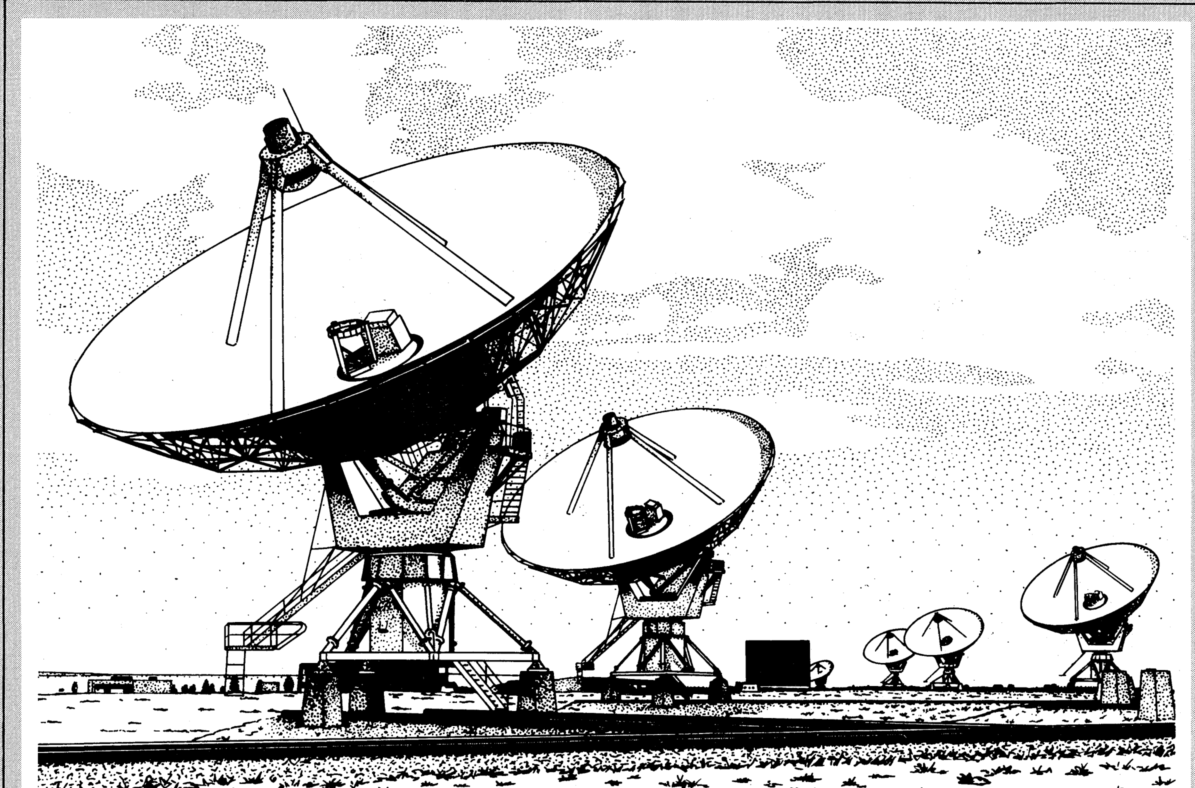
AN INTRODUCTION TO THE NRAO VERY LARGE ARRAY



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AN INTRODUCTION TO THE NRAO VERY LARGE ARRAY

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National Radio Astronomy Observatory*

Socorro, NM 87801

*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the U.S. National Science Foundation.

4/83

Aerial view of the Very Large Array
as seen from the northeast

PREFACE

The purpose of this INTRODUCTION TO THE NRAO VLA is to provide astronomers who wish to observe with the VLA most of the basic information they need to use the instrument. It is an introduction rather than a complete user's manual because we wish to provide both an overall view of the instrument and a level of information appropriate to those who may not already be experienced with interferometry and aperture synthesis.

When the first edition of this Introduction was produced in 1978 as a "bound" volume, there were formidable barriers to up-dating. This resulted in a delay of almost four years before an up-dated version was produced. It is for this reason that we now produce the Introduction in both "bound" form and in three ring notebooks. At the price of an increase in bulk, the notebook format should make the task of updating chapters less formidable for regular users of the VLA. Once an individual has an Introduction notebook, it will be their responsibility to ask for and replace newly updated sections. For those who regularly use the VLA, this can be best accomplished after arrival at the VLA site. For those who use the VLA infrequently, a written inquiry at least several weeks before a planned observing session may be more practical.

