures to be taken to accomplish this requirement.

The second aspect of temperature affects to be considered involves the impact of either high or low temperatures on the structural strength, mechanical tolerances and clearances, drive and gear box performance, bearing lubrication and performance of electronic controls, data handling and receivers. All of these effects are subject to control provisions in the final design stage. The specifications Section 3.3.2. set forth the temperature ranges in which the antenna will be in either the precision or secondary operating condition and which establish the design parameters for the antenna. It is not anticipated that any of the selected sites will be exposed to lower temperatures than the -30 deg C (-22 deg F) for appreciable periods of time such that any appreciable structural or mechanical special measures (other than possible gear box heating for the Central Washington antenna) will be required. The high temperature range +40 deg C (104 deg F) has been set forth to establish a reasonable range for air conditioning and heating design.

3.2 Specifications

3.2.1 General Statement of Work

The work described herein shall consist of the furnishing of labor, materials, services, drawings, data, detailed specifications, test documents, and other items required for the detailed design, manufacture, assembly on site, alignment, and testing of antennas for the VLBA antenna system.

3.2.2 Objectives of the Program

The objectives of the effort under this subcontract are the following:

- The design of an antenna that meets the operating parameters and requirements set forth in this specification.
- The design for an antenna that is optimized for production of a quantity of ten (10) antennas, taking advantage of economies that may be realized by maximum duplication and standardization of parts, use of tooling to minimize labor, and simplification

of assembly effort. Since assembly of the antennas will be at ten widely separated sites geographically, antennas shall be designed for manufacture and shipping in such modules as will minimize shipping and assembly costs to the extent possible.

- A design that takes into consideration ease of maintenance and the reliability of components to minimize maintenance.
- The manufacture of antennas using the techniques and tooling developed and specified in the design effort.
- The assembly and alignment of the antennas according to the specifications and procedures set forth during the design stage.
- The performance of acceptance tests according to the acceptance documents prepared in the design stage to establish that antennas meet the specified performance requirements.

3.2.3 Design and Performance Parameters

The antenna system for which this antenna is designed consists of ten (10) antennas with 25-meter diameter reflectors located at ten (10) sites, widely separated geographically. Design parameters are therefore set forth for climatic conditions which may not exist at each station.

The antenna shall be an elevation over azimuth configuration, with a 25-meter diameter solid surface which is approximately a paraboloid of revolution as the main reflector. The observing systems to be used shall be both Cassegrain and prime focus. The Cassegrain observing system shall be considered the normal mode of operation. The feed for prime focus operation will be permanently mounted in the center of the subreflector and will be used by moving the subreflector away from the main reflector to position the prime focus feed close to the prime focus. A clear opening of approximately 4 feet in diameter will be required at the apex of the feed legs symmetrical about the reflector axis.

The antenna shall be of wheel and track design and shall meet the following mechanical and operating parameters and conditions.

3.2.3.1 Mechanical Parameters

- Diameter: 25 meters (82.02 feet)
- Focal length: 9 meters (29.53 feet)
- f/D: 0.36 (An alternate f/D of 0.32, with focal length of 8 meters, is under consideration.)
- Sky coverage: Elevation +5 deg to 125 deg ; Azimuth +_ 270 deg
- Operational frequencies: Cassegrain: 43 GHz, 22 GHz, 15 GHz, 10.7 GHz, 8.46 GHz, 2.3 GHz, 1.4/1.7 GHz
- Prime focus: 611 MHz, 325 MHz
- Surface accuracy: Installed rms of 0.45 mm (0.018 inches), including manufacturing, alignment, gravity, operating wind and thermal errors under the specified precision operating

conditions. Peak deviation from the best fit design surface of revolution shall not exceed 1.40 mm (0.55 inches) under precision operating conditions.

- Reflector surface: The reflector surface shall be a surface of revolution which approximates a parabola but which is shaped to increase gain. The maximum deviation of any point on the shaped surface will not exceed 30 mm (1.2 inches) from the basic parabola; coordinates will be furnished later. Panels shall be individually adjustable, doubly curved, solid surface aluminum panels. The panels must withstand either a 20 lb/sq ft uniform load or a concentrated load of 250 lbs over a 6-inch square area without suffering permanent deformation. A circular area of approximately 10 ft in diameter in the center of the reflector will not be covered with reflector panels.
- Panel gap: Spacing between panels shall be 2 mm (0.080 inches) +_0.075 mm (0.030 inches).
- Axis Alignment:

Azimuth axis tilt to plane perpendicular to gravity: maximum error of 15 arcseconds.

Total azimuth axis runout: 10 arcseconds maximum error.

Azimuth axis non-repeatability: 4 arcseconds maximum.

Orthogonality elevation to azimuth: 15 arcseconds maximum error.

Offset of elevation axis from azimuth axis to a maximum tolerance of 0.100 inches.

Orthogonality of Collimation Axis to Elevation Axis: 15 arcseconds maximum error.

Subreflector axis to collimation axis: the structure of the apex of the feed legs must locate the center of the opening coincident within 0.1 inches and the axis of the opening parallel within 30 arcseconds of the collimation axis of the reflector.

- Counterbalancing: Overbalanced to allow the antenna to return to zenith with no drive power under no wind, no ice, no snow conditions.
- Drive Requirements: Azimuth and elevation drives shall have a capability of driving the antenna at a velocity of 90 per minute in azimuth and 30 per minute in elevation, with the reflector in any attitude under the specified operating conditions. Azimuth and elevation drives shall drive the antenna at sidereal tracking rates with an accuracy as specified in paragraph 3.2.4.2 below.

3.2.3.2 Operating Parameters and Conditions

- General: Antenna will be exposed to the elements at various sites and under various climatic conditions, with some sites perhaps as high as 10,000 ft above mean sea level. The antennas are to be designed for a life expectancy of 20 years. No damage to the operating components of the antennas must occur due to airborne sand or dust or accumulation of frozen or liquid water.

- Precision (Primary) Operating Conditions: The antenna shall meet the required precision pointing and surface accuracies under the following conditions:

- Temperature range: -18 deg C (0 deg F) to +30 deg C (86 deg F)
- Rate of change of ambient air temperature is no greater than 2 deg C per hour.
- No parts of the telescope structure differ in temperature more than 3.5 deg C (6.3 deg F).
- The relative humidity is between 0 and 50%.
- The wind at 12 m elevation is no greater than 6 m/sec (13.4 MPH), with gusts of +_ 1 m/sec (2.24 MPH) superimposed. Wind from any direction with the reflector in any attitude.
- No snow or ice load.

- Normal (Secondary) Operating Conditions: The antennas must continue to operate under "normal" operating conditions but it is understood that the pointing, tracking and surface accuracies set forth under precision operation will not be achieved. Normal operation must be possible under the following conditions:

- Ambient air temperature: -30 deg C (-22 deg F) to +40 deg C (104 deg F.)
- Relative humidity: 0 to 98%
- Rain rate: up to 5 cm (2 in) per hour
- Ice and snow load: none
- Wind (measured at 12 m elevation) velocity up to 18 m/sec, with gusts of 2.5 m/sec superimposed. Wind may be from any direction; reflector in any position. A special condition will be provided which will allow the antenna to operate in winds to 24 m/sec, but for which the acceleration time to full speed may be 4 secs of time and maximum speed may be allowed to fall to 60 deg/min in azimuth for the worse case of wind direction and antenna attitude.
- Requirements to be met in moving to stow and in the stowed position:
- Slew to stow: The antenna shall be capable of being slewed to the stow position in elevation in winds of 60 mph (26.8 m/sec) with all exposed surfaces of the structure coated with 1 cm radial thickness of ice. The slew rate may fall to 10 deg/minute.
- Slew to dump snow: The antenna shall be capable of dumping snow by slewing at 20 deg/min to any position 5 deg above the horizon, with a wind of 25 mph from any direction and with an original snow load in the reflector of 4 lbs/sq ft. No damage or overload shall occur to either structure, drives or brakes.
- Survival: The antenna is to be designed to survive in the zenith position in winds of 110 mph with 1 cm of radial ice on all exposed surfaces. When loaded under these conditions, design yield stresses of materials shall not be exceeded and no permanent deformation shall occur. Stow brakes shall be provided capable of holding the antenna in the zenith position when subjected to the design survival loading.

3.2.4 The Antenna Performance

3.2.4.1 Surface Accuracy

Under the precision operating conditions specified in 3.2.3 above, the rms of the deviations from the design parabola shall not exceed 0.45 mm (0.018 inches). This rms shall include the manufacturing rms, the panel setting rms, gravity effects and wind and thermal effects. The panel setting rms; however, may be calculated by permitting translation of the design surface along the collimation axis and rotation of the design surface about an axis perpendicular to the collimation axis and parallel to the elevation axis. Gravity effects may be calculated from an elevation angle which is 30 deg from the zenith.

Under these same conditions the peak deviation of the surface from the design parabola shall not exceed 1.5 mm (0.060 inches).

3.2.4.2 Pointing and tracking errors

The pointing error is defined as the difference between the commanded position of the antenna and the position of the main beam of the reflector. Tracking error is a part of the pointing error and includes the effects of the servo update rate and axis velocity as determined by axis position. The repeatable pointing error is due to gravity deformation, axis alignment error, inductosyn offset, bearing runout, bearing alignment, and similar errors. The non-repeatable pointing error is due to wind forces and gusts, acceleration forces, effects of temperature differences and temperature changes, inductosyn resolution, inductosyn error, data converter errors, servo and drive errors, position update rate, bearing non-repeatability and random errors. The repeatable pointing error for this antenna shall not exceed 3 minutes of arc.

The non-repeatable pointing error is divided into two types of error with different statistical behavior. The first type of non-repeatable errors behaves correctly, in a statistical sense, with errors changing in magnitude and sense within times up to a minute. Such errors average out fairly well in observations taken over several minutes. Non-repeating errors of this type, under the precision operating conditions of 3.2.3 above, shall not exceed 8 arcseconds RSS. This figure shall be derived by making an RSS of all errors of this type with the antenna in any attitude and while tracking a source at the specified sidereal tracking rates. The values of individual errors which contribute to the RSS error budget should be rms values wherever these can be determined. It may only be possible in some cases, such as wind induced distortions of the reflector, yoke if used, alidade and tower, to identify the antenna attitude and wind direction which gives to greatest error (the "worst case"). One-half of such "worst case" error values should be used in the RSS error budget.

The second type of non-repeatable pointing error is that which usually results from thermally induced distortions of the antenna structure. These errors have time constants typical of the times over which serious temperature changes or temperature differences occur. These times may lie between several minutes and a few hours.

It is possible to control the magnitude of this type of pointing error by reducing the temperature differentials between structural elements by either active or passive (the preferred) measures. Passive measures to be investigated in the design stage shall include antenna paint systems to control reflectivity and reradiation from members where effective. After such design efforts have been made, the antenna must, under the precision operation conditions, suffer no RSS non-repeatable pointing errors of this type which exceed 7 arcseconds in magnitude. The antenna design shall assure that temperature differentials do not occur more than 5% of the time which places the antenna outside the precision operating condition.

3.2.4.3 Slewing Motion

Slewing motion is defined as the rapid movement of the antenna about either axis simultaneously or independently. The antenna shall be capable of driving at the rate of 30 deg/min of time about the elevation axis and 90 deg/min about the azimuth axis in winds to 18 m/sec (40.3 MPH) with the reflector in any attitude. It shall be possible to slew either axis independently while the other axis is stationary or moving at the tracking rate, or to slew both axes simultaneously. The antenna shall be capable of accelerations of 0.25 deg/sec2 about the elevation axis and 0.75 deg/sec2 about the azimuth axis except for the special conditions set forth in 3.2.3.2. above.

3.2.4.4 Tracking Motion

The antenna shall be capable of tracking a stellar source at the azimuth and elevation rates which correspond to the sidereal rate for the source position and maintaining the pointing accuracy as set forth in 3.2.4.2 above under precision operating conditions with a command update rate of 10 times/sec. The cone of avoidance near the zenith when in the tracking mode shall have a half-angle less the 2.5 deg.

3.2.5 General Requirements

3.2.5.1 Feed Legs and Apex

The feed leg supports shall be designed to support simultaneously a subreflector of 2.5 m diameter and adjusting mechanism, weighing approximately 1300 lbs, and a prime focus feed of approximately 300 lbs. The feed legs shall also be designed to support a cable weight of 4 lbs/ft on each leg. The apex structure shall be designed so that a clearance of 18 to 24 inches exists between the bottom of the apex structure and the focal point of the main reflector. Its configuration shall be such that a clear opening of approximately 48 inches diameter exists on the center line of symmetry for the location and attachment of the adjustment mechanism. The feed legs and apex, including a 2.5 m subreflector, shall not cause RF blockage in excess of 6 percent of the total aperture area.

3.2.5.2. Vertex Equipment Room and Feed Mounts

An approximately circular room with a minimum of 200 sq ft area, having an inside diameter of approximately 16.0 ft by 7.5 ft height for mounting of feeds and equipment, shall be provided. The floor of this room shall be parallel to the ground with the antenna pointed at zenith and shall be a minimum of 8 ft below the vertex of the antenna. This room shall be provided with the following features:

- Mounting provisions for up to seven 2 ft x 2 ft x 7 ft ceiling mounted racks, with a total weight of 2000 lbs.
- An access door for access by personnel and for means of installing racks by use of hoist.
- Thermal insulation and air conditioning to provide 23 deg C $\pm$ 0.5 deg C (74 deg F $\pm$ 1.0 deg F) temperature control with an interior heat input of up to 3 kW. A proportional control gas modulated cooling system is recommended. No specific humidity conditions are required.
- The roof of the building shall contain a removable mounting ring for the mounting of feeds. Dimensions of this ring shall be determined in the design stage, but it is anticipated that it will be approximately 10 ft in diameter.
- The vertex room shall be electrically shielded so as to prevent the leakage of radio frequency interference out of the room. The room will be constructed so that signals in the frequency range 1 MHz to 44 GHz are attenuated by at least 30 db when they leak from the room.

3.3 Antenna Configuration Studies

3.3.1 Standard Yoke and Alidade Antenna

In the preparation of the initial VLBA proposal studies (dated Feb. 1981 and May 1982) the VLA antenna was used as a baseline for design comparisons and for cost estimating purposes since extensive knowledge of both that telescope's performance and costs existed. This antenna is a quite good antenna of its type and as it existed came quite close to meeting the reflector and pointing requirements for the VLBA antennas. To meet requirements of the VLBA it was merely necessary to estimate additional costs for improving certain features of the VLA antenna to the requirements of the VLBA. Basically these consisted of improving the panel manufacturing accuracy, the panel setting accuracy, and the pointing performance of the pedestal and yoke and alidade sections.

3.3.1.1 Reflector Performance

For 43 GHz performance and using the standard lambda/16 surface accuracy requirement the required surface RSS accuracy is 0.438 mm or 0.017 inches. This can be broken down into an error budget as follows:

	Inches
Reflector distortion due to gravity (90 deg wrt* 50 deg)	- 0.010 RMS
Panel manufacturing accuracy	- 0.008 RMS
Panel setting accuracy	- 0.008 RMS
Wind (13.8 MPH)	- 0.006 RMS
Thermal (Refl.)	- 0.004 RMS
	RSS = 0.0167 inches

* with respect to

This budget encompasses the major controlling error items (a few minor items are ignored). A comparison with the error budget actually accomplished for the VLA reflector (design target RSS accuracy of 0.032 inches) would be:

Achieved VLA Error Budget

Reflector distortion due to gravity (90 deg wrt 50 deg)	0.0129 in. RMS
Panel manufacturing accuracy	0.0133 in. RMS
Panel setting accuracy	0.0106 in. RMS
Wind (15 MPH)	0.007 in. RMS
Thermal (Refl.)	0.005 in. RMS
	RSS = 0.023 inches

As can be seen from examining the above 2 tables the VLA reflector and panels almost meet the required surface accuracy and with minor improvements in reflector gravity performance and panel setting but with improved panel manufacturing accuracy the reflector performance of a VLA type yoke and alidade antenna could be satisfactory for operation at 43 GHz. In the limited time and with the limited number of personnel available in the recent review cycle further design development of the yoke and alidade reflector has not been done.

3.3.1.2 Pointing Error Budget

In arriving at a pointing error budget the required non-repeatable pointing error is not as easily agreed upon. Factors varying between B/10 and B/5 are generally used where B is the half-power beamwidth. At 43 GHz this would require a non-repeatable pointing error of between 7 arcseconds and 14 arcseconds depending on the selected criteria. The difficulty of defining the required non-repeatable pointing error is compounded when we try to define whether this is RMS, RSS or peak error or define how the errors are computed. It has been our practice to calculate a pointing error by taking an RMS of each type of contributions and taking an RSS of the various different contributors to arrive at the final pointing error. In place of the RMS (where that would require very extensive calculations as in the case of wind induced pointing errors) we have specified that a peak error be calculated and that one half of that peak value be used in establishing the values to be used in the RSS table. In the case of temperature effects however this procedure of taking an RSS of the RMS of individual contributors gives a distorted picture of the true pointing error as the temperature effects on the reflector, yoke and alidade and pedestal may be directly additive. The specifications (section 3.2.4.2) have been written to provide for control of thermal distortions in a specific sense in that under precision operating conditions non-repeatable pointing errors due to thermal differentials should not exceed 7 arcseconds. All other non-repeatable pointing errors when summed in the RSS pointing error budget should not exceed 8 arcseconds.

With specific reference to the pointing performance of a yoke and alidade type antenna for VLBA and remembering that a complete pointing analysis for an upgraded VLA type antenna has not been performed an error budget for the yoke and alidade antenna under the precision operating conditions would be:

Servo System ~ RMS	2.50 arcseconds
Data System ~ RMS	2.12 arcseconds
Reflector - Wind (1/2 Peak)	0.75 arcseconds
Yoke - Wind (1/2 Peak)	5.20 arcseconds

Az. Brg. RMS	0.65 arcseconds
Pedestal ~ Wind (1/2 Peak)	3.25 arcseconds
Fndn. wind (1/2 Peak)	1.50 arcseconds
RSS	7.18 arcseconds

The thermal pointing error budget for the precision pointing conditions would be:

Reflector ~ 1/2 Peak	0.60 arcseconds
Yoke ~ 1/2 Peak	5.1 arcseconds
Pedestal ~ 1/2 Peak	1.6 arcseconds
Error	7.3 arcseconds

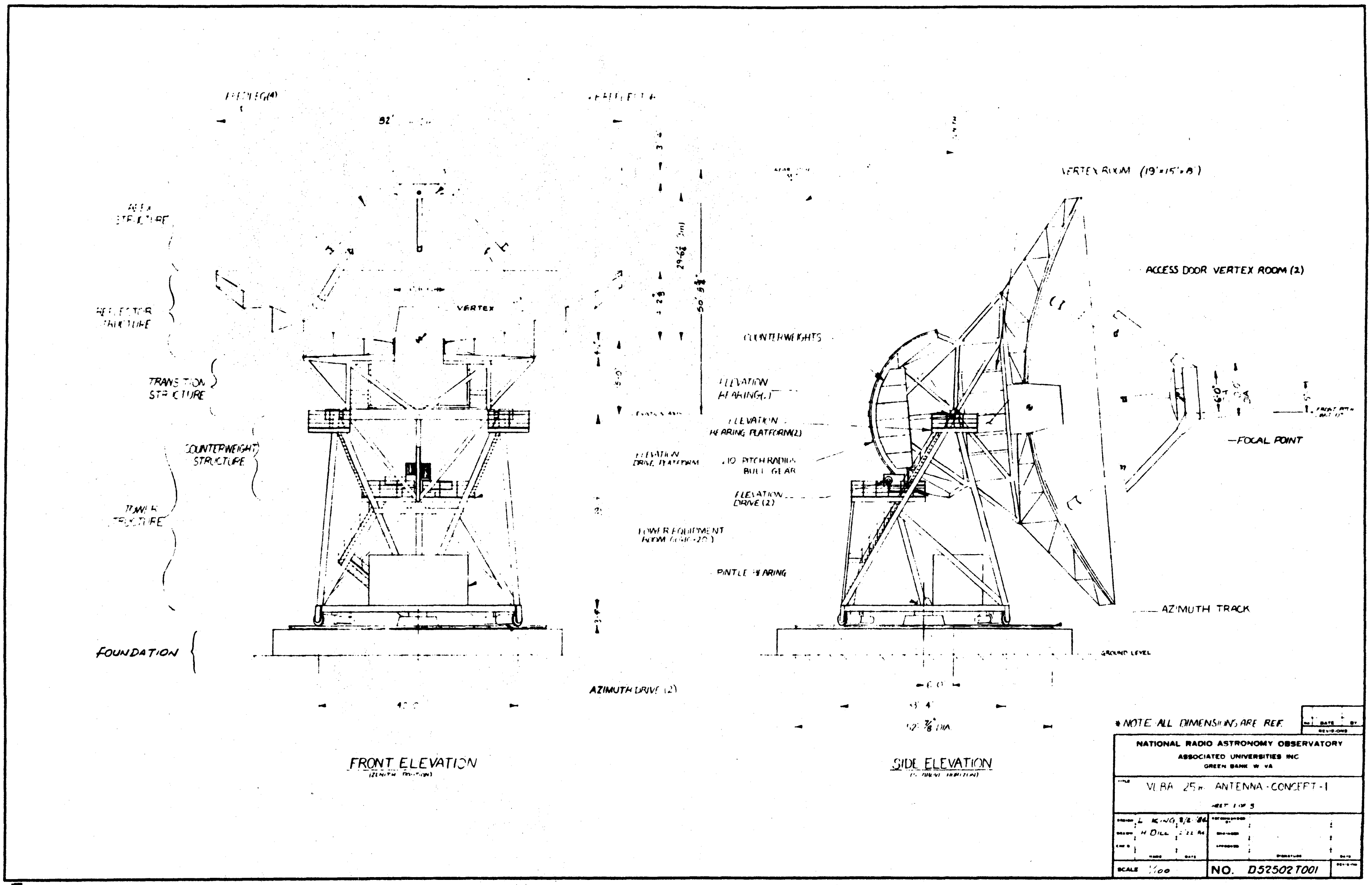
Note that this thermal error is not an RMS or RSS value as in general the thermal errors will occur on each component of the antenna simultaneously and will be directly additive. The above thermal budget also assumes extensive passive thermal control of both the Yoke Section and the Pedestal Section of the antenna.