Each Chapter will have the current revision number indicated in the Table of Contents, as will the lower left corner of each page in each Chapter. Occasionally pages, but not entire Chapters will have more recent revision dates.

Due to the nature of this Introduction many details are left out. It will be updated only on time scales of many months or years. Other manuals that are maintained at the VLA site are intended to provide more detailed and up to date information. Principal amongst these are:

1. the Observer's Reference Manual (ORM);
2. the Calibrator manual;
3. the Observational Status Report; and
4. the AIPS Cookbook
5. the Guide for Spectral Line Observers

The user can obtain copies of most of these manuals at the VLA site. For most purposes the many copies kept at appropriate places around the VLA site should be sufficient.

Another source of information about the VLA is the Proceeding of the NRAO-VLA Workshop on "Synthesis Mapping". These proceeding contain lectures on various topics prepared by NRAO staff, with many details about matters important to those who wish to obtain a deeper understanding of aperture synthesis instruments like the VLA.

Many individuals have contributed to producing the past and present versions of this Introduction. Also, many of the ideas and text used in various portions of this introduction are borrowed or paraphrased from the work of individuals on the VLA staff who are too numerous to mention here.

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Chapter 1

THE BASIC INSTRUMENT

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April 1982 Editon

ABSTRACT

We present a general overview of the aperture synthesis radio telescope called the Very Large Array (VLA). This includes a brief history of the background of the instrument and a summary of the general characteristics of its major hardware components.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. THE HISTORY AND CONCEPT OF THE VLA

The basic concept behind the VLA is that of an aperture synthesis radio telescope capable of making radio pictures over the entire northern sky with a resolution comparable to that of optical telescopes. Before describing the basic instrument, let us briefly describe the evolution of the VLA concept and the early history of its implementation.

The ideas behind the VLA were developed at NRAO within a few years after the beginnings of NRAO itself. Because of the pioneering efforts of M. Ryle, B. Mills and W. Christiansen, radio astronomers during the period 1957 to 1962 were well aware that the way to obtain a high-resolution radio mapping instrument was to place radio telescopes in large arrays and use the resulting interferometric data in conjunction with the aperture synthesis technique originated by Ryle. Therefore, in the years following the ground breaking for NRAO in Green Bank on October 17, 1957, two weeks after Sputnik, the beginnings of the VLA concept arose as a natural result of NRAO's mandate to provide radio astronomy instrumentation for US radio astronomy. In 1960 the National Science Foundation (NSF) established a committee of radio astronomers, headed by John Pierce of Bell Telephone Laboratories, to consider the future of radio astronomy. During the following year it became clear that NRAO should provide a high-resolution radio picture-making instrument. In 1962 the Pierce committee report recommended to the NSF that NRAO should proceed with the design of a 1' resolution array. D. S. Heeschen, then acting director of NRAO, distributed a memo assigning specific array design responsibilities to NRAO staff members in September of 1962. Development of an 8" resolution array in Green Bank was begun the next spring as a first step in familiarizing NRAO personnel with interferometer arrays. This resulted in the linking of a second 85-foot telescope to the original 85-foot Howard E. Tatel telescope to form NRAO's first interferometer pair. A third 85-foot telescope and a radio link to a 42-foot (later 45-foot) telescope were added later to give spacings from 100 m to 35 km.

In the summer of 1964 detailed design studies for the VLA began at NRAO. In August of that year the Whitford report gave its highest recommendation in the area of astronomy instrumentation to a large array consisting, as an example, of 100 85-foot antennas capable of 10" resolution mapping. NSF funded the detailed design work for such an instrument in fiscal years 1965 through 1967, at which time there was a specific NRAO design group headed by G. W. Swenson, then on leave from the University of Illinois. In January 1966 the first progress report of this design group was released. It recommended that the design goal of the instrument be changed to 1" resolution so it would be a radio imaging device with resolution comparable to optical telescopes. Their report was followed in January 1967 by the publication of Volumes I and II of the VLA proposal. The specifications of the VLA at this time involved 36 25-meter antennas operating mainly at 11 cm and located on three arms of a Y, with each arm 21 km in length. It was part of this plan that 3-cm and (21-cm) spectral line capabilities would eventually be added. The Y-shaped array concept was suggested by Y. L. Chow, who served as a consultant to the VLA design group.

During the summer of 1967 it was announced that NSF had declined to ask for funding for the VLA, and shortly thereafter the design group was largely disbanded, though some members remained on the NRAO staff. A low-key design effort continued at NRAO and in January 1969 Volume III of the VLA proposal was released. This volume reduced the number of proposed VLA antennas to twenty-seven. The preparation of Volume III was, in part, a response to the first meeting of the Dicke committee which had recommended, as part of a proposed plan for instrumentation in radio astronomy, that the funding of VLA design be continued. At a later meeting the Dicke committee recommended the building of a number of instruments, including the VLA. Based upon the Volume III modifications of the VLA proposal, the arguments for the construction of the VLA continued during the years 1969 to 1971. This was the period in which the Greenstein committee was considering various proposals for astronomy instrumentation. The VLA proposal was also being discussed by the President's Science Advisory Committee and the Office of Science and Technology. In late spring 1971 the final report of the Greenstein committee was released, with the VLA described as first priority amongst four strongly recommended projects.

The VLA project was widely supported by the US astronomical community; therefore, in October 1971 the NSF requested three million dollars for FY1973 to begin construction of the VLA. In December 1971 Volume IV of the VLA proposal, dealing with possible sites for the array, was released. At that time the site on the Plains of San Augustin in New Mexico was favored, and during the next year it was chosen as the site for the VLA because it was large, flat, isolated, relatively inexpensive to acquire, and located at a high altitude. In January 1972 the VLA appeared as a line item in the

Presidential budget and the following August Congress appropriated three million dollars for the first year of VLA construction. The project was budgeted at 76 million dollars and was to be completed in 1981, with a basic funding rate of ten million dollars a year. During the period 1972-1973 the basic design of the VLA electronics system was conceived by S. Weinreb. Also during that time period the basic concepts of the on-line and off-line computer systems were formulated by B. G. Clark, R. M. Hjellming and W. R. Burns.

During 1972 NRAO began hiring VLA construction staff, J. H. Lancaster was named program manager, initial items were procured and contracts let. E-Systems was selected as contractor for the 28 antennas (27 in normal operation with one undergoing regular maintenance). By this time the design of the electronics system had evolved to the point in which operation at four wavelength ranges, 18-21 cm, 6 cm, 2 cm, and 1.3 cm, was planned. Both continuum and spectral line work was envisioned and four different configurations of the 27 antennas, designated A (35-km maximum dimension), B (11-km), C (3.5-km), and D (1-km), were chosen.

In April 1974 the initial site and wye construction began. Next July construction began on the first two antennas, with delivery in late 1975. The antenna assembly building was completed in January 1975 and the first antenna transporter finished in July. Single-dish tests started on antenna 1 in August 1975 and on antenna 2 in October. Computer control of these antennas, initially located on stations W10 and W18, with 1.1-km separation, was implemented in the last half of 1975. The on-line computer system, and all electronics not located on the antennas, were housed in a trailer near W10. A second trailer provided offices for the-on-line computer group. The only other VLA working area was the technical services building.

On February 18, 1976 the first "fringes" (interferometer signals) were obtained from antennas 1 and 2. By June 1976 the control building and the cafeteria were finished and transfer of equipment and personnel to these buildings began. Antenna 3 was functioning in the array, located on the southwest arm, in September 1976. At this point the pace of events was accelerating rapidly, with a new antenna being delivered roughly every seven weeks. On November 12-15, 1976 the first astronomy program was scheduled and carried out with four antennas functioning at 6 cm, two antennas functioning at 21 cm, two antennas functioning at 2 cm, and three antennas functioning at 1.3 cm. By late spring 1977 a characteristic pattern of two antennas functioning in a test subarray, and four or more antennas operating at the same time in a subarray devoted to astronomical programs, was well-established. The first map of an extended source was made May 24, 1977 when the planetary nebula NGC 40 was mapped at 6 cm, using 6 to 7 antennas, by B. Balick, R. M. Hjellming and R. C. Bignell.

By early 1978 the array was scheduled for astronomical observing roughly half of the time so that operations at the site were a mixture of scientific observing and construction of the remaining antennas, electronics, railroad, and computer systems.

The last antenna, Number 28, was accepted on November 19, 1979, and by the middle of 1980 all antennas had been made operational. Formal dedication of the array occurred October 10, 1980. By that time astronomers were regularly observing with nearly all 27 antennas, and the normal cycle of always working on maintenance of one antenna out of 28 in the antenna assembly begun. Regular operation of the entire array as a continuum and spectral line instrument dominated the activities at the VLA site by early 1981. The final construction budget for the VLA was $78.3 million, only slightly above the $76 million planned in 1972.