3.3.1.3 Relative Manufacturing and Assembly Costs

The yoke and alidade type of antenna is slightly heavier in weight than a wheel and track antenna of the same general accuracy because of the heavy plate of the yoke and alidade and the heavy members used in fabricating the pedestal. The drives, trucks and rails of the wheel and track antenna are somewhat more expensive than an azimuth bearing and gear but because of the machining required for the azimuth bearing for an accurate antenna the azimuth motion system costs are approximately equal.

3.3.2. Wheel and Track Antenna

As stated in 3.3.1 previously, because of current familiarity, the "baseline" costs estimates and performance estimates used a "yoke and alidade" type antenna. The recent effort in the antenna area has concentrated on a "wheel and track" type antenna because of superior pointing characteristics and somewhat cheaper costs. Two wheel and track configurations have been considered; the first would use a reflector very similar to the existing VLA reflector while the second would use an advanced design reflector and elevation wheel structure to obtain clearly superior gravity performance which would open the possibility of higher frequency operation. Figures 3.1 through 3.5 show views of this improved performance antenna. The azimuth structure would be the same for either of the two types of wheel and track antennas.



VERTEX
COUNTERWEIGHTS
ACCESS DOOR VERTEX ROOM (2)
FOCAL POINT
PINTLE BEARING
AZIMUTH TRACK
GROUND LEVEL
FOUNDATION
AZIMUTH DRIVE (2)
FRONT ELEVATION
SIDE ELEVATION
* NOTE ALL DIMENSIONS ARE REF.
NATIONAL RADIO ASTRONOMY OBSERVATORY
ASSOCIATED UNIVERSITIES INC
GREEN BANK W VA
VLBA 25m ANTENNA - CONCEPT - 1
NO. D52502T001

Figure 3.1

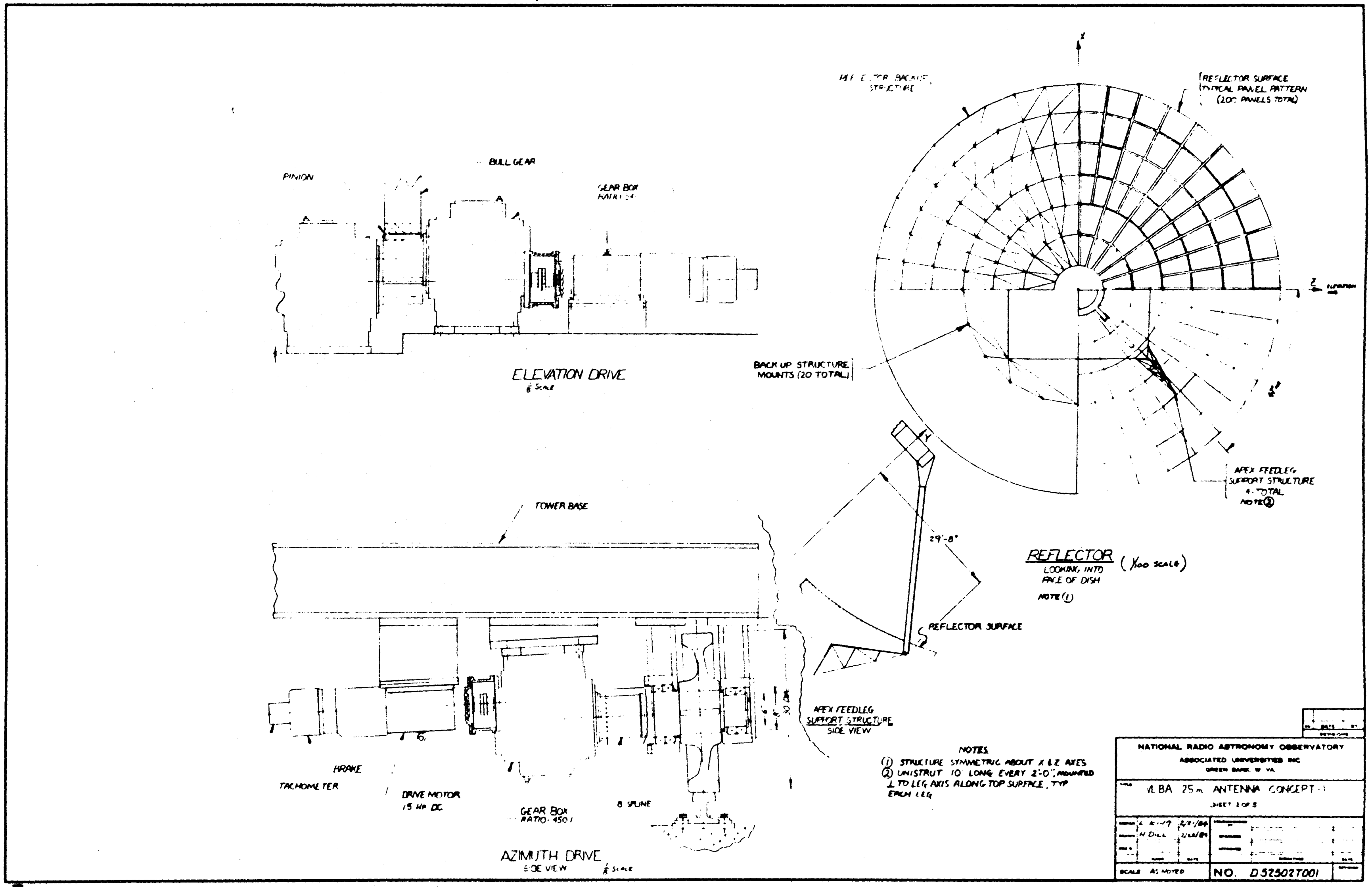

REFLECTOR SURFACE
TYPICAL PANEL PATTERN
(200 PANELS TOTAL)
BULL GEAR
PINION
GEAR BOX
ELEVATION DRIVE
BACK UP STRUCTURE
MOUNTS (20 TOTAL)
APEX FEEDLEG
SUPPORT STRUCTURE
4 TOTAL
NOTE ②
TOWER BASE
29'-8"
REFLECTOR
LOOKING INTO
FACE OF DISH
NOTE ①
(1/100 SCALE)
REFLECTOR SURFACE
APEX FEEDLEG
SUPPORT STRUCTURE
SIDE VIEW
NOTES
① STRUCTURE SYMMETRIC ABOUT X & Z AXES
② UNISTRUT 10 LONG EVERY 2'-0", MOUNTED
⊥ TO LEG AXIS ALONG TOP SURFACE, TYP
EACH LEG
BRAKE
TACHOMETER
DRIVE MOTOR
15 HP DC
GEAR BOX
RATIO: 450:1
8 SPLINE
AZIMUTH DRIVE
SIDE VIEW
NATIONAL RADIO ASTRONOMY OBSERVATORY
ASSOCIATED UNIVERSITIES INC
GREEN BANK, W. VA.
VLBA 25 m ANTENNA CONCEPT 1
SCALE AS NOTED
NO. D52502T001

Figure 3.2

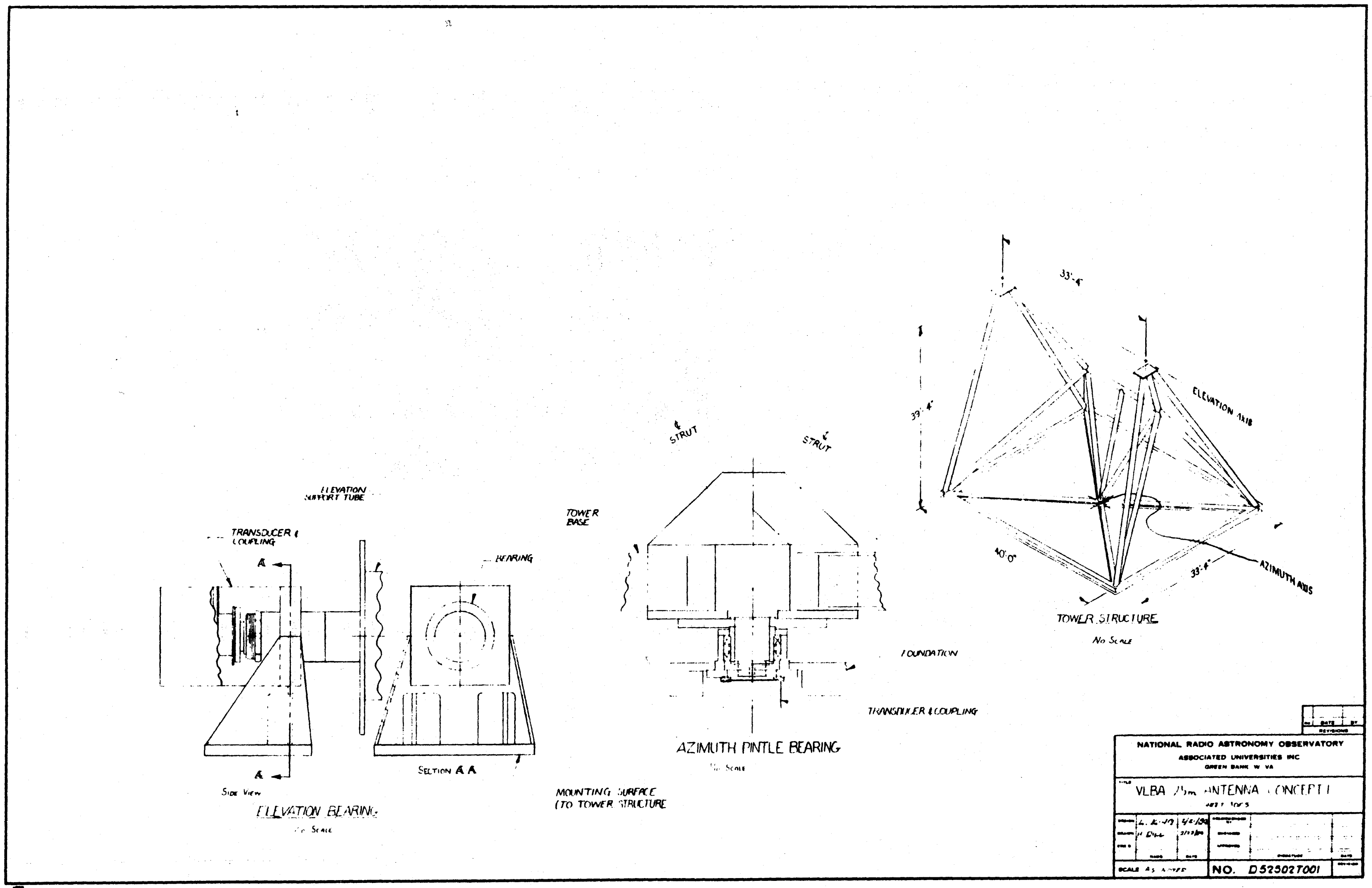
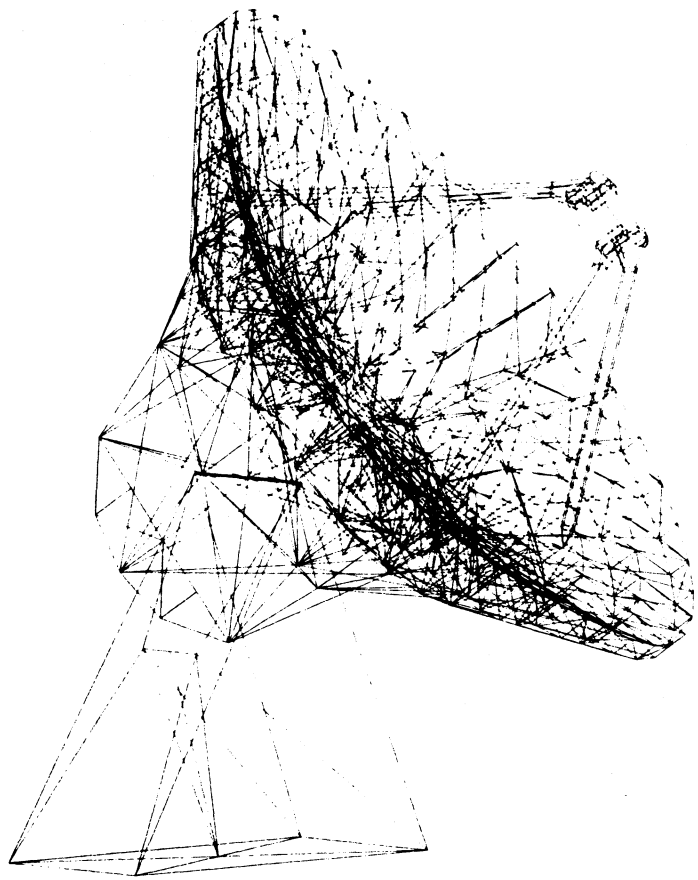

TOWER STRUCTURE
No Scale
ELEVATION AXIS
AZIMUTH AXIS
33'-4"
40'-0"
STRUT
TOWER BASE
FOUNDATION
TRANSDUCER & COUPLING
AZIMUTH PINTLE BEARING
MOUNTING SURFACE
(TO TOWER STRUCTURE
ELEVATION SUPPORT TUBE
BEARING
SECTION A A
Side View
ELEVATION BEARING
NATIONAL RADIO ASTRONOMY OBSERVATORY
ASSOCIATED UNIVERSITIES INC
GREEN BANK W VA
NO. D52502T001

Figure 3.3



NOTE

(1) DIAMETER — 25 METERS (82 FEET)
FOCAL LENGTH 9 METERS (29.5 FEET)
SKY COVERAGE — ELEV 0° TO 85°
AZ ± 270°

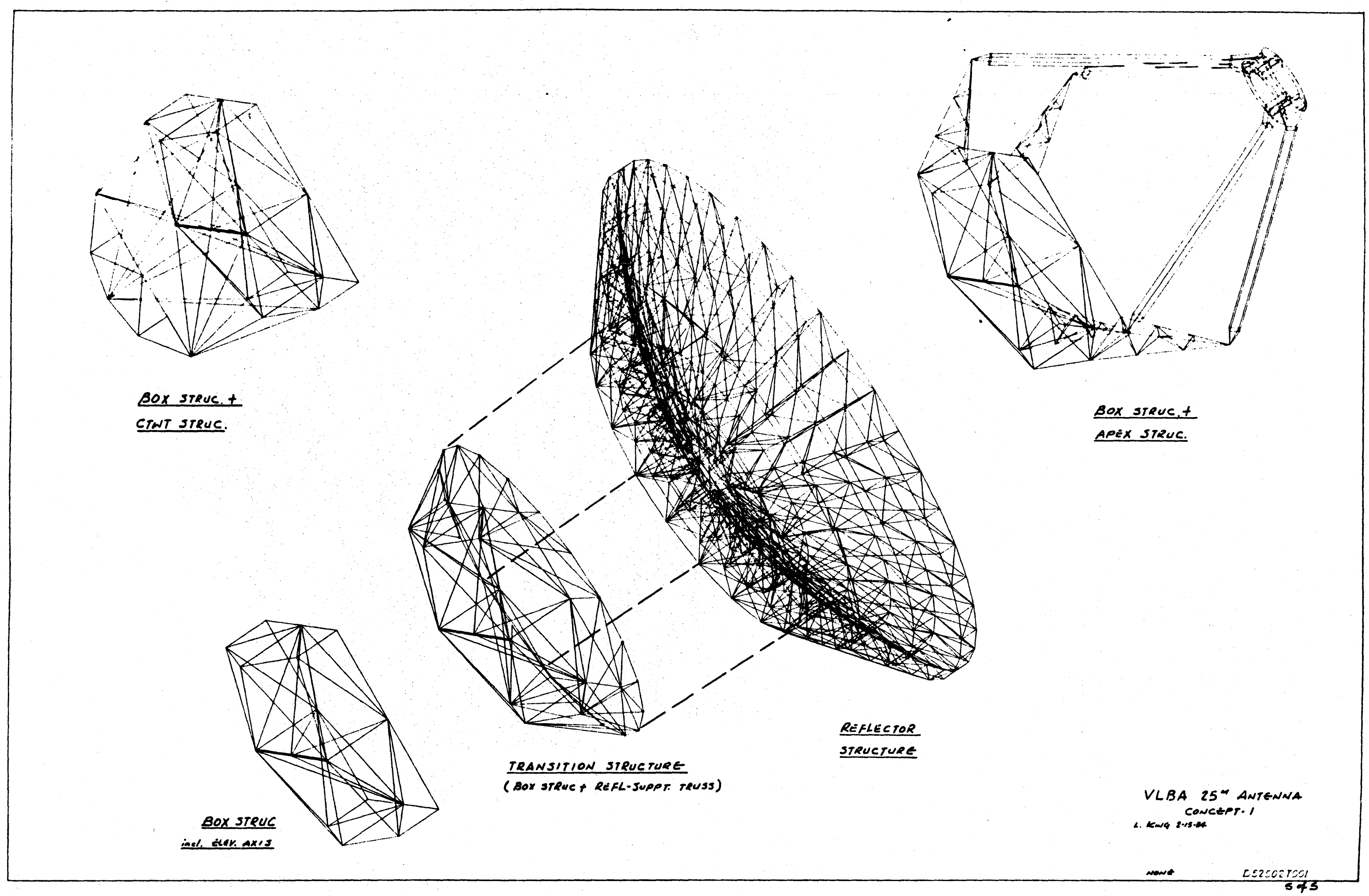
(2) THIS DWG SHOWS LOCATIONS OF STRUC JOINTS & MEMBERS OF THE DESIGN. IT IS NOT TO BE INTERPRETED AS REQUIRING ANY PARTICULAR SHAPE OR TYPE OF INDIVIDUAL STRUC JOINTS OR MEMBERS

(3) REF SPECIFICATIONS AND STATEMENT OF WORK OF VLBA REQUEST FOR PROPOSAL FOR DETAIL REQUIREMENTS OF DIMENSION & DESIGN

VLBA 25M ANTENNA
CONCEPT-1
L KING 2-15-84

NONE D52502T001
4 of 5

Figure 3.4



BOX STRUC. +
CTWT STRUC.
BOX STRUC. +
APEX STRUC.
REFLECTOR
STRUCTURE
TRANSITION STRUCTURE
(BOX STRUC + REFL-SUPPT. TRUSS)
BOX STRUC
incl. ELEV. AXIS
VLBA 25M ANTENNA
CONCEPT-1
NONE
D52502T001

Figure 3.5

3.3.2.1 Reflector Performance

In general there are two types of elevation structures for a 25 meter telescope:

(A) An integrated reflector/elevation wheel design in which the reflector is an integral part of the elevation support structure. This design is quite compact, weighs less than the second type and is consequently somewhat cheaper. The surface deflections for the compact type however show two stiff quadrants over the elevation bearings and two soft quadrants 90 degrees from the elevation axis which are further distorted by reactions from the drive forces. The surface rms errors due to change in gravity direction are larger for this type of design than for a design in which the support and reaction forces are more evenly distributed to the reflector.