2. THE VLA SITE BUILDINGS

Figure 1-1 shows photographs which give a panoramic view of the major buildings located at the VLA site. Most of these pictures were taken from the middle of the entrance road in front of the VLA control building. In the top picture the tall building in the left background is the antenna assembly and maintanence building, the trailer to the far left is the "bunkhouse" trailer used for back-up rooms when the visiting scientist's quarters (VSQ) are full, the building in front of the antenna assembly building is the technical services building with labs and offices, and the warehouse buildings are beyond the buses used for transportation between Socorro and the VLA. In the background are antennas west of the buildings. The middle picture in Figure 5-1 shows shows part of the VLA control building to the right, the office and library building (which also contains the VAX post-processing computers) in the background, and the area in front of the VLA control building with flagpole, sculpture, etc. The bottom picture is again a view from the entrance road with, from left to right, a portion of the office and library building, the control building, the cafeteria, and portions of the visiting scientists quarters (VSQ).

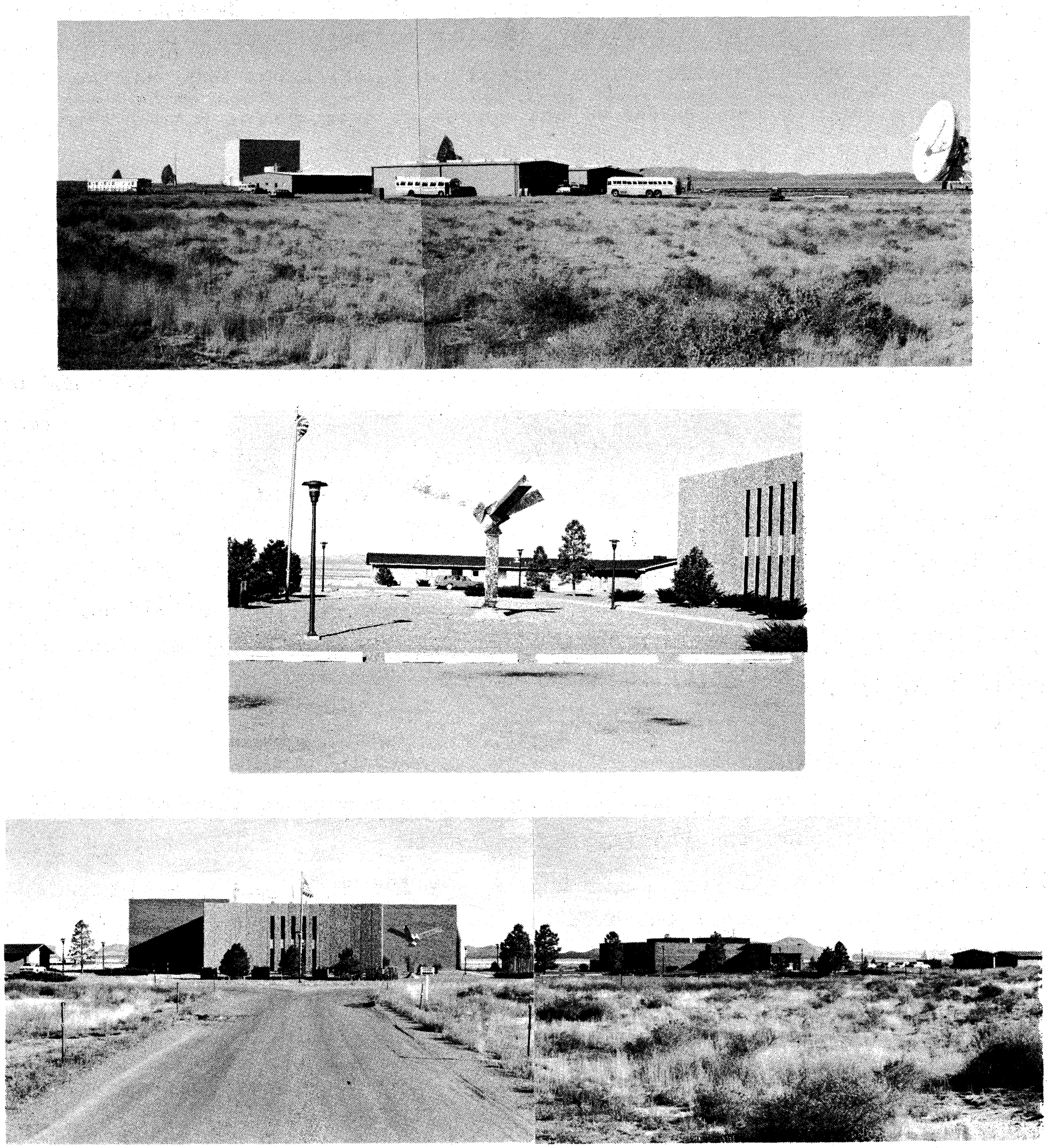

Figure 1-1. Photographs giving a panoramic view of the VLA buildings. The top picture, taken from the main entrance road, shows the bunkhouse trailer at the left, then the antenna assembly building, technical services building, and warehouse buildings. The center picture shows the sculpture in front of the control building, with the library/office building in the background. The bottom picture shows the control building, cafeteria, and visiting scientist quarters as viewed from the entrance road.

3. THE BASIC ANTENNA

The antennas constructed for the VLA were specially designed for VLA use. The mounts for each antenna are altazimuth and fully steerable. The reflector surfaces are 25 meters in diameter and are shaped with high-surface accuracy to optimize antenna efficiencies when used in the Cassegrain mode for wavelengths ranging from 1.3 cm to 21 cm. As seen in Figure 1-2, the base of each antenna is triangular, with sides of length 9.75 metres, with each corner having built-in bolts that mount on concrete foundation pedestals when located at an antenna station and on plates on an antenna transporter while being moved. Figure 1-3 shows an antenna transporter in action, moving an antenna along the twin railroad tracks that constitute the antenna transportation system. Table 1-1 contains some of the major design and performance parameters for the basic VLA antennas.

4. THE ANTENNA FEED SYSTEM

The importance of allowing a number of different frequencies to be operational on the VLA antennas at any one time and the desirability of higher aperture efficiencies and lower spillover temperatures led to a Cassegrain feed system for the VLA antenna. An overall view of this system is shown in Figure 1-4 with a close-up of the feeds shown in Figure 1-5. The subreflector is located on a movable mount at the prime focus of the main reflector. The asymmetric subreflector has a hyperbolic surface which rotates under computer control so that, with the main beam aligned on the electrical axis of the antenna, incoming radiation is focused on a point on a circular ring of possible positions at the Cassegrain focus. In this geometry, the phase gradient across the aperture of the main reflector due to the feeds being off-axis is exactly cancelled by a phase gradient introduced by the tilt of the subreflector. The feed ring has a radius of 98 cm with respect to the main reflector axis with the relative locations of the initial four feeds around the feed circle defined by the angles 6, 25, 135, and 335 degrees for the 1.3, 2, 18-21, and 6 cm feeds, respectively.

The choice of 1.3, 2, 6, and 18-21 cm as the main observing bands for the VLA was determined by a combination of technical and astronomical considerations. The prime consideration was the location of the radio astronomy protected bands and the various atomic and molecular lines associated with these bands as shown in Table 1-2.