The VLA design is one of the best of the integrated reflector-elevation structure designs in that the heavy star-shaped plate girder in the reflector structure at the elevation bearing and elevation wheel girder radius plus the system of ring trusses does smooth out the gravity distortions of the surface caused by the supports and drive and counterweight reactions. For a wheel and track antenna the VLA type reflector as proposed for the yoke and alidade antenna would quite adequately reach the performance required as shown in Section 3.3.1.1.

(B) The second type of elevation structure is one in which the reflector structure is supported on a number of equally spaced points provided by a transition structure between the reflector structure and the elevation wheel/counterweight structure. The support stiffnesses are thus equalized to give an improved gravity RMS at the surface. The various homology antenna designs are good examples of this type of antenna. One feature of this type of antenna is that the surface is pushed further away from the elevation axis and the elevation weight is consequently heavier.

The proposed advanced design is of this second type. The reflector structure is a conventional radial rib design with circular trusses, and is supported at 20 equally spaced points by the transition structure. The basic geometry of the transition structure is a box-cone structure. The elevation axle and the single elevation gear forming the cone are connected to the base of the box section.

A comparison of this advanced design reflector and the VLA reflector is tabulated as follows:

	Proposed Design	VLA
Surface RMS (Gravity)	(90o wrt 60o) 0.123mm(.0048in)	(90o wrt 50o)0.330mm(.013in)
	(0o wrt 60o) 0.147mm(.0057in)	(90o wrt 50o)0.300mm(.0118in)
Elev. Struc. Wt.	324,500 lb.	256,150 lb.

3.3.2.2 Pointing Error Budget

The pointing error budget for the wheel and track antenna will be quite similar to the error budget set forth in Section 3.3.1.2 for the yoke and alidade antenna with a contribution from the rail and wheel non-repeatability replacing the azimuth bearing contribution at the yoke and alidade. It is however in meeting the requirements of the pointing error budget that the wheel and track antenna clearly demonstrates its superiority to the yoke and alidade antenna. Due to its wide base and space frame design up to the elevation bearing level (as opposed to the more narrow base, the small diameter azimuth bearing and the beam action of the yoke arms of the yoke and alidade antenna) the wheel and track antenna is much more resistant to rotation and translation of the elevation bearing platform with respect to the base which is the main source of pointing error due to wind forces.

An extensive analysis of the base structure below the elevation bearings for the wheel and track antennas has not been performed for the VLBA but the same base structure would be used for either type of reflector chosen (with minor configuration changes).

3.3.2.3 Manufacturing and Assembly Costs

Of the two types of wheel and track antennas under consideration the advanced reflector design will be appreciably the heavier. A comparision of approximate weights of the three types of antennas considered would be:

	Yoke & Alidade	Conventional Wh. & Tr.	Adv. Des. Wh. & Tr.
Surface Panels	12,800#	12,800#	12,800#
Feed Legs, Solor.	6,200	6,200	6,200
Reflector	58,700	58,700	50,700
Elev. Wheel	42,300	36,200	132,600
Ctwt.	116,000	116,000	96,600
Yoke & Alidade	64,000	-	-
Tower	55,000	96,000	96,000
Drives, Platforms, etc	22,000	16,000	16,000
Misc. (Equip, Cables)	21,000	15,000	15,000
Azimuth Trucks	-	16,000	16,000
Pintle Bearing	-	8,000	8,000
Vertex R.M. Feeds	19,400	19,400	incl.
Totals	418,200	400,000	449,900

Material and fabrication costs for the yoke and alidade antenna would be marginally higher than for the conventional wheel and track because of the slightly higher weight and because of the machining required for the azimuth bearing to achieve the required accuracy. The advanced design wheel and track material and fabrication costs will be higher than the other two due to the higher weight. Assembly costs of the advanced design wheel and track will be slightly higher than for the other two designs because of the increased weight and greater height of the antenna.

3.4 Cost Estimates and Comparisons

VLBA Proposal dated May 1982 Chapter VII contains the estimate for ten VLA type yoke and alidade antennas. As stated in that write-up and previously in this report that design was used as a baseline to prepare the May 1982 proposal in the full knowledge that a wheel and track type antenna could more easily meet the pointing and performance requirements and could possibly be less expensive. The estimate of cost for that system given in 1982 dollars in that document is briefly summarized (based on delivery of 5 antennas in 1983 and 5 antennas in 1984) as follows:

Antennas, Engineering, Tooling	$16,856k
AUI Supplied Antenna Components (10x63k)	630k
	$17,486k

A. Wheel and Track Antenna - Concept I

An estimate for a wheel and track antenna using a VLA reflector (upgraded) has been prepared and is as follows:

A.	Antenna Engineering Costs (Contr)	$ 660k
	Servo Design	65k
	Focusing Feed Mount Design	25k
		$ 750k
B.	Three Antennas Delivered in 1985	$ 4,257k
	Antenna and Panel Tooling	110k
		$ 4,367k
C.	Four Antennas Delivered in 1986	$ 5,677k
D.	Three Antennas Delivered in 1987	$ 4,367k
	TOTAL	$15,161k

To the above must be added the cost of the feed support ring and the feed support tower at the vertex of the antenna which estimated at $30k x 10 = $300k.

It should be noted that this estimate is in terms of 1983 dollars and no escalation has been added for delivery in later years. It should also be noted that this estimate is based on an optimum commitment schedule; that is that commitment is made in the antenna contract for all ten antennas. If commitment is made in this manner considerable economies can be accomplished by the antenna manufacturer in procurement of the more costly materials and equipment (such as structural material, gear reducers, gears, azimuth rail and antenna drives) even though fabrication, delivery and antenna assembly is spread over three years.

B. Wheel and Track Antenna - Concept II

An estimate for a wheel and track using an advance design reflector has been prepared since one of the suggestions made by the VLBA scientific committee was that consideration be given to the possible operation at 86 GHz sometime in the future. As explained in Section 3.1.2 and 3.3.2 a standard reflector has difficulty reaching the gravity deformation performance required for 86 GHz frequency so an advanced design reflector was developed. It should be emphasized however that the estimate prepared here does not represent an antenna which could operate at 86 GHz in that we have only provided for the reflector back-up structure performance and have not provided a position system, surface panels of the required accuracy or for the required accuracy at the azimuth rail system. The surface panels for 86 GHz in particular are beyond the present budget limitations in that manufacture to the required accuracy would require a different and far more expensive manufacturing process than those proposed for the 43 GHz presently contemplated. As stated in Section 3.3.1.1 the panel manufacturing accuracy required for 43 GHz operation is 0.0008 inches RMS which two sources have assured us is achievable but which is about the limit of a "standard" manufactured panel. The estimated manufacturing costs of such panels is $31.00 per square foot making the panel costs per antenna approximately $179,000. We do not have good estimates from manufacturers for panels required for 86 GHz operation but since a more exotic method of manufacturing would be required have estimated (based on panel costs for the 12 meter antenna) that costs may run around $160.00 per square foot making the panel costs reach $900,000.00 per antenna.

With this understanding then the estimate for the advanced design wheel and track antenna is as follows:

A.	Antenna Engineering Costs (Contr)	800k
	Servo Design	65k
	Focusing Feed Mount Design	25k
		890k
B.	Three Antennas Delivered in 1985	4514.7k
	Tooling	167.0k
	AUI Supplied Equipment	222.0k
		4903.7k

C.	Four Antennas Delivered in 1986	6019.5k
	AUI Supplied Equipment	296.0k
		6315.5k
D.	Three Antennas Delivered in 1987	4514.7k
	AUI Supplied Equipment	222.0k
		$4736.7k
	TOTALS	$16,846k

It should be noted that this estimate is in terms of 1983 dollars and no provision for escalation has been added for delivery in later years. It should be also noted that this estimate is based on an optimum commitment schedule, that is that commitment is made initially in the antenna contract for all ten antennas. If commitment is made in this manner considerable economies can be accomplished by the antenna manufacturer in procurement of the more costly materials and equipment (such as structural material, gear reducers, gears, bearings, azimuth rail and antenna drives) even though fabrication, delivery and antennas assembly is spread over several years.

3.5 Recommendations on Configuration and Design

On the basis of the performance forecasts set forth in Section 3.3 and the cost estimates set forth in Section 3.4 it is recommended that a wheel and track antenna design be chosen in preference to a yoke and alidade design for two reasons.

A. The wheel and track antenna because of its wider base and better configuration is better suited mechanically to achieve the pointing precision in the expected wind and temperature regime than the yoke and alidade design.

B. The wheel and track antenna from the estimate would appear to be somewhat cheaper in price.

As to a choice between the two wheel and track designs studied a clear choice is not so evident; there is no question that the first wheel and track design is appreciably cheaper than the second concept and will quite adequately meet the requirements of the proposed 43 GHz. If the possibility of later conversion to 86 GHz operation as suggested by the scientific committee is however a viable consideration the reflector design for concept I does not offer the gravity performance that would be desired. Analysis to see if a reduced area of the surface would support satisfactory performance has not been done and is one area which should be pursued prior to final engineering design. As far as non-repeatable pointing performance is concerned the two designs will yield essentially equal performance. As stated in Section 3.4 however the concept and estimate presented herein merely provides a structural capability to operate at 86 GHz. Surface panel accuracy and some mechanical features to perform at 86 GHz frequency have not been provided for.

It is recommended that scientific appraisal of the value of 86 GHz operation be made in the light of the approximate $1.7 million additional cost which would be required now and the later cost of approximately $700k per antenna for the surface panels required plus costs of removing old panels and installing and aligning new ones. In the meantime an analysis of the performance of limited areas of the concept I antenna should be prepared for scientific evaluation.

Update 840423 WGH

Since the Sept. 15, 1983 publication of Chapter 3 - Antennas of the VLBA report additional design development, antenna specification preparation and project planning have modified the results presented in that report. The results of the additional effort are summarized as follows:

(A) Design Development

A decision has been made to adopt the configuration described in the Sept. 15 report as the advanced design reflector with the wheel and track base. This decision has been made with the following two goals in mind:

(1) The advanced design reflector combined with a well designed base and tower of wheel and track configuration provides a telescope structure whose gravity, wind and thermal performance makes it possible at some future date to convert to 86 GHz operation. This upgrading to 86 GHz operation would require the replacement of the antenna surface panels with higher accuracy panels, a more accurate panel alignment and upgrading of some of the antenna subsystems.

(2) If conversion to 86 GHz operation is never made however, superior 43 GHz performance will be achieved due to the better pointing and surface distortion characteristics of the advanced design antenna.

Non-repeatable pointing error due to wind at 7 m/sec has been calculated for the advanced design antenna as follows:

Pitch Angle	Refl. RMS	Refl. P.E.	Tower P.E.
0 degrees	20 micrometers	0.33 arc.sec.	5.57 arc.sec.
60 "	57 "	1.47 " "	3.06 " "
90 "	14 "	2.18 " "	3.51 " "
120 "	19 "	2.49 " "	4.93 " "
180 "	9 "	0.52 " "	6.55 " "

(B) Antenna Specifications

Complete antenna specifications expanding and modifying those specifications set forth in Section 3.2 have been prepared and issued as RFP-VLBA-01. For an up-to-date version of the specifications RFP-VLBA-01 should be consulted.

C) Project Planning

At the time of preparation of Chapter III of the VLBA report it was anticipated that antenna procurement could be scheduled on a basis which would provide for the optimum procurement of antennas which would result in the lowest possible cost for the antenna materials and components. The procurement schedule has been stretched out since then to accomodate a more level funding schedule which essentially adds one year to the completion schedule and resulted in adjustments to the estimated antenna costs.

SECTION 4

CONTROL AND MONITORING

B. G. Clark

4.1 Specifications

Monitor and Control Bus: see Appendix A.

Standard Interface: specification in preparation.

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 during correlation 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 an 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 epuipment 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 cross-correlation in near real-time.

The hierarchy of decision making between the central computer and the small computer located in each antenna has not yet been decided. On the one hand, if the station computer is limited to simple, repetitive tasks then its hardware and software should be more reliable and easy to maintain. On the other hand, the ability to perform sophisticated tasks during periods of communication outages may then be limited; also, we do not want to foreclose the possibility of later implementing control schemes which would tax the communication system, although none are envisioned at this time.

A major consideration in the system design is reliability. NRAO's experience with data transmission via telephone links suggests that such links cannot be relied upon for real-time control, but we lack detailed statistics of the expected outages. In order to minimize the effect of loss of communication, we propose to utilize leased lines for normal operation, with dial-up lines also available at each station as a backup. In addition, control information will be sent well in advance, with sufficient buffering at the station to allow a ride-through of several hours without communication (this could be expanded to 24 hours or more if necessary). Monitor information will be similarly buffered.

The strongest efforts will be made to make the user interfaces as uniform as possible, not only for the interfaces of operators, scientists, and engineers but also for all systems of the VLBA that a single person might have to deal with. There is a special concern that the control languages for the real-time array functions and for the correlator control functions be as similar as possible.

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.

It will be possible to divide the array into two or more sub-arrays which may be controlled independently so that, for example, eastern stations may observe a new source while western stations continue to observe a source which is no longer visible to the eastern stations. For pointing checks, and for maintenance and testing, a sub-array may consist of one station only.

The tasks planned for the array control computer are given below.

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.

MONITOR DATABASE FILLER. This program would put monitor data sent from the various stations into a conveniently accessible disk file 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, I would make a very much denser monitor data base for the VLBA, 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. This program is likely to be a bit more complicated than at first appears, since it should be able to cope with any station being out of communication for hours, and still be able to produce a nicely time ordered log file ready for submission to the correlator control computer.

STATION COMPUTER INITIALIZER. Unless the station computer runs from ROM this would include the down-line load. It would also send such stuff as date, time, location, tables of equipment present, etc.

ARRAY CONTROL. This is the program which would be used to assign a station from one subarry to another, and would also have minor functions such as noting equipment out-of-order causing an alternate setup.

MONITOR DATA PLOTTER/LISTER. Equivalent to the VLA programs Monplt and Monlst. Probably should be available over the link to the stations, though in a real pinch, accessability over a dialup might be acceptable. These programs would access either the monitor data base or the array log (the two data sources containing rather different material; the monitor data base will be primarily of interest to the maintenance staff, and the array log to the correlator computer and to the astronomer).

REAL TIME FRINGE CHECK. Receives data from the fringe check buffers from the array and does the correlation. On a VAX 750 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. Incidentally, this program will be providing a delayed input for the log writing program, which will again complicate its life.

OBSERVATION PLANNING AID/OBSERVATION REQUEST GENERATOR. The VLA has been threatening a major revison in OBSERV for a year now. It seems likely that this could serve as a basis for the program for the VLBA scheduling. It is also clear that additional auxiliary functions will be needed, such as display of rise/set times at various stations, (u,v) tracks, etc.

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.

4.2.3 Functions of undecided residence

The following programs might be written to run in the station computer or in the array control computer.

DEVICE CONTROL PROGRAMS. These are the equivalent of the VLA Modcomp DMT overlays. They could run in either the station computer or in the array control computer, so long as a terminal can access them from the other computer using the dedicated computer link. Having the programs run in the array control computer and accessed by a separate, dial up, modem appears unacceptable.

DATA FLAGGER. This would automatically set two flags--antenna off source (including subreflector not set), and LO chain malfunction--based on the monitor data. The latter should be overrideable; the VLA experience is that the monitor equipment is at fault nearly as much as the LO chain itself. A possible implementation is to run this program in the station computer and have it insert these two bits into the Mk III type data header blocks. The correlator could then recognize these bits, and not correlate data when they are set (with the LO chain bit overrideable by input from the correlator control computer). It is a bit of a bother to have the data flagger merely make entries in the array control computer log, which is then sent to the correlator control computer for execution.

MONITOR DATA 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.

4.2.4 Programs for the station computer

The following programs would run in the station control computer.

THE ANTENNA DRIVER. This program might send az-el to the antenna controller at a 20Hz rate, or might send more sophisticated stuff at a slower rate. The VLA uses a linear extrapolation for ten seconds, with the full spherical triangle solved only every 10 seconds. It would seem more likely that the spherical triangle would be solved at the full 20Hz rate for the VLBA antenna. This eliminates one level of tasking and the concomitant handshaking. The price is about ten or fifteen percent of the CPU, either for a CPU with floating point hardware, done in Fortran, or for a CPU without floating hardware, done in assembler scaled binary fixed point.

THE NEW SOURCE EXECUTOR. This program would be responsible for switching between two observation control blocks, mentioned above. The program would primarily make sure that all of the receiver switches are thrown to the correct position.

NEW SOURCE ORGANIZER. In order to permit more observation requests to reside in the in-core buffer of requests received from the array control computer, the latter would be sent in some rather condensed form, and expanded to make an observation control block. There is a lot to be said for sending the observation requests as text, rather than binary. It makes it possible to examine them from anywhere in the system in a rather easy fashion, and, if care is taken, to constructively interfere with them. Even if the control block is sent verbatim, a program to mark it active, and possibly to do some precomputations for next use, is needed.

MONITOR DATA INHALER. This program would maintain the core image of monitor data, as mentioned above.

MONITOR DATA LOGGER. This program would sample the monitor data core image at appropriate intervals and store it into a buffer, with appropriate identifying information, still in the station computer.

TAPE SYSTEM CONTROLLER. This program would 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 include Observation request receiver, monitor log sender, possibly a fast monitor data sender (if the device control programs mentioned above reside in the array control computer), a fringe check data sender, and a real-time remote debugger. It does not appear necessary for the station computer to initiate communications, but to simply respond to the polling of the array control computer.

4.2.5 Hardware

The exact sizing of the hardware of the systems depends on decisions yet to be made about where various programs are to be run. The material below is thus highly preliminary, but should give an idea about the order of size of the systems we are contemplating.

The central control computer might be a machine corresponding to a VAX11/750 with three megabytes of memory. The main peripherals will include two 1600/6250 bpi tape drives, perhaps 512 Mbytes of disk memory, a line printer, and a number of console printers and CRT terminals. A card reader may be necessary but it is hoped other media will serve as the main observing program transport. A multiplexor system will be provided, both to communicate with the array stations and to provide remote user dial in. Hardcopy graphics are needed on this system, either by means of a printer-plotter as the line printer or by a separate 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 as a backup, if the software and communications systems are compatible. If not, it might be necessary to have redundant devices to provide the required backup.

4.2.6 Communication

The achievement of the communications necessary for the VLBA has been carefully considered by A. Shalloway, with a report presented in VLBA memorandum 299. One of the more constrictive requirements derived from this study is given by the fact that it is cost effective (with a payout period of roughly five years) to purchase our own satelite equipment, rather than leasing lines from the telephone company. In order to preserve this option, it is highly desirable that the discipline on the links be a polled multidrop, preferably SLDC/HLDC. It is not yet clear whether this should be implemented in the station computers or in a separate communication processor feeding the station computer.

Because the purchase of satelite equipment is a large capital investment, we wish to preserve this as an option, but not to excercise the option yet. The first stations will be implemented by reserved telephone lines, but with multidrop polling disciplines rather than through the use of statistical multiplexors.

In addition to the reliability of our equipment, the reliability of the telephone links is of great concern. We propose to have a dial-up line available at each station as a backup. It should be noted, however, that most of the stations are at remote sites. Experience at similar locations has shown that a loss of communication often involves all lines to the site. Although existing statistics are controversial, occasional outages are assumed a reality.