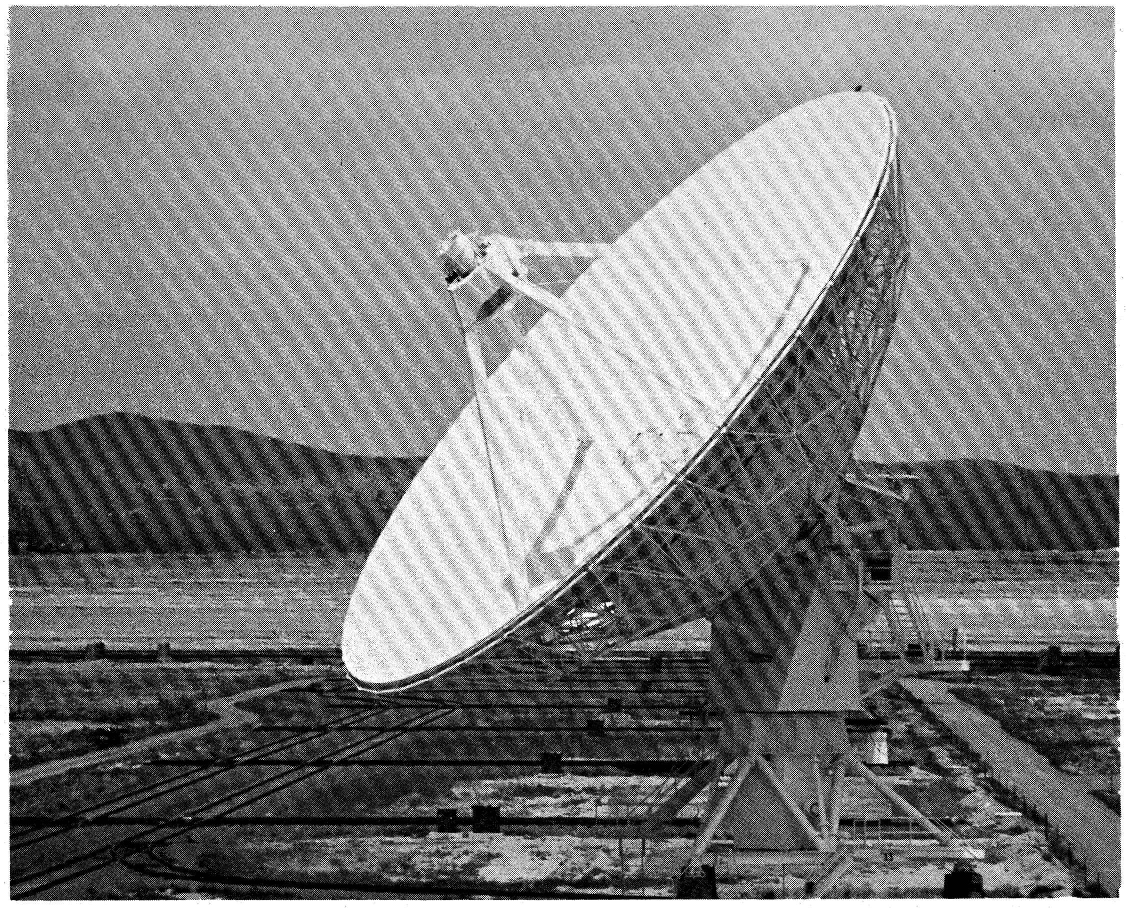

Figure 1-2. A photograph of a VLA antenna, showing the Cassegrain focus system, supporting structures, and the triangular antenna base mounted on three concrete pedestals. The tracks leading to other stations are seen beyond this antenna, and the twin railroad tracks of the southwest arm are seen at the lower left.