4.2.7 Control and Monitoring At Each Station

It is expected that all equipment at each station will be connected to a common digital bus, over which control and monitor signals will be sent in a simple serial format. The system must have sufficient capacity not only to handle normal operation, but also to support remote diagnosis of faults when they occur. Sufficient monitor information must be routinely collected to establish the quality of the astronomical data and to enable timely repairs to be made; but much more detailed information must be available on demand for troubleshooting.

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 VLBA Memorandum 302, which appears as an appendix to this section of the Project Book. The bus protocol specified 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 controller can be a very simple kind of computer. It will not need any peripherals other than the monitor/control bus of the antenna hardware and the modem connecting it to the central computer. In normal operation, it will have only straightforward, repetitive jobs to perform. However, some of these may be of such complexity to perform that we see the necessity of a higher level language than assembly for the programming of this computer. 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 sumbstancially more reliable to have programs in local ROM memory. It may even be profitably to split residence, having a kernal program in ROM, and others, changed more frequently, on disk.

Each antenna station will operate unattended most of the time, and some stations will have no regular personnel. Therefore, extensive support of local work independent of the array control computer is not required. Nevertheless, during installation, checkout, and maintenance work all facilities available at the AOC are likely to be needed sometime. This may be done through the use of terminal access to the central array control computer, by directly using the station control computer, or by the use of a portable microcomputer attached to the station control computer. All of these options will work. The best solution is the subject of current study.

The type of computer that will be used as the station controller is not yet clear. Consideration is being given to each of these options.

(a) a single microcomputer with no peripherals;

(b) a single microcomputer with the addition of a 5 megabyte Winchester disk. In this case, an observing system will be developed in which the disk will not be required for array operation;

(c) two identical microcomputer/disk systems, with provisions for automatic switching to the backup system when necessary. In this case, the disk might be needed for array operation.

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

4.2.8 Manpower

The software development for the control and monitor system is estimated to require 16 man years. Most likely we will be able to purchase commercial software, such as data base systems for some of the utility programs. The costs of such software will be deducted from the cost of 16 man years of programming.

Hardware development, installation, and testing (consisting mainly of interfaces to the station equipment) is expected to require an average of one electronics engineer and two electronics technicians for the duration of the project, or 15 man years total.

APPENDIX A

Monitor and Control Bus at Each VLBA Station
- Specification -
Revised 84/03/05

GENERAL DESCRIPTION

This specification describes the characteristics of a serial digital data bus for controlling and monitoring all equipment at a station in the VLBA. To avoid possible confusion, some terms will be defined here. A CONTROLLER is considered to be the station computer and its interface to the bus. A MONITOR AND CONTROL INTERFACE, or simply INTERFACE, is something that connects a piece of equipment in a station to the bus. A DEVICE is such a piece of equipment; e.g., a front end or a local oscillator module might be a device.

The bus will consist of two logic signals, each on a shielded twisted pair, wired as a multi-drop party line. The signals are called Transmit Data (XMT) and Receive Data (RCV). There will be one Controller and numerous Interfaces connected to the bus. The Controller will be the only source of Transmit Data, and the Interfaces (one at a time) will be the only sources of Receive Data. Data will be bit-serial at a rate of 56 kbaud and the transmissions will be byte asynchronous, each byte consisting of 8 data bits, one parity bit (odd) and start and stop bits.

Detailed specifications of bus line characteristics, levels, timing tolerances, routing and other conventions are stated below. Unless otherwish specified, EIA standard RS-422 and EIA PN 1360 will be followed.

MESSAGE FORMAT AND SEMANTICS

Every message on the XMT line will be exactly five bytes long, with the bytes called SYNC, Address High (ADH), Address Low (ADL), Control Data High (CDH) and Control Data Low (CDL). The SYNC byte is a fixed code to indicate the beginning of a message and shall have even parity to distinguish it from ordinary data. If the most significant bit of ADH is 1, then the message is a control message; otherwise it is a monitor request message. The remaining 15 bits of ADH/ADL form a binary address in the range 0 through 32767.

Messages on the RCV line will be either one byte acknowledgements or three byte monitor data responses, as discussed below.

BUS PROTOCOLS

Each Interface must receive ADH and ADL of every message on the XMT line (that is, there must be no dead time during which an interface is not listening). Each Interface is assigned a block of contiguous addresses to which it alone responds. The block may be of any length, but it must be disjoint with the address blocks of all other Interfaces. The last few addresses of each block are dedicated to functions occuring within the Interface, as specified below.

If the address transmitted was within the assigned block of an Interface, then within 200 microseconds of the end of the last bit of ADL, that Device must begin to transmit a one byte acknowledge code on the RCV line. If the message was a control message, then the Interface must also receive and store CDH and CDL, and within 500 microseconds of the end of CDL it must begin to transmit a second acknowledge byte on RCV. The codes for acknowledge bytes are defined below. If the message was a monitor request, the (single) acknowledge byte must be followed within 300 microseconds by two bytes of monitor data obtained from the address specified by ADH/ADL. (Thus, the time available to acquire the monitor data is 500 microseconds plus the time for transmission of one byte.)

The Interface must check parity on all bytes received. If SYNC, ADH or ADL has a parity error, the Interface shall not respond (just as if the address were outside its block), but shall increment an internal counter and look for the next valid SYNC. If SYNC, ADH and ADL have valid parity and a control message is specified, but CDH or CDL has a parity error, then the second acknowledge byte must be replaced by a negative-acknowledge code (NAK), CDH/CDL must not be passed to other equipment and a second parity error counter shall be incremented. The values of both these counters shall be assigned to monitor addresses.

The Controller may begin transmitting another message as soon as all acknowledge bytes have been received. For control messages, this means the second acknowledge byte. For monitor requests, a new message may be started immediately after the single acknowledge byte, without waiting for the two monitor data bytes. The maximum-speed timing for a sequence of control messages and for a sequence of monitor requests is illustrated in Figure 1.

The Controller must also check parity on all bytes received on the RCV line. If an acknowledge byte has incorrect parity or an incorrect code, the Controller may note that there is a possible problem, and may take remedial action, but no particular action is specified. If no response is received within 200 microseconds, then the Controller may again note a possible problem, and proceed to transmit the next message. If a parity error is detected on a monitor data byte, then both bytes of the monitor word shall be ignored.

BUS SIGNAL CHARACTERISTICS AND CONVENTIONS

It is expected that more than 32 Interfaces will be required at a station. In that case, the bus will be split into several lines with up to 32 drivers and/or receivers per line. Thus a RCV line would have up to 32 drivers and one receiver (the Controller), and a XMT line would have one driver (the Controller) and up to 32 receivers. At the Controller, each line shall have its own transmitter or receiver. Command messages shall be broadcast on all XMT lines; there shall not be any line selection based upon the presence of the addressed Interface on any given line.

These conventions shall be followed:

Transmission rate: 56 kbaud, including all framing and parity bits;

Transmission lines: #24 twisted pair, shielded, (roughly 100 ohms characteristic impedance), max length 500 feet, terminated with a 100 ohm resistor;

Drivers and receivers shall be bridged across lines with stubs less than 20 feet;

RCV drivers shall be tri-state, connected to the bus only when required to respond to a monitor request.

Line HV safety:
Clipping surge arrestors shall be used on the bus lines between the control building and the antenna. The surge arrestors shall be located at each end of the bus run and shall shunt the surge currents to a suitable ground.

Interfaces which service equipment subject to lightning-induced currents shall be protected by high voltage isolators such as optical isolators. The isolators shall be interposed in the lines between the Interface and the Device. Examples of such Devices are the subreflector drive and the weather instruments.

Bus signals shall conform to EIA RS-422 and EIA PN 1360; particular attention is called to the following items:

Mode - Differential transmission and reception, +-2 to +-6 volt signal range.

Drivers and receivers capable of operating in the presence of Common mode voltages over the range of -7 to +12 volts.

No device damage due to line contention of two drivers.

Max driver output current, hi Z state - +- 100 ua.

Max driver output current, power off - +- 100 ua.

Receiver input sensitivity - +- 200 mv, min.*

Receiver input resistance - 12 kohms, min.

Driver output signal - +- 1.5 V min. into a 54 ohm load.

No device damage due to loss of power on one or more drivers or receivers.

*(On the RCV line, which has numerous tri-state drivers, it may be necessary to use a larger receiver threshold to ensure that the receiver can detect the state in which all transmitters are inactive, and do so even in the presence of noise. There are several ways of doing this, including biasing the RCV line and adding an extra line to the bus, and the actual method has not yet been chosen. The final version of this specification will include a description of the chosen method. Device designers should be aware that this might affect the requirements for the Interface transmitters.)

STANDARD CODES

The defined hexadecimal codes for special characters are given below. The SYNC byte will be transmitted in even parity, so that it is a truly unique byte that will never be encountered in data.

SYNC	16
ACK	06
NAK	15

ADDRESS AND DATA CONVENTIONS

The last sixteen monitor addresses of an interface's block are reserved for internal functions of the interface; all interfaces must report the following information when a monitor request with one of these addresses is received:

Address	Value
BE-15 thru BE-10	(reserved for future use)
BE-9	Address of last control message received
BE-8	Control data for last control message received
BE-7	Address parity error counter, all messages
BE-6	Control data parity error counter, all messages
BE-5	Invalid SYNC character counter
BE-4	Control data parity error counter, messages in block

BE-3 (reserved for special use by standard interface)
BE-2 Count of correctly received control messages
BE-1 Count of correctly received monitor data requests
BE-0 Address of beginning of block

where BE is the Block End address. When a control message is received with an address of one of the counters, that counter shall be loaded with the control data (normally zero, to reset the counter).

It is strongly recommended that each device devote at least one monitor address to identification information. This should include information about the revision level of the device, especially if it affects the required control word formats or the meaning of monitor data. The designer must decide at what level of complexity to specify this information (e.g., circuit board, module, subsystem). It is recognized that a subsystem may use more than one interface, and that an interface may service two or more logically separate devices.

It is also strongly recommended that logically distinct functions not be mixed within a single control word, even if this means that only a few bits of each word are used.

When a monitor word is used to convey status information, the syntax for "normal" status should include at least one bit set to logical 1 and at least one bit set to logical 0. This avoids having certain failure states (where all bits appear the same) interpreted as "normal."

It is recommended that each address used by a device for control messages have a corresponding monitor address (preferably the same address) on which the last control data received may be read back. It is also helpful if monitor data which represents the state of a device has a format similar to that of the control data which sets its state (i.e., corresponding bits should have the same meaning). It is strongly suggested that distinct addresses be used for monitor and control functions, except for the read back function mentioned above.

STANDARD INTERFACE TO EQUIPMENT

A standard interface which satisfies the requirements of this specification will be specified in a separate document, and an implementation of the standard interface will be made available to all device designers. It is intended that the standard interface will meet the needs of most devices, and its use wherever possible is encouraged. However, device designers may develop their own interfaces provided that they conform to the present specification.

The following is a summary of the characteristics of a standard interface; please see the separate specification for details. The interface is basically a serial-to-parallel and parallel-to-serial converter, where the serial side is the bus and the parallel side connects to the device. The device connections will consist of: (1) the relative address of messages which fall within the interface's assigned block (difference between the actual address and the beginning of the block); (2) a control data word with the most recently received control message in the block; (3) input for a monitor data word; (4) appropriate handshaking lines; (5) optionally, 8 differential analog inputs for -10 V to +10 V signals. If installed, the analog interface will automatically convert the 8 signals to 12-bit twos-complement representations and assign these numbers to the first 8 addresses in the block; conversion will take place when a monitor data request for the corresponding address is received. (The control data and monitor data words might be multiplexed onto the same lines; see the specification.)

The implementation of the standard interface will include a microcomputer and appropriate firmware in PROM. Detailed documentation on the hardware and firmware will be made available to device designers. It will be possible for designers to use this microcomputer to add small amounts of computing ability to their devices, if they provide their own firmware. The interfacing functions of the standard firmware will be organized into subroutines in such a way that the special firmware need only replace a relatively short main program.

XMT	SYN	ADH	ADL	CDH	CDL		SYN	ADH	ADL	CDH	CDL	
RCV				ACK		ACK				ACK		ACK

Figure 1a. Timing for control messages. Maximum interval, start of CDH to start of first ACK, 200 microseconds. Maximum interval, start of CDL to start of second ACK, 500 microseconds.

XMT	SYN	ADH	ADL	CDH	CDL		SYN	ADH	ADL	CDH	CDL		
RCV				ACK		MOH	MOL			ACK		MOH	MOL

Figure 1b. Timing for monitor messages. Maximum interval, start of CDH to start of ACK, 200 microseconds; maximum interval, end of ACK to start of monitor high (MOH), 300 microseconds.

SECTION 5

FEEDS, SUBREFLECTOR, RELATED OPTICS

P. J. Napier

5.1 Specifications

Items (a) through (c) below are essential requirements.

(a) An optics and feed system is required which 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, 22.2-24.6 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 is required for the 2 GHz and 8 GHz bands so that both bands can be used at the same time with coincident beams in the sky.

Requirements (d) through (g) below are considered to be highly desirable and must be satisfied to the extent possible within the constraints imposed by budget and space limitations.

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

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

(f) Space should be provided so that feeds for 5.90-[illegible] GHz,10.2-11.2 GHz and 86 GHz bands can be installed if funds are available at the end of the construction project or at some other time in the future.

(g) Feeds should be positioned so that dual-band operation (as in (c) above) can be provided for the frequency pairs 5/22 GHz and 10/43 GHz at some time in the future.

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 or beside 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 ten 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. The important dimensions of the Cassegrain geometry are:

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

5.3 Component Design

5.3.1 Main Reflector Profile

The shaped main reflector 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. 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.

5.3.2 Asymmetric Subreflector

The asymmetric subreflector is designed to give uniform phase in the aperture of the main reflector, even though the feed is offset. 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. Requirements for the computer controllable movement of the subreflector are:

Subref rotation about main refl axis = +-180 deg. minimum
Subreflector focus towards main reflector = 4 cm minimum
Subreflector focus away from main reflector = 66 cm minimum

Requirements for the positional stability of the subreflector to provide adequate gain and pointing performance at 85 GHz are:

Lateral offset between subref vertex and main axis = 3 mm max
Angle between subref 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 currently planned and budgeted to be a metal coated fiberglass reflector of the type used at the VLA. Its accuracy will be approximately .015 mm rms which will cause significant gain loss at 86 GHz. 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 .6 GHz feed.

5.3.3 0.31-0.34 GHz Feed

Three options exist for this feed. A simple prime focus feed, such as crossed-dipoles in a cavity, could be placed off-axis at the edge of the subreflector. In this position the beam would be approximately four beamwidths off-axis resulting in significant gain loss. An aperture efficiency of between 30 and 40 percent could be obtained. If this option is chosen, because the antenna has an elevation over azimuth mount, it is important that the off-axis feed be as close as possible to the vertical plane orthogonal to the elevation axis and containing the main reflector axis so as to avoid increasing the cone of avoidance near the zenith. The advantage of the off-axis location is that the feed would have minimal impact on G/T at the secondary focus and could be left permanently in position. A second possibility is to mount a simple wire antenna feed, such as crossed-dipoles or pairs of orthogonal dipoles on the subreflector. Here the problems are interference with the performance of the 0.6 GHz feed and the Cassegrain feeds. Experience at the VLA shows that any significant structure on the subreflector rapidly degrades Cassegrain performance so it may be necessary to manually dismount the feed, contravening requirement 5.1(d) above. The third possibility would be to swing a feed in and out of position beneath the subreflector using a moving mechanism located on a quadrupod leg. Experience at the VLA will help in selecting the best system. Circular polarization will be formed using a quadrature hybrid coupler in front of the low noise amplifiers.

5.3.4 0.58-0.64 GHz Feed

This feed should be small enough so that it can be permanently mounted in the shadow area in the middle of the subreflector. A coaxial cavity feed or crossed-dipole feed are possibilities currently being investigated. A quadrature hybrid in front of the amplifiers will be used to form circular polarization.

5.3.5 1.35-1.75 GHz Feed

This feed will be 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 developed for the major portion of the horn. Fabrication techniques to be investigated include metal coated fiber glass or foam and sheet metal fabrication. Circular polarization over the large bandwidth will be obtained by using a VLA style room temperature dielectric-in-waveguide quarter wave plate in front of the Greenbank style quad-ridged orthomode junction.

5.3.6 2.15-2.35 GHz Feed

This feed will be a compact corrugated horn as described in 5.3.6 above and will use a cryogenically cooled sloping septum polarizer to generate circular polarization. A resonant grid dichroic plate will be placed above the feed to provide a dual band capability with the 8 GHz feed. This plate reflects the 8 GHz signal over to the 8 GHz feed but allows the 2 GHz signal to pass through with low loss.

5.3.7 4.6-5.1 GHz, 5.9-6.4 GHz, 8.0-8.8 GHz, 10.2-11.2, 14.4-15.4 GHz and 22.2-24.6 GHz Feeds

All these feeds will be conventional corrugated horns using cryogenically cooled sloping septum circular polarizers. The 8 GHz feed will have an elliptical reflector above it as part of the 2/8 GHz dual frequency system.

5.3.8 42.3-43.5 GHz Feed

This feed will be a conventional corrugated horn. 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 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		84	36
0.58-0.64		24	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
5.9-6.4	3.578	32	94
8.0-8.9	2.602	24	71
10.2-11.2	2.045	19	56
14.4-15.4	1.487	14	41
22.2-24.6	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. The program to generate the prototype geometry and to perform the analysis was provided by G. James at the CSIRO Division of Radiophysics. The table below gives estimates of aperture efficiency. Esurf is the reflector surface efficiency assuming that the main reflector surface rms is 0.45 mm and the subreflector rms is 0.15 mm. 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; the low phase efficiency for the 0.32 GHz feed results from its off-axis location. 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
0.32	.99	.83	.83	.86	.63	.95	.35
0.61	.95	.83	.83	.86	.95	.95	.51
1.5	1.00	.96	.90	.86	.98	.95	.69
2.3	1.00	.96	.92	.86	.98	.95	.71
4.9	1.00	.97	.93	.86	.98	.95	.72
6.1	.99	.97	.93	.86	.98	.95	.72
8.4	.98	.97	.93	.86	.98	.95	.71
10.7	.97	.97	.93	.86	.98	.95	.70
14.9	.92	.98	.93	.86	.98	.95	.67
22	.83	.98	.93	.86	.98	.95	.61
43	.48	.98	.93	.86	.98	.95	.35
86	.05	.98	.93	.86	.98	.95	.04

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. Ttotal 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. All contributions are in degrees kelvin.

Freq (GHz)	Tloss	Tspill	Tscatter	Tsky	Ttotal
.32	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
6.1	2	1	5	6	14
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 approximately 0.05 beamwidths.

SECTION 6

RECEIVERS

M. Balister and A. R. Thompson

6.1 Specifications

6.2 Description

This section deals with the front-ends at each of the VLBA antennas. Also discussed here are the possible radio link to the New Mexico antennas and the water vapor radiometers that will be mounted on the antennas. The block diagram (Figure 6.1) covers the antenna electronics, the recorder acquisition equipment (described in Section 9) and the monitor and control electronics (described in Section 4).

6.2.1 Front Ends

The current frequency range, noise performance, and construction plan for front-ends are summarized in Table 6.1. A block diagram of the 8.4 GHz front-end is shown in Figure 6.2; a similar block diagram will apply to 1.5 through 15 GHz front-ends.

TABLE 6.1 VLBA FRONT-END SUMMARY - MARCH 1984

Frequency Range	Type	Receiver Noise	System Noise	Start Date	Where Constr	Delivery Date	Comments
.312-.342	360K FET	65K	139K	8/83	VLA	Per Ant	
.580-.640	360K FET	75K	109K	6/85	CVL	Per Ant	
1.35-1.75	15K FET	12K	30K	1/84	GB	Per Ant	
2.15-2.35	15K FET	16K	36K	10/85	GB	1/87	
4.60-5.10	15K FET	20K	35K	10/84	GB	Per Ant	
5.90-6.40	15K FET	22K	36K	1/88	CVL	1/89	Optional Until 6/87
8.0-8.8	15K FET	25K	46K	8/83	VLA	1/87	HEMT?
10.2-11.2	15K FET	29K	45K	1/87	CVL	1/88	Optional Until 6/86
14.4-15.4	15K FET	45K	63K	6/84	CVL	Per Ant	HEMT Retrofit?
22.2-24.6	HEMT or MASER	40K 10K	67K 37K	6/86	GB	1/89	
42.3-43.5	HEMT or MASER	80K 20K	115K 55K	1/86	CVL	1/89	

FIGURE 6.1

STATION BLOCK DIAGRAM

See attached Drawing Number D58000K001

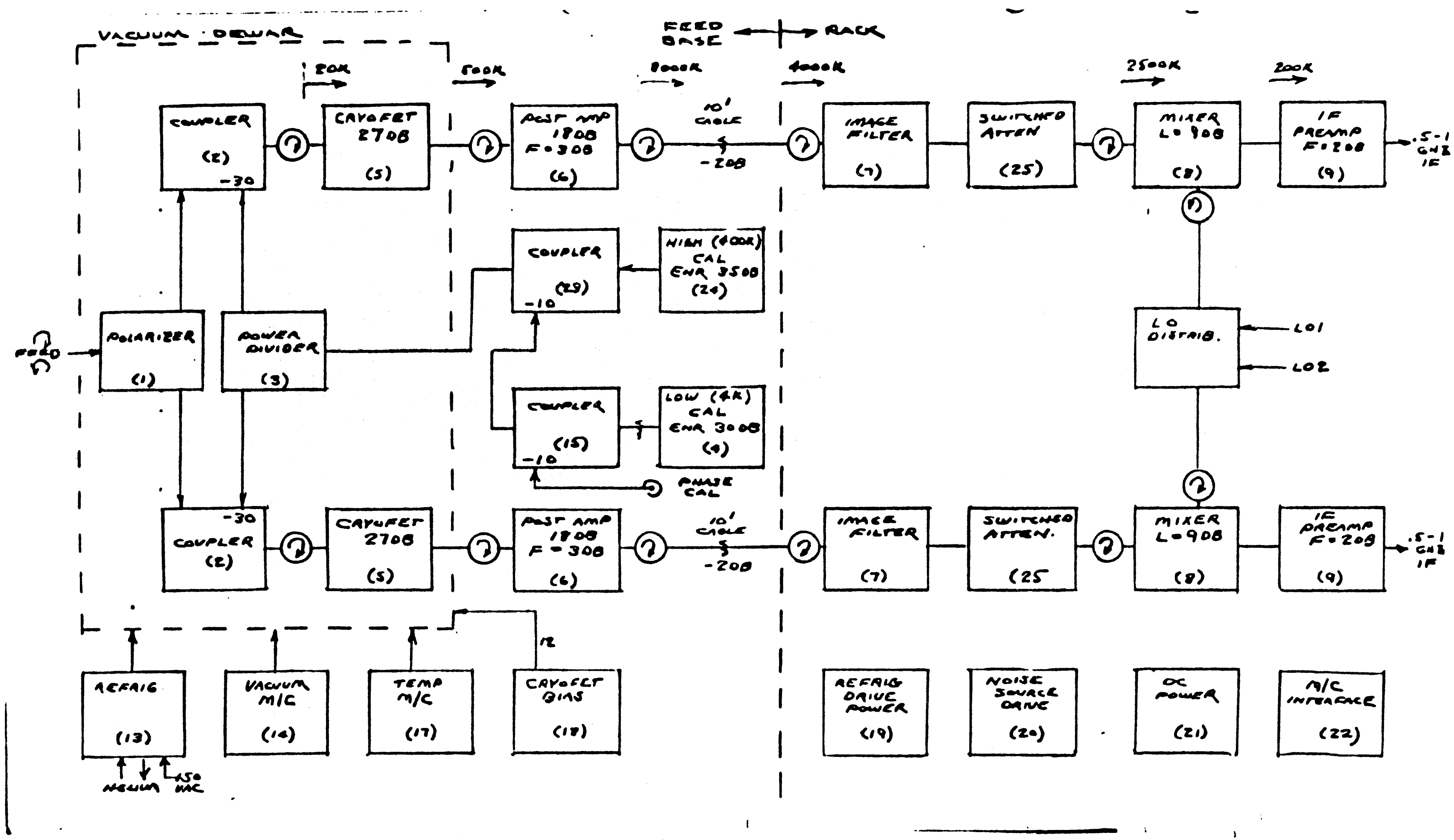


Figure 6.2 - Typical front-end block diagram. Sheet 1 of 1. 1-30-84

Originally, reflected wave masers were proposed for use at 22 and 43 GHz, the higher frequency maser being single channel. Since May 1982, NRAO has completed its prototype design work on the 43 GHz maser and it has been decided that it would be feasible to make this maser dual channel as proposed at 22 GHz. Cooled mixers would follow the amplifiers to minimize the second stage contributions.

However, there are now other alternatives to the use of masers which are being seriously considered. Superconductor-insulator-superconductor (SIS) mixers are now operational on radio telescopes at 115 GHz. The performance of these devices may be competitive with masers at 43 GHz. One problem is the requirement for the closed cycle, 2K refrigerator system. NRAO has a current program to develop such a system for future millimeter wave receivers. Another alternative is a cooled 22 GHz parametric amplifier. A 22-24 GHz unit with < 20K noise temperature has recently been reported and is being investigated.

A further new development during this period has been the appearance of high-electron-mobility-transistor (HEMT) low-noise devices. The noise performance of these devices cooled to 77K exceeds that of the best conventional GASFET's cooled to 20K when measured at a frequency of 10 GHz. They are well suited for higher frequencies and NRAO is currently negotiating for the development and supply of suitable devices for the VLA/-VLBA projects. One of the design goals is to build devices with < 30K noise temperature at 23 GHz. Use of HEMT devices would simplify the construction, lower the cost and make for more reliable operation at 20K instead of at 2 or 4.5K necessary for SIS or maser receivers at the two highest frequencies. As yet, we have no hard data to evaluate the performance penalty compared with masers; however, it is felt that the loss will be outweighed by the advantages that will go with their use.

The situation regarding the lower frequencies is generally unchanged; however, an initial study indicates that coverage of 4.6 to 6.3 GHz by a single front end would cause a 20% degradation in 5 GHz sensitivity and 40% greater cost compared with a 4.6 to 5.1 GHz front-end. Varactor-tuned amplifiers and a cooled frequency diplexer have been investigated but the present plan is a separate 5.9 to 6.4 GHz front-end.

Sixty 15 GHz GASFET amplifiers have been built for the VLA. The first twenty have an average midband noise temperature of 35K; the next ten with a later batch of transistors average 45K. About 10K must be added for transition and window losses, but the VLBA specification of 45K appears to be possible with careful selection of transistors.

6.2.2 Radio Link for VLA Area Antennas

It has been proposed that the two antennas within New Mexico should be linked by microwave systems to the VLA site to allow real time correlation with the VLA and tape recording at the VLA site. This is certainly feasible for the antenna at Pie Town which is nearest to 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 Memo No. 213.

In a more recent study in VLBA Memo No. 240, the effects of rain attenuation, multipath fading and variation in the angle of arrival of the signal have been considered in some detail. These studies have indicated that a link from the northern New Mexico antenna at Los Alamos would probably not be feasible within the cost and manpower currently planned. It has been proposed that this antenna be put into operation using the hydrogen maser and tape system. The possibility of a radio link may be reexamined later in the light of experience with the shorter link from the antenna.

6.2.3 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 will be reduced by measuring the amount of water vapor above each antenna using water vapor radiometers (WVR) and applying a phase correction based on this measurement. A WVR 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 proposed to leave the construction of the WVRs until late in the program so that the project can benefit from the development efforts that are currently underway at the VLA, JPL and other laboratories.

6.3 Cost Estimates

6.3.1 Front Ends

A detailed labor and materials cost estimate has been made assuming that masers will be selected for the two highest frequencies. We feel that this approach will be the most costly in manpower and materials. This seems fair, since although the other approaches will probably be less costly for the production receivers, there will be a significant requirement for development money for SIS or HEMT devices.

A summary of results and some explanatory notes are given in Table 6.2. The total front-end cost of 462.9 k$ (1983 $) is close to the estimate of 456 k$ (1982 $) per antenna given in the VLBA proposal.

TABLE 6.2. VLBA Receiver Front-End Cost Estimate, 1983 k$

Frequency	Amplifier Design				Subsystem Design				Fabrication Installation				Total Labor			
	E	T	S	D	E	T	S	D	E	T	S	D	E	T	S	D
.312-.342	0	0	0	1	4	3	2	2	6	10	5	0	10	13	7	3
.580-.640	3	4	1	1	4	3	2	2	6	10	5	0	13	17	8	3
1.35-1.75	0	0	0	1	6	4	3	3	6	10	6	0	12	16	9	4
2.15-2.35	6	4	2	1	6	4	2	2	6	12	5	0	18	20	9	3
4.6-5.1	3	2	1	1	6	4	2	2	6	12	5	0	15	16	8	3
8.0-8.8	6	3	1	1	6	4	2	1	6	10	5	0	18	17	8	2
10.2-11.2	3	3	1	1	6	4	2	1	6	10	5	0	15	17	8	2
14.4-15.4	0	0	0	1	6	4	2	1	4	10	5	0	10	14	7	2
23/43	18	16	5	6	8	7	3	3	67	97	7	3	93	120	15	12
System					12	12	0	3	6	6	6	2	18	6	6	5
Total	39	32	11	14	64	37	20	20	119	187	54	5	222	256	89	39

Frequency	Labor Cost	Total Materials	Total Cost
.312-.342	87	67 (13)	154
.580-.640	110	67 (13)	177
1.35-1.75	108	191 (15)	299
2.15-2.35	137	182 (25)	319
4.6-5.1	115	182 (25)	297
8.0-8.8	126	182 (25)	308
10.2-11.2	115	182 (25)	297
14.4-15.4	87	182 (25)	269
23/43	667	1133 (228)	1800
System	104	605	709
Total	1656	2973	4629

Notes: E, T, S, and D are engineering, technician, shop and drafting man-months. Engineering labor is costed at a 1983 labor rate of $45k/man-year; other labor is costed at a labor rate of $26k/man-year. Both rates include benefits.

"Total Materials" - column includes development materials but does not include spares, i.e., 10 final systems are priced. Figure in parentheses is development cost.

"System" includes overall front-end system design, cryogenics compressors and lines, and phase calibration.

Cost of the optional 5.9-6.4 GHz front end is not included in estimates.

Design labor has been separated into amplifier (GASFET or maser) design, and subsystem which includes dewar, transition, final L.O., mixer, calibration, and monitor circuits. A total 96 k$ per antenna of cryogenics costs has been split into refrigerator costs included in the cost for each frequency and a common system cost for compressors and helium lines. All cryogenic costs have been listed as materials but may be exchanged for labor costs if a decision is made in favor of internal fabrication of compressors and 4K modification of cooling heads.

6.3.2 Radio Link for VLA Area Antennas

This area is still being actively looked into. In the current cost estimates, we have budgeted for ten hydrogen masers. We are assuming that for the Pie Town antenna, the radio link will include provision of standard frequencies from the VLA maser, and that the link costs will be equal to or less than that of the maser that we will not need to purchase.

6.3.3 Water Vapor Radiometers

A provisional cost estimate has been made at 50k$ per unit when building 10 units.

6.4 Construction Plan

Building all front-ends by mid-1988 would result in a large peak requirement in engineers at the beginning of the project, especially in 1984. Given the difficulty in hiring suitable engineers, plus the low level of funding in 1984, we propose postponing the design, fabrication and installation of the 22 and 43 GHz front-ends. The installation of these frequencies will not be completed until the end of 1989. This also allows economies of purchasing and fabricating all front-ends at one frequency in a single batch. The installation of front-ends would be performed in groups as follows:

Group A: 1.5, 5 and 15 GHz receivers will be installed as antennas are completed between mid-1986 and mid-1988.

Group B: 0.327 and 0.615 GHz will be installed with Group A as the antennas are completed.

Group C: 2.3 and 8.3 GHz receivers would be installed by a second crew alternating with Group A/B installers.

Group D: 23/43 GHz receiver will be installed in 1988-9.

Group E: 6.0 and 10.7 GHz receivers are considered to be the lowest priority, current funding only covers cost of one of these receivers.

A construction schedule is shown in Figure 6.3. In the manpower plan, two engineers and two technicians should transfer to the operations staff in mid-1988 for maintenance and future improvements to front-ends. The construction plan for the rest of the electronics would be arranged to match the antenna construction plan such that the necessary electronics would be available for antenna and array testing at frequencies available at the time of the tests.

It is likely that some testing at 22/43 GHz would be desirable before the availability of front-ends for these frequencies. In this case, it is proposed that a few receivers be constructed for these frequencies, probably using prototype amplifiers. These would enable the antenna performance to be measured before acceptance from the manufacturer.

VLBA FRONT-END CONSTRUCTION SCHEDULE

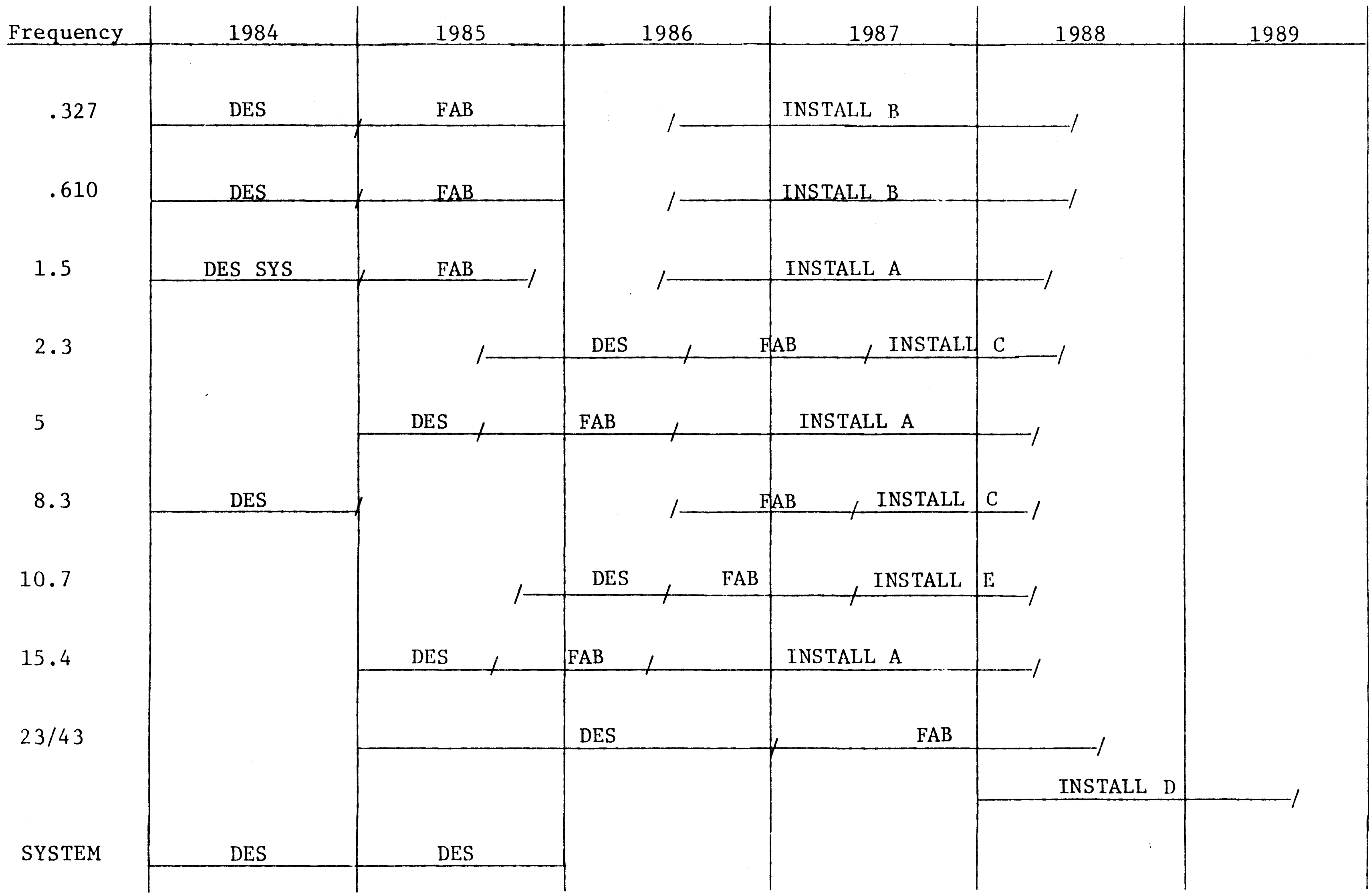


FIGURE 6.3

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Sheet 1 of 1

SECTION 7

LOCAL OSCILLATORS

L. R. D'Addario

7.1 Specifications

For the exact tuning range on each band, see VLBA Memo No. 295.

Detailed specifications for each component of the LO system have not yet been determined. Power levels, phase stability, interfaces, monitoring, and other details need to be specified.

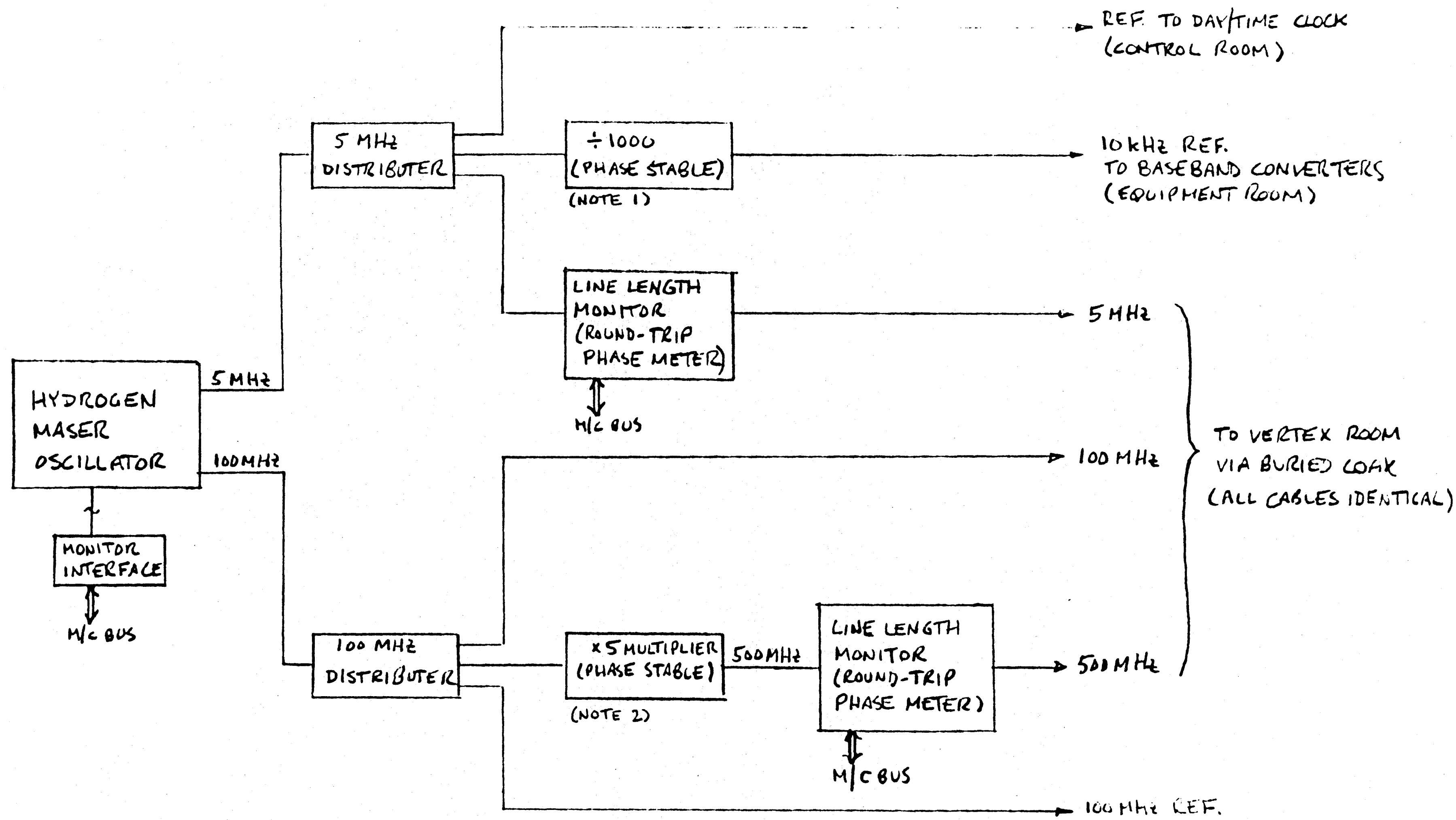
7.2 Description

The frequency conversion scheme has been considerably revised from that described in Volume I of the VLBA proposal. Here we describe the present plan, which is depicted in Figures 7.2.1 and 7.2.2.