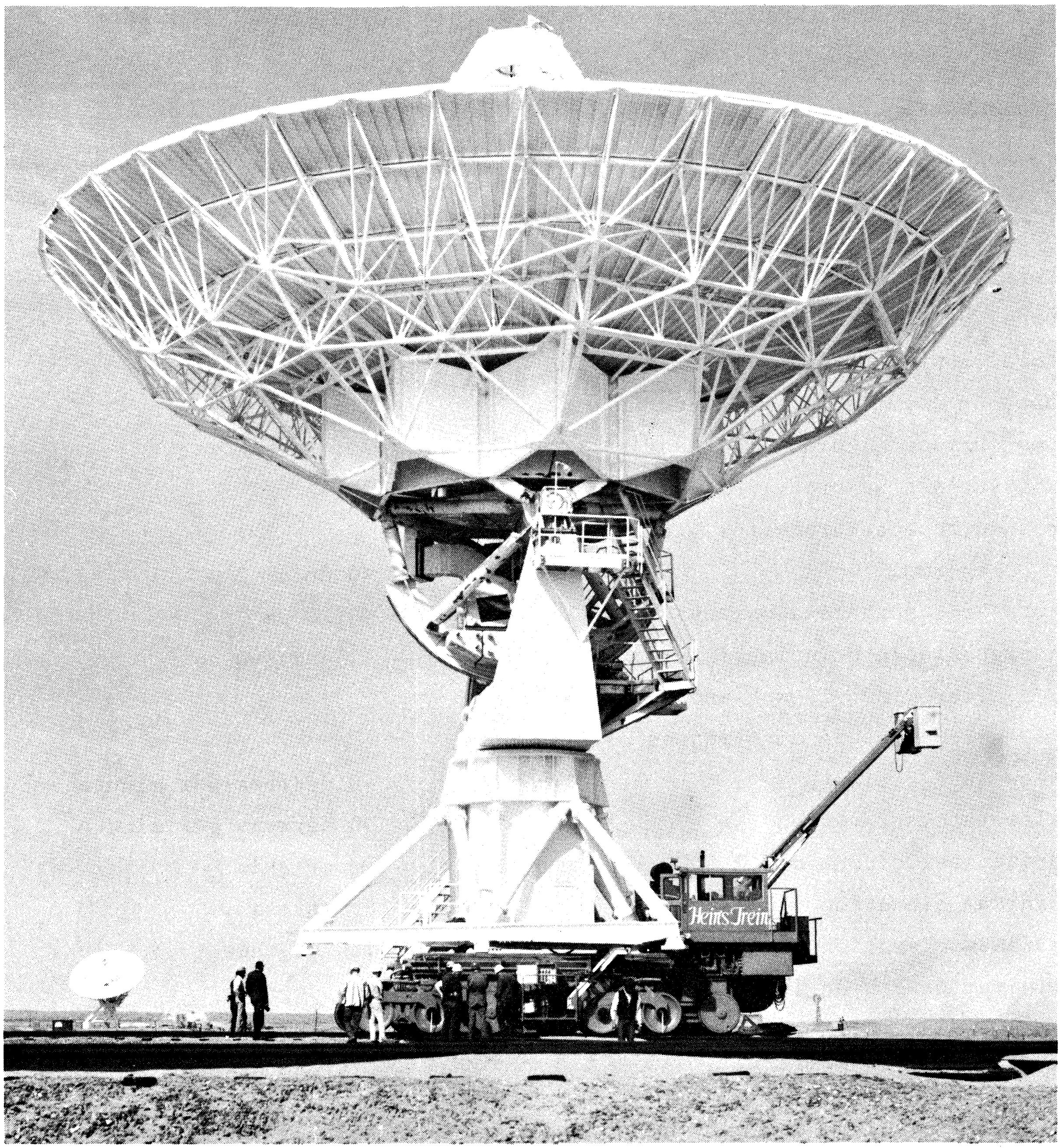

Figure 1-3. One of the VLA transporters moving a VLA antenna along the twin-railroad track that is the basis of the antenna transportation system.

TABLE 1-1

VLA ANTENNA PARAMETERS

main reflector diameter	25 m (82 feet)
antenna half-power beamwidth	~1.5 λ (λ in cm)
antenna beamwidth between first nulls	~3.6 λ
total geometric aperture	491 square metres
focal length of main reflector	9 m
maximum asymmetric subreflector width	1.83 m
rms surface accuracy for panels	<0.38 mm
rms surface accuracy for panel setting	<0.46 mm
rms surface accuracy for gravity, wind, thermal	<0.36 mm
total rms surface accuracy	<0.70 mm
nonrepeatable pointing errors (for wind <15 mph and <5 degree temperature differences of structure)	<15 arcsec
slew rate, azimuth	40 degrees per minute
slew rate, elevation	20 degrees per minute
drive, servo controlled 5 hp motors	2 per axis
minimum elevation	8 degrees
maximum elevation	125 degrees
minimum zenith angle for tracking	0.5 degrees
azimuth limits relative to track azimuth	±270 degrees
total weight of antenna	419,000 pounds
resonant frequency, torsional	2.2 Hz
resonant frequency, rocking	2.3 Hz
wind speed limits: precision operation	<15 mph
normal operation	<45 mph
survival at stow (snow/ice load 20 lbs per square foot)	<110 mph

Nominal antenna efficiencies for the four wavelength ranges are 50%, 65%, 54%, and 46% for 18-21, 6, 2, and 1.3 cm, respectively. The observing feed is changed by rotating the asymmetric subreflector about the main reflector axis so that the secondary focal point moves around the feed circle to the required feed. The time needed to rotate the subreflector between feeds is proportional to the angle between feeds measured around the feed circle. The longest travel time is the 25 seconds needed to rotate from the 6 cm feed to the 18-21 cm feed.