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 1.3 cm and 0.7 cm bands, this is done in a single mixing. For those bands where the input bandwidth exceeds 500 MHz (namely 3.6 cm, 3 cm, and 2 cm), the band is covered by two L.O. tuning frequencies, one above and one below the signal band; this allows good image rejection provided that the bandwidth does not much exceed 1000 MHz. To cover the bandwidth of the 3.6 cm front end (8.0 to 8.8 GHz) requires two L.O. frequencies on each side of the band.

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 L.O. signals for all bands through 2 cm. To accommodate dual-band operation, two such synthesizers are needed. A switching arrangement which allows each synthesizer to connect to any receiver is considered unnecessarily complicated and expensive, but the arrangement shown in Figure 7.2.2 allows most of the interesting dual-band setups to be implemented. A transfer switch is provided to swap the roles of the synthesizers, allowing single-band operation to continue on any band even if one synthesizer fails.

At 3.6 cm, it is considered necessary to be able to observe both ends of the band simultaneously. To accomplish this, we provide two mixers for each polarization, with one driven by a fixed-frequency oscillator at 9.4 GHz (so that it converts the upper portion of the band), while the other mixer remains driven by the synthesizer



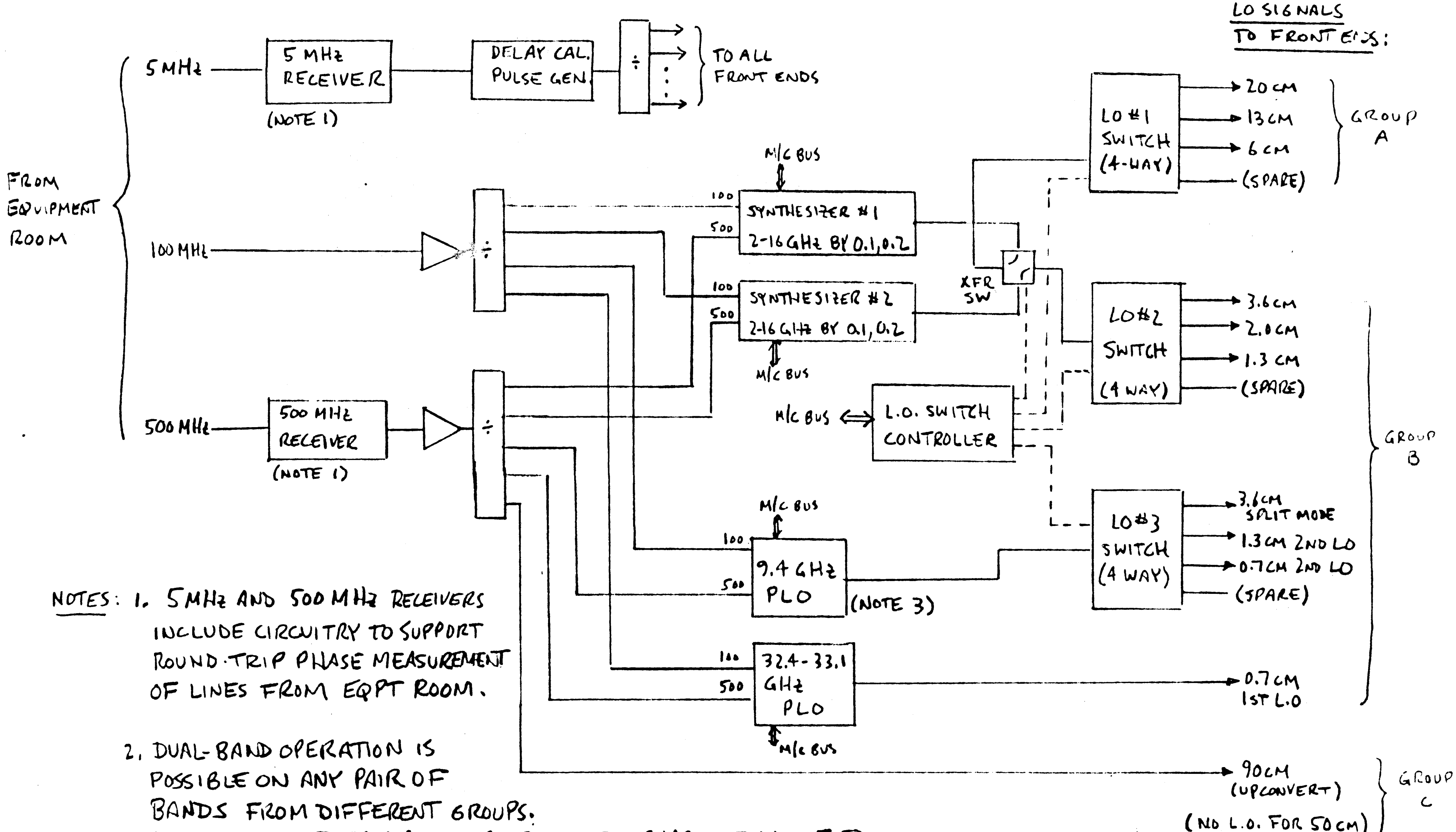
NOTES: 1. AN ADDITIONAL MASER OUTPUT AT 10 kHz MIGHT BE AVAILABLE, IN WHICH CASE THE FREQUENCY DIVIDER COULD BE ELIMINATED.

2. AN ADDITIONAL MASER OUTPUT CONTAINING A 100 MHz COMB MIGHT BE AVAILABLE, IN WHICH CASE THE x5 MULTIPLIER COULD BE REPLACED BY A 500 MHz FILTER.

FIGURE 7.2.1, sheet 1 of 1.

VLBA LOCAL OSCILLATOR SYSTEM:
EQUIPMENT ROOM PORTION,
BLOCK DIAGRAM

831216 LRD



NOTES: 1. 5 MHz AND 500 MHz RECEIVERS INCLUDE CIRCUITRY TO SUPPORT ROUND-TRIP PHASE MEASUREMENT OF LINES FROM EQPT ROOM.

2. DUAL-BAND OPERATION IS POSSIBLE ON ANY PAIR OF BANDS FROM DIFFERENT GROUPS. ASSIGNMENT OF BANDS TO GROUPS CAN BE SOMEWHAT MODIFIED IF NECESSARY.

3. IN CASE ADDITIONAL FLEXIBILITY IS NEEDED IN THE FUTURE, THE 9.4 GHz PLO CAN BE REPLACED BY A THIRD SYNTHESIZER.

FIGURE 7.2.2, sheet 1 of 1

VLBA LOCAL OSCILLATOR SYSTEM:
VERTEX ROOM PORTION
BLOCK DIAGRAM

831216 LRD

(which can be set to convert the lower portion of the band). We also provide switching so that any two mixer outputs may be connected to the two I.F. channels. The 9.4 GHz oscillator is also needed for the 1.3 and 0.7 cm bands (see below); its use here leaves the second synthesizer available for dual-band operation.

The two highest frequency bands require an additional frequency conversion in order to maintain image rejection. A single 9.4 GHz fixed, phase-locked oscillator provides the second L.O. for both receivers. The 0.7 cm receiver uses an additional synthesizer for its first L.O.

Four 500 MHz bandwidth IF signals are selected by switches from the 26 possible outputs of the front-ends, and these four signals are transmitted by cable to an equipment room in the station control building. To avoid excessive complexity in the switches, a full 26-by-4 matrix is not implemented; nevertheless, every front-end output can be connected to either of two IF channels, so no band is lost in the event of a single-channel failure.

At the equipment room, the IF signals are converted to baseband in image-rejecting mixers, with the L.O. tunable over the 500 to 100 MHz range in .01 MHz steps. A distribution and switching arrangement allows an IF to be connected to any baseband converter. The baseband signals are quantized and sampled in the digitizing process. The sampling clock generator is thus the final L.O. (These operations are part of the Digitization System, covered in Section 8 of the Project Book.)

All L.O. signals are ultimately derived from the hydrogen maser frequency standard. Most of them must be tunable, with coarse tuning (about 100 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 (see Figure 7.2.1). 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 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 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.

SECTION 8

DIGITIZER

A. E. E. Rogers

8.1 Specifications

8.1.1 General

Number of I.F. inputs:	4
I.F. frequency range :	500 - 1000 MHz
Number of baseband channels:	32 (16 upper and lower sideband pairs)
Baseband L.O. coverage:	500-1000 MHz in 10 KHz steps
Baseband bandwidths:	8,4,2,1,0.5,0.25,0.125,0.0625 ext MHz
Sample clock rates:	16,8,4,2,1,0.5,0.25,0.125 MHz
Sample Quantization:	4-level coded in 2 bits or 2-level coded in 1 bit
Data format:	modified MK III
Flexibility:	1) Each baseband converter can connect to any of the 4 I.F.s 2) Baseband converters are independent and can have different L.O. frequencies and bandwidths 3) Any formatted output can be assigned to any baseband signal (within the restrictions given below)
Restrictions:	1) All channels must be sampled at the same rate 2) All channels are sampled in either a 2 bit or 1 bit/sample mode 3) Maximum digitization throuhput(might be in 2 units - see sect 8.1.5) 32x16=512 Mbits/s

8.1.2 Interfaces

8.1.2.1 I.F. Input from Receivers

Signals:	4 I.F.s in the range 500 - 1000 MHz
Levels:	I.F. distributor can accept -42 to +22 dBm
Cables:	RG-9 or equivalent
Connectors:	Type N (male on cable ends from receivers)

8.1.2.2 Frequency and Time

FREQ:	
Signals:	5 MHz at +13 dBm (nominal)
Cable:	RG-9 or RG-142 or equiv
Connector:	Type N or SMA
TIME:	
Signal:	20 Hz square wave -0.5 to +0.5 volt plus 1 pps? to allow for the possibility of manually synchronizing the formatter
Cable:	RG-142 or equiv
Connector:	SMA or BNC

8.1.2.3 Communications

via MONITOR/CONTROL bus see sect 4

8.1.2.4 Output to Recorder

Signals: 32 balanced ECL (16 balanced ECL to each recorder)

8.1.3 I. F. Distributors

Input frequency range:	500-1000 MHz
Input level:	-42 to +22 dBm
Square law linearity:	< 1% from 5% to full scale
Input atten range:	0 to 63 dB in 1 dB steps
Isolation between outputs:	> 20 dB

8.1.4 Baseband Converters

Input range:	492-1008 MHz
Gain through conv(2 MHz BW):	46 +- 1 dB (Auto-level off)
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 for input > -14 dBm:	> 25 dB
Temperature coeff of phase:	< 10 deg/ deg C/ GHz
L.O. settling time:	< 1 sec
L.O. leakage into input:	< -60 dBm
Temperature coeff. of gain:	< 0.1 dB/ deg C
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) <20 deg betwwen units across upper 20%
6) <0.2 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

Bandwidths: 8,4,2,1,0.5,0.25,0.125,0.0625 MHz and external filter

Data processing:

1) Total power integration and synchronous detection with periods of an integral number of 20 Hz half-cycles or 25 msec
2) Auto-leveling of output power

Monitor and control:

FUNCTION	#bits	control	monitor
IF input select	2	Y	Y
L.O. frequency	16	Y	Y
L.O. unlock	1	N	Y
USB bandwidth	4	Y	Y
LSB bandwidth	4	Y	Y
USB gain	8	Y	Y
LSB gain	8	Y	Y
USB TPI input select	3	Y	Y
LSB TPI input select	3	Y	Y
USB TPI for last ref period	16	N	Y
LSB TPI for last ref period	16	N	Y
USB TPI(sig-ref)	16	N	Y
LSB TPI(sig-ref)	16	N	Y
#cycles to be averaged	16	Y	Y
USB auto-level on/off	1	Y	Y
LSB auto-level on/off	1	Y	Y
serial number	16	N	Y

8.1.5 Formatter

Video input level:	0+-0.5 dBm
Input impedance:	50 ohms unbalanced
Threshold equivalent DC offset and hysteresis:	< 5 mv
Sampling epoch precision and jitter	< 2 nsec
Sampling modes:	2-level (1 bit) and 4-level (2 bits)
Number of video inputs:	32 (16 USB plus 16 LSB)or 16 (8 USB plus 8 LSB) in each of 2 identical formatters
Sample rates:	16,8,4,2,1,0.5,0.25,0.0625 MHz

Output format:	1) Similar to MK III but without data replacement 2) Sign and magnitude bits always assigned to separate formatter outputs 3) Output clock rate is either slightly higher than the sample clock rate (to account for sync block and parity) or slightly higher than half the sample clock rate. When in the "half-rate" mode odd and even samples will be on separate formatter outputs.
Output format modes:	Continuous,blocked;normal rate,half-rate
Added note:	For reasons of reliability and ease of maintenance the I.F. processing and digitization electronics might divided into 2 separate racks. In this case each rack would contain I.F. distribution for 4 I.F. inputs, 8 baseband converters, a formatter, decoder and data buffer. Normal astronomy observing would only require one rack and so observations could continue even if one rack fails. Only certain observing modes like one compatible with the present POLARIS program (which uses 8 X-band frequencies and 6 S-band frequencies) would require both racks. Each of the 2 recorder racks could be interfaced to both acquisition racks to allow one recorder to access all 16 baseband converters.

8.2 Description

(In preparation)

SECTION 9

RECORDERS AND PLAYBACK

A. E. E. Rogers

9.1 Specifications

9.1.1 General

Average recording rate:	100 Mb/s for 24 hours unattended
High data rate (HDR):	200 Mb/s or greater
Parity error rate:	< 10**-4 worst case
Sync error rate:	< 2 per min.
Loss of data due to errors	< 1%
Weight of tape/day/station	< 50 lbs at average rate

Added note:
If the recording medium is 1 inch wide by 1 mil thick a packing density of 16 Mbits/square inch has to be achieved to generate less than 50 lbs per station per day. If VHS cassettes are used the packing density has to be about twice as high since 50% of the weight of the VHS cassettes is in the package.

9.1.2 Interfaces

9.1.2.1 Formatters to Recorders see sect. 8.1.2.4

9.1.2.2 Recorders to Processor see sect. 10.1.2.1

9.1.3 Recorders

In addition to general specifications in sect. 9.1.1 the following "characteristics" are generally accepted:

Backup capability:	1 recorder "rack" is considered a spare and system should meet general requirements with one rack down

IF LONGITUDINAL:

Number of Model 96 recorders:<4 per site for economic reasons

IF VCR: An automatic cassette changer which moves tapes in and out of bins is required to be able to reduce the number of machines and to provide a reliable way of keeping track of cassettes.

IF Professional TV recorder: Recently high density digital storage systems have been developed using studio TV recorders. The most promising of these systems(developed by KODAK) records at 100 Mbits/sec with a recording density of 34 Mbits/square inch on 1 inch wide tape. This system is also able to handle very large reels so that it may be possible to record one day's data on one or two large reels. At this time the cost of these systems is expected to exceed budget allocations especially if an extra transport is required at each site to act as a spare.

9.2 Description

(In preparation)

SECTION 10

CORRELATOR

M. S. Ewing

10.1 Specifications

10.1.1 General

Number of Antennas:

Full Mode:	2 - 10	
Half Mode:	11 - 14	
Quarter Mode:	15 - 19	

Maximum Data Rate per antenna:

Full Mode:	256 Ms/s (megasamples/sec)
Half Mode:	128 Ms/s
Quarter Mode:	64 Ms/s

Sample Rates: 16, 8, 4, 2, 1, 0.5, 0.25 Ms/s

Number of Channels: 1 - 16
(There are no longer any "subchannels".)

Bits per sample: 1 or 2 (Channels carry 2 bits at all times, but low-order bit is ignored in 1-bit sampling.)

Sample Quantization:
3- or 4-level sampling coded in 2 bits
2-level sampling coded in 1 bit

Sample rates (oversampling): 2, 4, 8 x channel bandwidth

Polarization Modes:
NP: non-polarized, full frequency resolution
P: full-polarization processing,
1/4 resolution (constant obs. bandwidth)
1/2 resolution (constant recording rate)
(see discussion below)

Delay coverage in single processing pass:

NP Full Mode:	1024 sample clocks ("lags")
NP Half Mode:	512
NP Quarter Mode:	128

(P modes: divide by 2 or 4)

Frequency Resolution in spectral line mode:

NP Full Mode: 512 "independent" channels
NP Half Mode: 256
NP Quarter Mode: 128

(P modes: divide by 4)

Autocorrelation available for each antenna:

1024 lag range
512 frequency channels
16 Ms/s, maximum clock rate
1- or 2-bits/sample

Divisible into two 512-lag correlators for polarization? **
Maximum dump rate: once per minute? **
Input multiplexor: select (any?) 1 or 2 channels of 16 **
Local accumulation and Fourier transform

(Is the autocorrelator useful at all for phase cal?) **

Phase Calibration for each antenna:

Number of simultaneously detected tones per channel: 1?**
(Can we timeshare a single detector among several channels?) **
Programmability: Select tone anywhere in passband with ?? Hz resolution. **
Frequency tracking capability: ?? **
L.O. quantization: 128 levels ? **
Maximum output dump rate: ?? **
(System: required tone SNR and phase cal. detector sensitivity?) **

Delay Corrections:

Geometric Delay - provided by Data Playback System under control of Correlator control computer.
Deskewing - provided by Data Playback System.
"Vernier" delay - +/- 1 bit in each correlator baseline

Fringe Rotation:

SSB lobe rotation via quadrature correlation, 2 multipliers/accumulators/lag. ("Conventional VLBI" approach)
Maximum required fringe tracking rate: 250 kHz (extreme terrestrial, 86 GHz)
(System: will LO offsetting be available to reduce this high rate - 1/32 of bandpass?) **
Max. instantaneous phase error: 10**-4 cycle (?) **
Effective LO waveform: 3 level
Required simultaneous phase centers: 2 (?) **
(implemented in fringe processor)

Fractional Bit-Shift Correction:

Phase slope applied in frequency domain every 12.5 ms (optional?) **
Or, post-accumulation correction applied.
Or, variable-phase sampling used at antenna.

```
+----------------------+
|   VLBA CORRELATOR    |
|  MAJOR MODE SUMMARY  |
+----------------------+
```

1 - 45 BASELINES (2 - 10 ANTENNAS)

- NON-POLARIZED -			-- POLARIZED -- CONST RCRD RATE			-- POLARIZED -- -CONST OBSV BW-		
LAGS /BSL	CHAN-NELS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT
1024	1	16	512	1	32	256	1	32
512	2	32	256	2	64	128	2	64
256	4	64	128	4	128	64	4	128
128	8	128	64	8	256			
64	16	256						

46 - 91 BASELINES (11 - 14 ANTENNAS)

- NON-POLARIZED -			-- POLARIZED -- CONST RCRD RATE			-- POLARIZED -- -CONST OBSV BW-		
LAGS /BSL	CHAN-NELS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT
512	1	16	256	1	32	128	1	32
256	2	32	128	2	64	64	2	64
128	4	64	64	4	128			
64	8	128						

92 - 171 BASELINES (15 - 19 ANTENNAS)

- NON-POLARIZED -			-- POLARIZED -- CONST RCRD RATE			-- POLARIZED -- -CONST OBSV BW-		
LAGS /BSL	CHAN-NELS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT	LAGS /BSL	CH. PAIRS	MSR /ANT
256	1	16	128	1	32	64	1	32
128	2	32	64	2	64			
64	4	64						

MSR = Maximum Sample Rate, Ms/s.

10.1.2 Interfaces

10.1.2.1 Data Playback System

(Further negotiation required with Data Acquisition group)

This specification could equally well be part of Data Acquisition/ Recorder Section (9).