The 18-21 cm feed, which is the largest feed visible in Figure 1-5, (on the left), is a corrugated horn illuminating a hybrid lens of dielectric and in waveguide elements (short circular tubes). Because this feed is large and lies in the near field of the primary aperture, the lens and waveguide elements are necessary to focus the wave on the corrugated horn.

The 6-cm feed is also a corrugated horn. The 2- and 1.3-cm feeds are the more conventional pyramidal multimode horns. All feeds have changeable polarizers at their outputs so that either dual orthogonal linear polarization or right-hand and left-hand circular polarization can be provided. Changing polarizers takes roughly twenty minutes per feed per antenna. The normal observing mode for all feeds is circular polarization.

Measurements of the polarization properties of the antennas show that the right-hand and left-hand circularly-polarized beams are separated by 0.06±0.005 beamwidths. The direction of this beam separation or "squint" is perpendicular to the plane containing the feed and the main reflector axis. The squint effect occurs at these levels because of the combination of a shaped main reflector and off-axis feed. With a pure paraboloid the effect would be smaller, and with on-axis feeds the squint would not occur. The existence of the squint effect has a negligible effect on linear polarization measurement - linear polarization sidelobes have a four-lobed pattern, rather than the two-lobed "squint" pattern. Similarly, there are only small effects for circularly-polarized sources at the center of the antenna beam; however, the measurement of circularly-polarized structure is seriously compromised because the squint effect couples the antenna pointing errors into the polarization measurements. Various means of eliminating the squint effect are under study for future implementation.