DATA INTERFACE

16 channels, clock rate up to 16 Mb/s

Channel data:		
All channel data samples contain two bits.		
2-level sampling:	High order bit = sign Low order bit ignored. (?)	**
3-level sampling:	High order bit = sign Low order bit = magnitude (1's complement arithmetic)	
4-level sampling:	High order bit = sign Low order bit = magnitude (2's complement arithmetic)	
Polarization:	Channels are organized into R-L pairs. (fixed assignments)	
Data stream interruptions:	none (full transparency)	
Data framing:	"similar" to Mark III (?)	**
Data Validity Flag:	independent, channel-by-channel (?)	**
	Or, not required due to EDAC algorithm. (Software validity info.)	**
Data Validity Resolution:	16 bits (?)	**
Data Timing:	Fully synchronous with correlator clock. Correlator provides 16 Mb/s clock and frame sync	
Frame Sync Period:	5 ms (80 K bits) (?)	**

ELECTRICAL SPECIFICATION

???

CHANNEL ALLOCATIONS/MODES (samples)

(Remember that both bits of 3- or 4-level samples are carried on each channel.)

Mode A: Full polarization, 16 Mb/s/channel, 128 Mb/s/antenna, 2-level sampling

Mode B: No polarization, 16 Mb/s/channel, 128 Mb/s/antenna, 2-level sampling

Mode C: Full polarization, 16 Mb/s/channel, 128 Mb/s/antenna, 3- or 4-level sampling

Mode D: No polarization, 8 Mb/s/channel, 128 Mb/s/antenna, 2-level sampling, 16 channels (geodetic bandwidth synthesis)

Mode E: No polarization, 16 Mb/s/channel, 128 Mb/s/antenna, 4-level sampling, 4X oversampling, 2 MHz IF channel width (wideband spectral line mode)

	signals				
CH #	Mode A	Mode B	Mode C	Mode D	Mode E
01	F01 R	F01	F01 R	F01	F01
02	F01 L	F02	F01 L	F02	F02
03	F02 R	F03	F02 R	F03	F03
04	F02 L	F04	F02 L	F04	F04
05	F03 R	F05	x	F05	x
06	F03 L	F06	x	F06	x
07	F04 R	F07	x	F07	x
08	F04 L	F08	x	F08	x
09	x	x	x	F09	x
10	x	x	x	F10	x
11	x	x	x	F11	x
12	x	x	x	F12	x
13	x	x	x	F13	x
14	x	x	x	F14	x
15	x	x	x	F15	x
16	x	x	x	F16	x

Mode F: Full polarization, 16 Mb/s/channel, 256 Mb/s/antenna, 2-level sampling, 32 channels (peak sensitivity, continuum)

Mode G: No polarization, 16 Mb/s/channel, 32 Mb/s/antenna, 4-level sampling, 2 channels 4X oversampling, 2 MHz IF bandwidth (maximum resolution spectral line)

SUB	---------------- signals ----------------	
CH #	Mode F	Mode G
01	F01 R	F01
02	F02 R	x
03	F01 L	x
04	F02 L	x
05	F03 R	x
06	F04 R	x
07	F03 L	x
08	F04 L	x
09	F05 R	x
10	F06 R	x
11	F05 L	x
12	F06 L	x
13	F07 R	x
14	F08 R	x
15	F07 L	x
16	F07 L	x

CONTROL INTERFACE

Low-speed interface is via 9,600 b/s asynchronous RS-232 connection. MAT, natural language format, or antenna control bus format (?) **

Commands to DPS controller(s):

<VERB> [<PARAMETER> [, <PARAMETER> [, ...]]]

<VERB> := { RESET, STATUS, DISPLAY, LOAD, UNLOAD, START, STOP, REWIND, DELAY? } **

RESET <RACK> <TRANSPORT>
Resets a given transport, rack, or changing robot to initial conditions

STATUS <RACK>
Returns a standard status message for a rack. (Up to about 200 bytes in length?) **

DISPLAY <RACK> <TRANSPORT> <MESSAGE>
Display a message on a device associated with a given rack or transport. Useful for operator instructions.

{ LOAD | UNLOAD } <RACK> <TRANSPORT> <TAPE_ID>
Loads or unloads a particular transport with a given tape. May select a bin in an automatic changer system or may involve manual intervention for a Honeywell-like system.

{ START | STOP | REWIND } <RACK> <TRANSPORT>
Perform the indicated function.

DELAY - A low- or high-speed function? **

<RACK> := Data Playback System Rack Number (01-23?) **
NOT antenna number.
<TRANSPORT> := Transport number within a rack (01-08?)**
Transport = 99 refers to entire rack,
transport = 98 refers to changing robot.
A Honeywell-like system may have only one transport per rack.
<TAPE_SLOT> := Tape physical identification number
Slot number in tape basket for VCR system.
(Long alphanumeric field)
<MESSAGE> := A quoted text string up to ?? characters** long (determined by display device)

HIGH-SPEED CONTROL INTERFACE
============================

Signals provided by correlator to DPS:

BIT CLOCK:	16 Mb/s (independent of sample clock?)	**
FRAME CLOCK:	200 Hz (frame boundaries)	**
CHECK CLOCK:	1 Hz? (for time code control)	**
TIME REQUEST:	TT-HH:MM:SS.SSS of time expected at next CHECK CLOCK on transport TT. ASCII coded sent at 9,600 bps (14 char. per transport)	**

DPS synchronizes itself to the clocks and the time requested to even 5 ms (?) boundaries. In general, each transport can sync to a different time. Transports normally free run against incoming clocks. Time requests sent only when resyncing is required. **

10.1.2.2 Post Processing System

Basic output format:	FITS?	**
Output Medium:	Multi-access disk (up to ?? days after correlating)	**
	6250 bpi tape archived periodically from disk	
Disk/tape interface:	DEC VAX CI bus or Systems Industries multi-cpu bus	
Data access protocol:	DEC VAXcluster MSCP, or SI SIMACS	

Data Provided:	Unfitted fringe visibility within defined fringe rate, delay windows (continuum) or fringe rate, RF frequency windows (spectral line)	
Nominal Data Output Rate:	??	**
Peak Data Output Rate:	??	**
Required disk capacity:	??	**

10.1.2.3 Schedules/Logging

(The following may belong to the Operations Section.)

The birth-to-death history of all experiments (proposals, schedules, observing logs, correlator logs, post-processing runs (?), and even publications (??)) will be kept in a distributed Database Management System, including array control computer, correlator control computer, post-processing computer(s), and administrative/scheduling computer (if any).

Correlation of data tapes will normally be first-in first-out on the basis of telescope schedules and logs. A correlator scheduling program will make a correlator control file from the logs with suitable help from Array administrators.

A summary report of all correlator runs (processor mode, clock and LO offsets, typical visibility levels, tape quality, etc.) will be entered in the database.

10.1.3 Operating Modes

Principal Options:

- Number of Antennas
- Polarized/Non-polarized
- Continuum/Spectral Line
- Quantization
- Frequency switching/non-switching (?)**
- Bandwidth per channel
- Number of channels processed
- Frequency resolution
- Number of processing passes per observation
- Speedup of playback over recording
- Interleaving of experiments
  - channel-by-channel
  - antenna-by-antenna
- Normal vs. Peak rate recording
- Field of View (delay and fringe rate passbands)

Multiple phase centers (phase referencing)
Oversampling
Pulsar Processing (time gating)

FULL ENUMERATION (?)

10.1.4 <u>VLSI Design</u>

10.1.5 <u>Calibration Requirements</u>

10.1.6 <u>Control Computer</u>

DEC VAX-11/750 or equivalent new VAX model
VMS operating system
Memory: 3 MByte(?) **
Local disk storage: 300 Mb disk(?) **
Array Control Communicatons:
DECnet if Array Control is DEC.
(Operations data base?) **
Post Processing Communications:
(1) Via FITS tape
(2) Via operations data base(?) **
Multi-access disk: 2,500 Mb? **
High Capacity Tape Storage: 125 ips, 6250 bpi, two drives
High quality graphics workstation as control console

10.1.7 <u>Satellite Computers</u>

Near-standard configuration (Caltech Tensor or Supernode, or commercial board sets.)
Fast 16- or 32-bit microprocessor (68000, 68020, 32032)
2 MByte memory
Fast Floating Point processor
Interprocessor communication, up to 10 high speed links
Effective Processor Power: 1 - 4 Mflops
Cost: approx $6,000

10.1.8 <u>Programming Environment</u>

Control Process (VAX): VAX Forth, C, (?) **
Calibration Process (VAX or satellite): Fortran (AIPS)
Fringe Process (satellite): C, Pascal, (?) **
Satellite software all developed on and downloaded from control computer

10.1.9 Physical Environment

Estimated standard electronics racks (2 x 2 ft):

Qty	Item	Racks
22	Data Playback Systems	22
2	Mark III Playback Systems	2
19	Sets of Station Electr.	10
2	Quadrants Correlator	6
1	Computer System	6
	TOTAL (C2S)	46 Racks

Floor space requirement:

Item	Floor Area
Electronics Racks (46 @ 20 sq ft)	900
Tape staging	500
Operator Control	200
TOTAL	1600 sq. ft.

Potential expansion: Upgrade C2S to C2F may take 15 additional racks, or 300 sq. ft. Quasat playback system may take 3 racks, 60 sq ft. Therefore, the total potential requirement (5-10 yr) is about 2000 sq. ft.

Electric Power (excluding air conditioning and lighting):

Item	Power
C2S correlator	30 kW
Computer	20 kW
(potential upgrade to C2F	30 kW)
TOTAL POWER	50 - 80 kW

All major racks to be supplied with individual AC circuits and independent ground returns to an isolated earth ground.

Commercial power shall be conditioned so that system crashes due to dropouts, surges, or unplanned outages will occur no more than once (?) per year. Motor generator or UPS may be required. **

Air conditioning:

Sufficient to remove 80 kW of heat, maintaining computer room conditions. Underfloor plenum for electronics racks (except computer). Most critical environmental specification set by tape playback system (see section 9); this may be in a separately conditioned room.

Maximum allowed cable runs:

Within correlator system:	10 m (?)	**
Between playback system and correlator:	25 m (?)	**
Between correlator and computer:	25 m (?)	**

10.2 Description

10.2.1 General

The correlator system is responsible for cross-correlation of the data streams from all VLBA and outrigger antennas. The correlator input comes from data playback systems similar to the recording systems used at the antennas. Correlated data are to be compressed to the greatest extent possible while preserving the relevant astronomical information. A computing system is incorporated for correlator control and for such calibration and data reduction procedures as can be accomplished in a routine manner. Astronomers will not normally interact with their data until it is passed to the post-processing system.

10.2.2 Interfaces

10.2.2.1 Data Playback System

10.2.2.2 Post Processing System

10.2.2.3 Schedules/Logging

10.2.3 Operating Modes

NOTE ON FREQUENCY RESOLUTION AND POLARIZATION PROCESSING

There has been some confusion on the subject of how much frequency resolution will be available for processing polarized data. If there are N correlator channels available for non-polarization processing, how many will there be for full polarization? There are two answers, depending on assumptions:

(1). CONSTANT OBSERVING BANDWIDTH. If the observing bandwidth B is maintained the same for P as for NP modes, the sample rate in R and L polarization channels will each be equal to the rate used in NP mode. The N correlator channels may be divided into 4 subcorrelators, handling the RR, RL, LR, and LL products separately. The delay coverage is N/4 samples, so the frequency resolution is 1/4 that achieved in NP processing.

(2). CONSTANT RECORDING RATE. Since both R and L channels must be recorded, we can have only 1/2 the observing bandwidth in P mode as in NP. Thus the sample rate will be halved, and the delay coverage can be doubled with the same rate of correlator arithmetic compared to case (1) above. The delay coverage is 2*(N/4) samples, so that the frequency resolution of 1/2 that achieved in NP processing.

The current correlator design allows for the full resolution of case (2) by reallocation of IF channels. We simply relabel the IF channels so that each observing band gets both a full R and L channel. This is appropriate for continuum observing; however, in most spectral-line work the bandwidth is fixed by the source, and case (1) applies.

10.2.4 VLSI Design

10.2.5 Calibration Requirements

10.2.6 Control Computer

A DEC VAX-11 computer is chosen to preserve maximum compatibility with the Caltech/JPL Block II correlator system. The VAX may also be selected for other VLBA subsystems. (See sections on Array control computer and post-processing.)

Since a very large and inexpensive computing capacity will be available in the satellite computers (see below), there is little need to select a VAX with very powerful numerical capabilities. It is necessary, however, to have substantial I/O power, since all correlator output data will flow through this computer to the data output media. It is desireable to use a high-level operating system like VAX/VMS for the output function because the output database must be compatible with the large post-processing facility and because flexible data access methods with good error control will help maintain overall data integrity.

A VAX-level environment is very helpful for correlator management and operator interface software. The correlator VAX could also serve for continuing program development and maintenance.

A VAX-11/750 appears to have adequate power for the control computer if model calculations are shipped out to a satellite. Simple extrapolations of Block II experience indicate that the VLBA correlator load would be somewhat more than 100% of a VAX-11/780 if model calculations are kept in the VAX. (Further evaluation required.)

10.2.7 Satellite Computers

The Block II Tensor processor is a reasonable prototype of the VLBA correlator satellite. Tensor consists of the following elements:

CPU:	68000, 8 MHz clock
Memory:	2 MByte, parity protected
IO:	4-channel 16 bit DMA; RS-232; video display
Aux. Proc:	32 bit integer processor; 1K complex FFT in approx. 5 ms.
Packaging:	1 large wirewrap board
Price:	$5 - 6K

The Caltech Concurrent Processor project is developing a processor which will effectively be a second-generation Tensor. It will include a faster 16- or 32-bit microprocessor and fast floating point. Its performance target is 1 - 4 Mflop/s. It is to be available in quantity by mid-1985.

There are also some commercial board-level computers that may be suitable for the VLBA role. These must be evaluated further.

In general, the satellite processor approach offers a price performance ratio at least a factor of 10 better than general purpose computers like the VAX. Programming for these systems is not much more difficult than for the general purpose environment. In fact, most software can be tested running on the VAX before it is installed in the satellite.

10.2.8 Programming Environment

Present software components of the Block II correlator are shown in the following block diagram along with the language used.

```
+-------------------------+
| CONTROL PROGRAM         |
| VAX-11/780 - VMS        |
|            FORTH        |
+-----------+-------------+
            |
+-----------+-------------+
| DELAY, LOBE ROTATOR,    |
| PHASE CAL. CONTROLLERS  |
|            MICROCODE    |
+-----------+-------------+
            |
+-----------+-------------+
| CORRELATOR SIGNAL PROC. |
| (FFT, PH. CAL., FBS CORR |
| ACCUM.)    MICROCODE    |
+-----------+-------------+
            |
+-----------+-------------+
| FRINGE PROCESSOR (TENSOR)|
| FFT: MICROCODE (HARDWARE)|
| GENERAL: PASCAL (68000) |
+-----------+-------------+
            |
+-----------+-------------+
| POST-PROCESSING         |
| GEODETIC/ASTRONOMICAL   |
|             FORTRAN-77  |
+-------------------------+
```

All 68000 programs are developed using VAX cross-compiling tools and 68000 ROM-based executives and debugging modules. Microcode is developed with VAX and AMD System/29 tools. PASCAL programs are tested in both VAX and 68000 environments.

For the VLBA, the Caltech/JPL team would like to capitalize as much as possible on Block II software. We propose to use the Forth control program and the PASCAL Fringe Processor program with as few changes as possible.

10.2.9 Physical Environment

(This section probably overlaps with the Operations section.)

A tentative floorplan for the correlator facility is shown below.

(FIGURE TO BE SUPPLIED)

Several correlator-related areas can be defined, each having its own peculiar requirements:

TAPE TRANSPORT AREA - A large number (22?) of tape playback racks in a single room. Control of temperature, humidity, and cleanliness will be most stringent here. (Consult Data Recording section.) There will be a large volume of tape to and from the tape staging area. Computer terminals and other displays will direct operators to mount and dismount tapes at appropriate times.

CORRELATOR EQUIPMENT AREA - This are will generate the bulk of the heat and will need heavy air cooling. There will be little traffic here. Conventional rules for access to equipment racks (3 feet front and rear clearance) should be followed.

COMPUTER AREA - The VAX control computer has certain components that require frequent operator intervention: tape drives, printer, and console. Except for these, the remaining equipment (disks and cpu) can be separated and located with the correlator equipment.

OPERATIONS AREA - The correlator operators will interact with a central operator's console with nearby desk space. This station will be continuously attended and should be reasonably comfortable for personnel -- noise level and air drafts under control.

TAPE STAGING AREA - This is a buffer between the VLBA (raw-data) tape library and the tape transport area. Large blocks of tape will be assembled here in anticipation of computer instructions to mount on specific tape drives. There will be a lot of traffic of people and carts loaded with tape.

RAW DATA TAPE LIBRARY - Storage for ?? weeks of VLBA raw-data tapes is required. Environmental conditions of this area, the staging area, and the tape transport area must be the same. Access is required to the shipping and the tape staging area.

MAPPING AREA - This area does not need special environmental control, except for good cleanliness. Separation of incoming and outgoing tapes is vital. Magnetic tape erasers must be carefully isolated from unreleased tapes. This area should immediately adjoin a shipping dock.

SECTION 11

POST PROCESSING

R. Burns

11.1 Specifications

11.2 Description

11.2.1 General

The processing path, as the data progresses from the correlator thru the map stage, is divided into two parts, fringe processing and post-processing. Historically fringe processing has referred to processing which operates on raw correlator output. This is further refined here.

Fringe processing is defined as those programs which are run automatically on correlator output (and which must keep up with the data). The "standard correlator output" is considered to be the output of the fringe processor.

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 Fringe Processing

11.2.2.1 Scope and Functions

There is a certain set of operations that must be performed on almost all VLBA visibility records and need only be done once. In the past, we have referred to some of these tasks as existing "in the processor". These tasks would be done in a dedicated computer with special hardware; we call this device the fringe processor. The hardware for the fringe processor is described in the correlator section (Section 10) because it is intimately connected with the correlator. The budget allotments for the fringe processor software are also in the correlator chapter. However, in order to present a unified overview of the data flow, the functions of the fringe processor are described here.

The fringe processor will receive raw correlator output, apply corrections due to correlator model limitations, slew out station doppler shifts, correct for discrete delay tracking, apply measured system temperatures and standard gain curves and fringe fit the calibrator source observations. All this will be done in real time with little or no data buffering between the correlator and the fringe processor. A block diagram of the fringe processor operation is shown in Figure 11.1.

The delays and phases calculated in the processor model and removed from the data by the correlator will be carried along in each data record (as is currently done in Mk III data sets). Thus the fringe processor output records (residual values) can be rapidly converted to interferometric observables. We cannot keep the observables only, time consuming model calculations would have to be repeated during various phases of map processing. The delays and phases used in the correlator can be saved as `random' parameters in the AIPS-like visibility records.

In the upper section of the block diagram, we apply phase slopes across delay channels and frequency channels. In the spectral line case, the station doppler shifts must be precisely tracked and removed. Current spectral line VLBI practice is to remove the doppler frequency shifts by rotating out phase slopes across the delay channels. We also remove the fractional bit delay tracking error by applying a phase slope across the frequency channels. Instrumental phase changes will be measured using something like the Mk III cal tone system. The instrumental phase shifts could be removed in either the delay channels or frequency channels, which ever is easier.

The remaining fringe processor operations are basically threefold. First, we would apply corrections to the processor model, corrections that change more rapidly than the downstream averaging interval. Second, the global fringe fitting task measures station based residual delays, delay rates and phases on regularly scheduled observations of calibrator sources. Third, the delays, rates and phases from the calibrators are used to track and remove residual delays and delay rates in the program sources. Thus we can average the visibility records to roughly 10 seconds and 4 to 6 frequency channels. The exact averaging dimensions will be limited by the field-of-view sizes rather than uncertainties in the processor model (atmosphere, clock drifts, small position errors). The data rate will be then reduced by a factor of several thousand. Finally, slowly varying corrections are applied to the averaged vis. records (T sys, standard gain curves, various geodetic models - polar motions, earth tides, general relativity, atmos. and ionospheric models). The fringe processor output would be archived and funneled into the VLBA AIPS analysis computers. The output data would be written in AIPS uv format with extension files

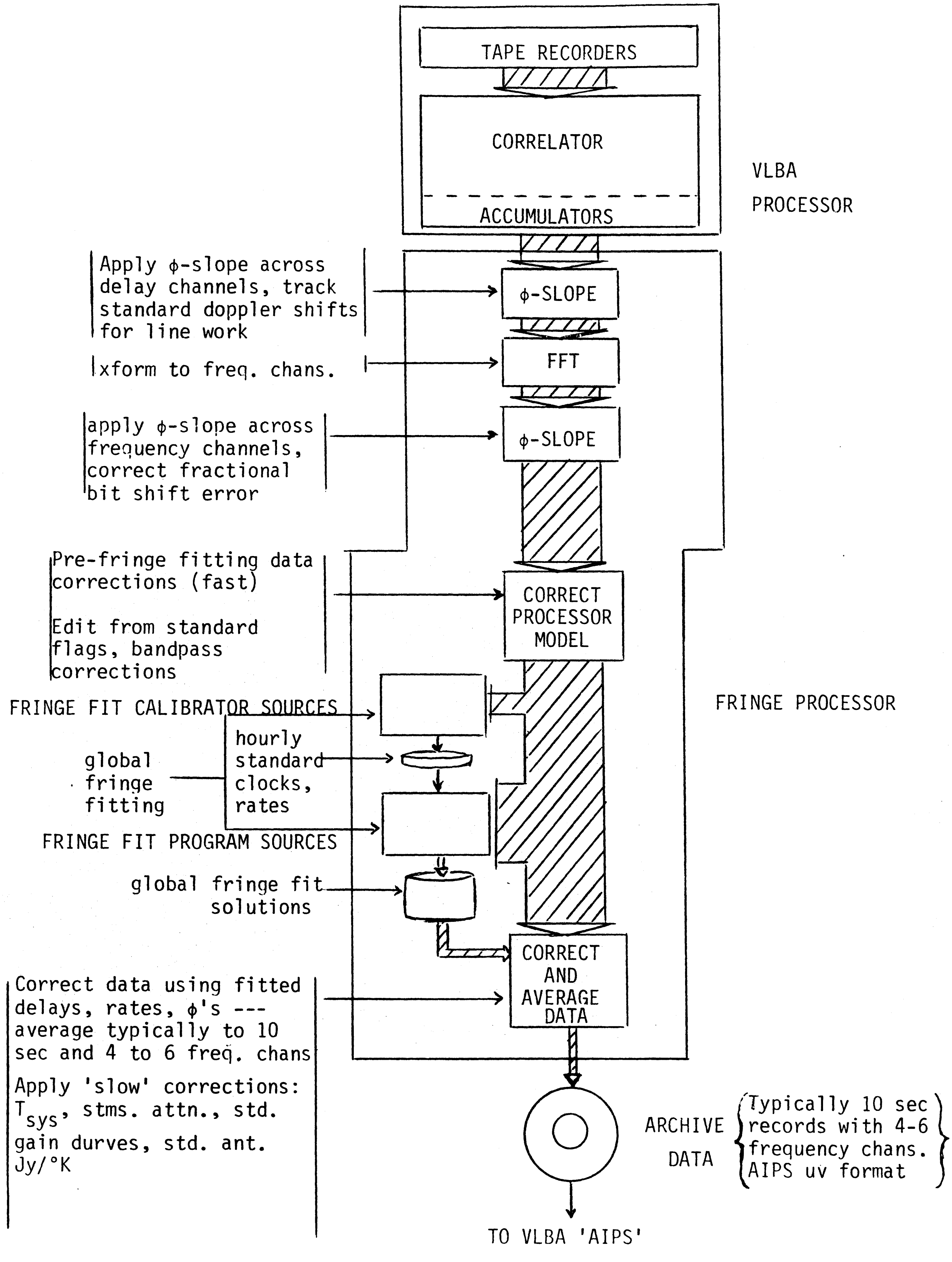


FIGURE 11.1

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containing the fringe solutions and complete descriptions of the models used by the correlator and fringe processor.

11.2.2.2 Internal Format

The details of the fringe processor internal data format have not yet been decided. However, since the fringe processor will generally not be accessible to the scientific users, the internal format may be designed for speed and efficiency of fringe processor operations rather than for great flexibility and portability to other systems. The fringe processor output will be the user's data archive and first contact with his data, and will be in a friendly format, probably AIPS or FITS.

11.2.2.3 Correlator Log File

There will be two quite separate data streams coming out of the VLBA processor: the auto- and cross- correlation data records with minimal data record headers (AIPS), and everything else. The \`everything else' should include details of the processor model used for the current data set. The processor computer should pass sufficient model constants, coefficients and specifications into the data base of the current data set. It must be possible to recalculate the processor model completely and exactly at any stage in the post-processing.

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.

11.2.3.2 Hardware

11.2.3.2.1 Current Hardware Thinking

The proposed hardware configuration is shown in Figure 11.2. 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. Development of the post-processing software may proceed using existing computer hardware at NRAO (VAX 11/780's). The VLBA post-processing computer hardware need not be purchased until late in the project schedule.

The configuration shown is based on a VAX 11/780 and is conceptually very close to that developed for the original proposal in May 1982. It is felt that the four VAX system still represents an attractive possible system. Some detailed changes have been made, however. The number of displays has been increased based on AIPS experience. The disk subsystem has been upgraded and the intercomputer interfacing improved taking advantage of more recent technology. More work needs to be done to compare the present concept to alternative approaches.

11.2.3.2.2 Size of Problem and Comparison to VLA

The computing needs of the VLBA and the VLA for post-processing are similar, although the uncertainties in the estimates of those needs are large. The VLBA map sizes will be driven for the most part by the program source structures rather than a need for removing confusing sources in the field-of-view. At the present time, most of the VLA post-processing needs come from map sizes determined by source structure and not from mapping huge fields-of-view to eliminate confusing sources. It is in this context that the VLBA and VLA post-processing requirements are similar. The data base sizes and data rates from the correlators of the two instruments are compared in Table 11.1. The table gives minimum data base sizes and rates, for a variety of VLBA and VLA observations, as set by the requirement that the data at the edges of the field of view not be degraded by delay or time average smearing and that sufficient delay channels be kept so that the fringes will not be lost because of clock errors. These are minimum numbers and assume that the best possible job will be done to determine the a priori clock and geometric parameters. For the two VLA continuum cases, the integration time has been set equal to a value that is often

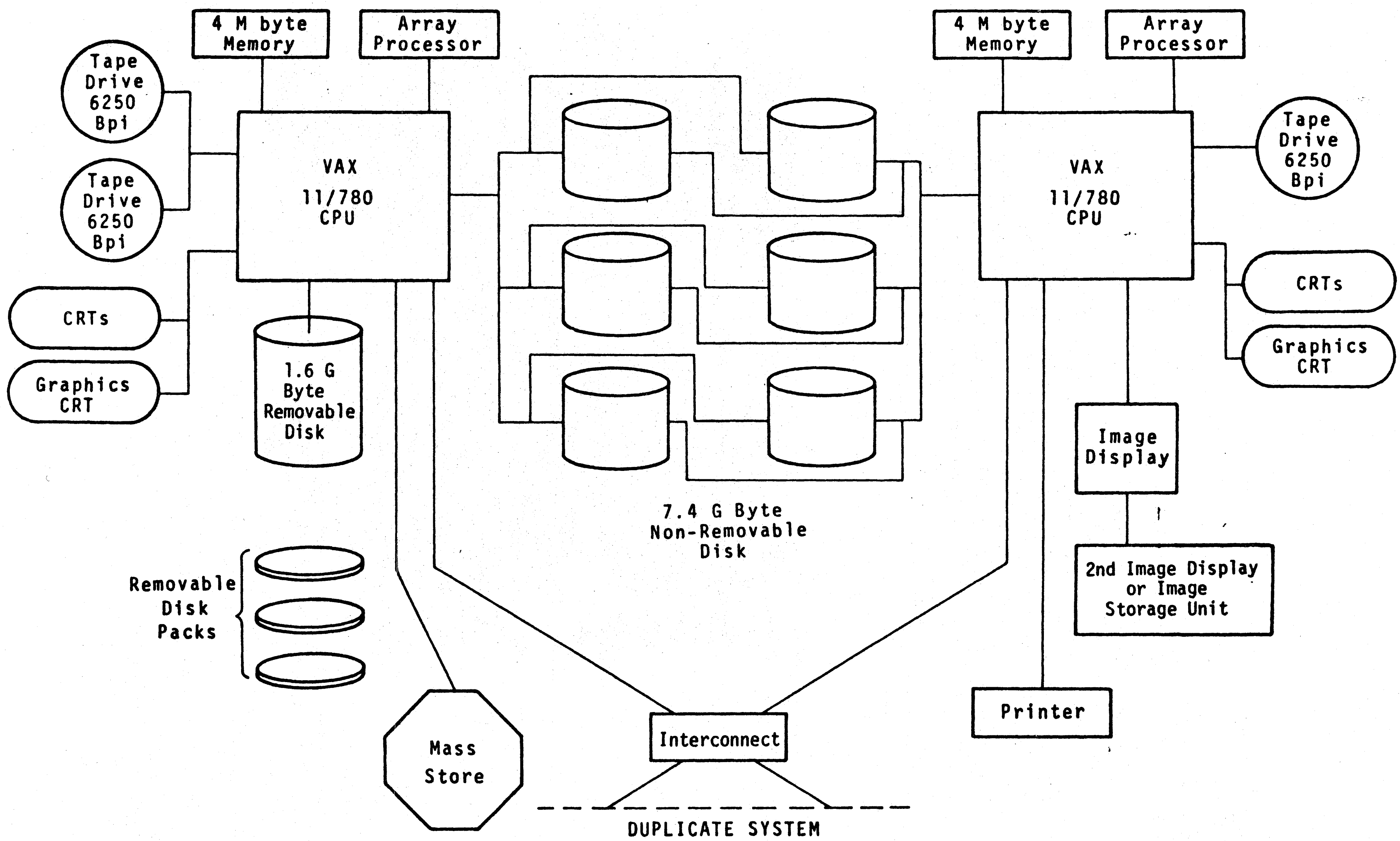

Figure 11.2

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used in current observations. The table shows that the volumes of data generated by the instruments will be similar. The precise relative values will be determined by the mix of observing programs.

The relative needs of the VLA and the VLBA are also a function of the tasks that must be performed on the data. These tasks aresimilar overall but differ in some details that make estimates of the relative needs uncertain. VLBA data will be fringe fitted, a process that is not done for the VLA data. Also VLBA data will require many passes through the self-calibration procedures to make maps. Conversely, useful observations can be made on the VLA in a few minutes while the VLBA will require much longer to obtain enough data for a good map. Therefore, more maps will be made per unit observing time for the VLA than for the VLBA. Also the dynamic range of maps made with the VLA is higher because of the larger number of antennas. Very high dynamic range maps generally require more processing than lower dynamic range maps.

Despite the large uncertainties in the estimates (the post-processing needs of the VLA still are not completely clear despite several years of operation!), it is apparent that the post-processing needs of the VLA and the VLBA will be similar. An amount of computing capability similar to what is available at the VLA should be provided for the VLBA. Since both instruments will use the same basic software and the same types of computers, it will be possible to distribute the processing capabilities within NRAO in the most effective manner to handle data from both.

It is clear from the extreme H20 maser case shown in Table 11.1 that there are scientifically reasonable observations that cannot be handled in a routine manner. For observations of sources that have interesting structure spread over fields that are thousands of resolution elements on a side, such as H20 in Orion, special techniques must be used to keep sizes of the data bases and the maps within ranges that can be handled. The existence of cases that are impossible to support fully shows that the post-processing system cannot be specified to handle all conceivable situations, but rather must represent the most effective capability that can be acquired at a reasonable cost and that can handle most of the needs of the array.

11.2.3.2.3 <u>Software</u>

<u>Decision to use Common Software for Processing VLBA and VLA Data</u>.

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 simi-

Table 11.1 840424

Specified Parameters:

L	Maximum baseline in km.
B	Number of baselines.
F	Frequency in GHz
BW	Bandwidth in MHz.
H	Hours of data per baseline.
X	Maximum offset from center of field.
P	Minimum points per fringe period.
S	Number of stokes parameters.
W	Number of bytes per vis. record. 22 for u,v,w,time,baseline,weight + 4*S*CU (CU is number or freq. or lags.)

Derived Parameters:

C	Number of channels (fixed for line - set by delay window for continuum)
CU	Number of channels used (allows for clock uncertainty - see VLBA Memo 204.)
T	Integration time. Set by P and X except for VLA continuum cases.
MBYTES	Megabytes required to store data set.
KVIS	Thousands of visibility records. (One per baseline per integration interval)
RATE	Bytes per second from correlator.
TAPES	Number of 6250 bpi tapes (180 Megabytes each).

Type of Observation	L	B	F	BW	H	X	P	S	C	CU	W	T	MBYTES	KVIS	RATE	TA
Moderate continuum field.	8000	45	10.6	32.00	10.0	0.20	2.0	4	3.	6.	122	25.07	7	64	218	0
Extreme continuum expt.	8000	91	43.0	64.00	10.0	0.20	2.0	4	7.	10.	175	6.18	92	530	2576	0
Large Field (eg. Hot spots)	4000	35	1.6	32.00	10.0	2.00	2.0	4	17.	20.	334	33.22	12	37	351	0
Moderate H2O maser obs.	8000	45	22.2	0.00	10.0	1.00	2.0	1	256.	256.	1046	2.39	707	676	19661	3
Extreme H2O (eg. Orion).	8000	45	22.2	0.00	10.0	15.00	2.0	1	1024.	1024.	4118	0.16	41799	10150	1161087	232
OH masers.	8000	45	1.6	0.00	10.0	2.00	2.0	4	256.	256.	4118	16.61	401	97	11157	2
VLA continuum.	35	351	5.0	50.00	10.0	100.00	2.0	4	11.	11.	203	20.00	128	631	3562	0
VLA snapshot.	35	351	5.0	50.00	0.2	100.00	2.0	4	11.	11.	203	20.00	2	12	3562	0
VLA H2O maser obs.	35	351	22.2	0.00	10.0	30.00	2.0	1	256.	256.	1046	18.24	724	692	20128	4

lar 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 now been developed by VLBI and VLA groups that use closure phases and "self-calibrated" amplitudes. As a result, the techniques used for both kinds of instruments are now very similar.

Need for Transportability. Much of the software developed in support of the VLBA will be run at various university facilities as well as at the VLBA control/processing center. Software involved in observation reparation 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 some 20 institutions. As such it is important that the software be transportable as possible.

There are various levels of transportability ranging from the simple use of FORTRAN on the one hand to quite sophisticated requirements on the other. The widespread use of the VAX11/780 in the VLBI community eases the problem by somewhat reducing the number of hardware environments which need be considered. However, it is not clear what the mix of hardw ıre might be ten years from now. As such, machine independence should be a consideration.

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. It is already being used for VLBI data reduction with current experiments. There are a few functions that are still needed (e.g., editting) for VLBI mapping operations but those should be available sometime during 1983. This package, or its successor, should be used for the VLBA. If there are capabilities that are missing, they should be added. 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 routines used on the VLBA data after correlation, including all editting 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. This both allows the user to make late changes to the displays and analysis and relieves the VLA (future VLBA) facilities of some of the computing burden generated by the observations. AIPS is currently known to be running about 20 sites outside NRAO. The portability of the software is maintained by isolating all machine dependent code in specially flagged subroutines (Z routines) and by coding all of the rest of the routines in standard Fortran.

It is not yet clear where the geodetic and astrometric analysis will be made. The capability should be provided within the standard package (e.g., AIPS) 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 do geodesy. This means that all alterations made to the data by the processor and reduction software should be undone or at least documented to the extent that they can be undone easily.

11.2.3.2.4 AIPS. Discussion. 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.

Tape format. The uv-FITS format will be used whenever data is written to tape whether correlator output, archive or processed data. This should allow the data from any stage of processing to be read by any computer with a uv-FITS reader so that the data can be freely translated on either NRAO or outside computers. 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., maps) 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 the AIPS database structure: the catalog header, the main data file and extension 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 extension 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 dimensions of each axis, the axis value incrument, 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 of the current AIPS might be circumvented by use of the channel number instead of frequency.

- Extension files. Extension files are used to store information not contained in the catalog header or the main data file. An example of an extension 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 extension files are the antenna files, the self-calibration solution files and the VLBI fringe fitting solution files. Extension 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 data. Extension file entries consist of fixed length logical records which may be complex data structures. VLBA data bases will use extension 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 core-to-core 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 extension 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 extension files are generally much smaller than the main data file the reduced I/O speed is usually not serious.

Possible improvements. A number of improvements to the AIPS system have been considered, some of which are discussed in the following:

- Catalog header. The current catalog header is designed for efficiency but is rather inflexible. In the current AIPS, changes in the catalog header require corresponding changes in all affected programs. Several possible solutions have been suggested, the most elegant but most difficult of which is to change the AIPS catalog header to partially or wholly consist of a FITS type header containing ASCII entries of the form "KEYWORD = value". This would give databases the great flexibility of the FITS tape format.

A modification of the scheme described above is to keep the current catalog header but add an ASCII extension file which contains keywords and values not contained in the header. This would be an adequate although unsatisfying solution. A third solution is to use the history file to keep the additional information. The current convention in AIPS is to make history entries in the form "KEYWORD = value" so that this information is easily available.

- Programmer-friendly routines. One of the more frequent complaints about programming in the AIPS system is that there are many details that the programmer must take care of. The complexity of the system makes it difficult for a new programmer; in particular, the I/O routines seem to be a problem. These details which allow for much of the speed and flexibility in AIPS tasks can be partially masked by higher level routines which are simpler to use but are more restrictive. Such an attempt has been made with limited success in the "WA WA" package of I/O routines.

Another approach to simplifying programming in AIPS which has been tried is a "skeleton" task which takes care of the I/O, task startup, cleanup, etc. and isolated the portions of the program which the programmer must change. This latter approach is more limited in use than general, simplified routines but appear to be relatively successful.

- Major revision of AIPS. At some point in the future it may be desirable to make major modifications in both the AIPS program and its tasks. Because the amount of effort involved with a major rewrite of the entire package is great, it should be considered only if it is possible to derive considerable benefit.

11.2.4 Special Considerations for Astrometry and Geodesy

Correlator. The primary correlator outputs of interest for astrometry and geodesy are the group delay (from bandwidth synthesis), the phase, and the phase delay rate. It is felt that these quantities should be readily and easily available. If these total values are kept in visibility records, there is no need ever to remember the details of the correlator model. If instead 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 (AIPS `random' parameters in visibility records). 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 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 map 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 expected 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.

11.2.5 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 support 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 capacity is very inelastic and difficult to predict. The question of separating the operational and development 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 editting programs for VLBA data. The greatest uncertainty in the manpower estimate concerns the special software required to support astrometry and geodesy. It may be attractive to integrate an existing non-NRAO, non-AIPS geodetic software package into AIPS.

11.4 Cost Estimates

Post-processing requirements are outlined in terms of the DEC VAX-11/780 system. This system should however only be taken as a possible system. this hardware need not be purchased prior to 1985. 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. Cost estimates are given below:

4	VAX 11/780 (SVAXECA-CA)		245	980k
	4	Mbyte memory		
	0.5	Gbyte disc storage (non-removable)		
	1	Tape drive (6250/1600)		
		Operating system		
4	3.2 Gbyte disc expansion (non-removable)			500k
	1.4	Gbyte expansion	50	
	1.8	Gbyte additional system	75	

4	0.8 Gbyte disc expansion (removable)		280k
	0.8 Gbyte additional system	70	
1	Mass store (high density tape similar to VCR under devel. at NRAO)	40	40k
2	Additional tape drives	25	50k
4	Array processors	75	300k
3	Image display subsystems	60	180k
1	Video disc (fast image refresh disk system under devel. at NRAO)	20	20k
2	Printers	30	60k
25	CRT terminals		40k
	20 text terminals	20	
	5 graphics terminals	20	
	Computer interconnection		150k
	Local Area Network	40	
	CI Interconnect	110	
	Miscellaneous	50	50k
Total Hardware			2,650k
Software Development (10 man-years)			450k
			$3,100k