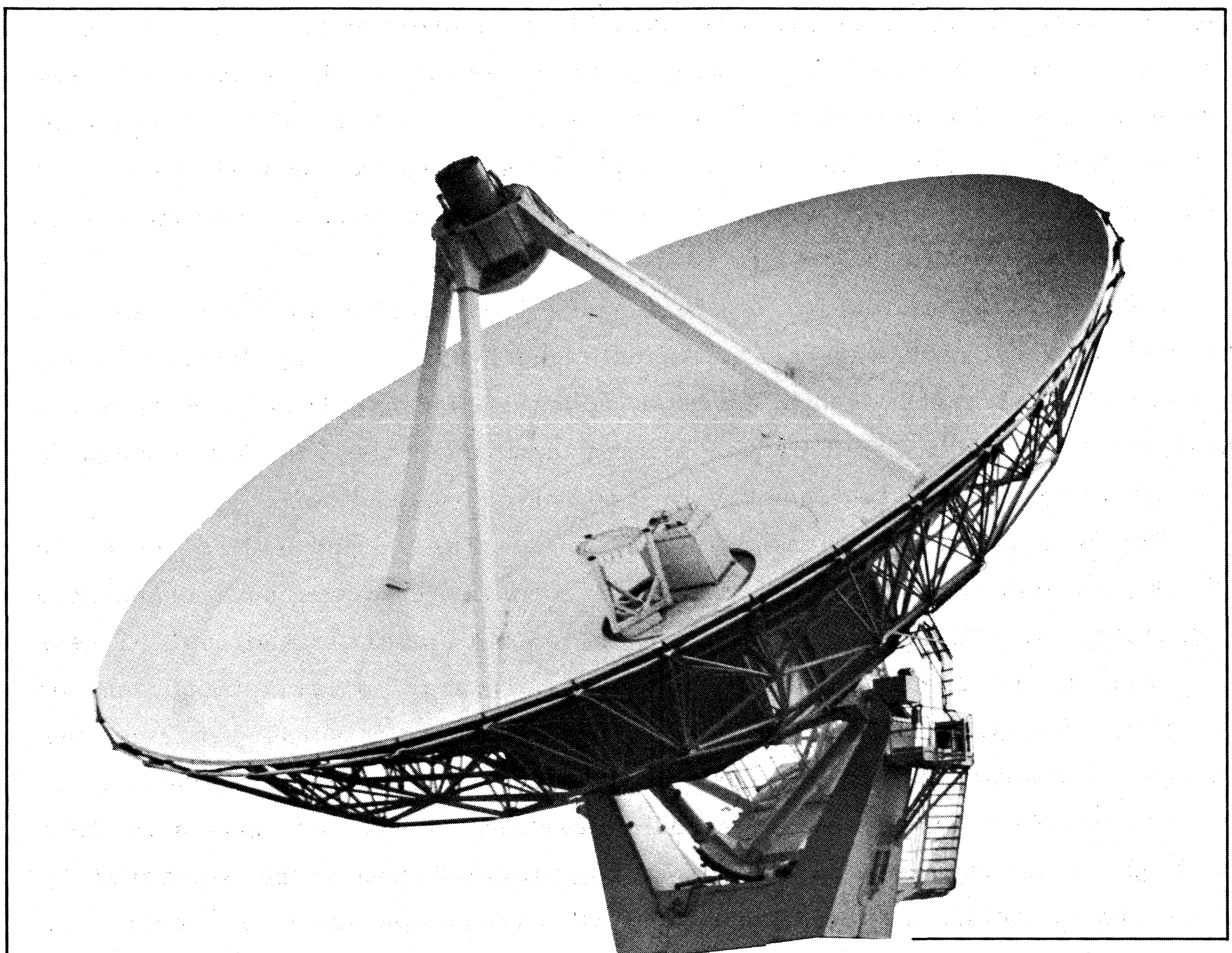

Figure 1-4. The Cassegrain system of a VLA antenna, showing the shaped parabolic reflector, a rotatable subreflector on a movable mount supported by four feed legs, and the four feeds on the feed ring at the Cassegrain focus.

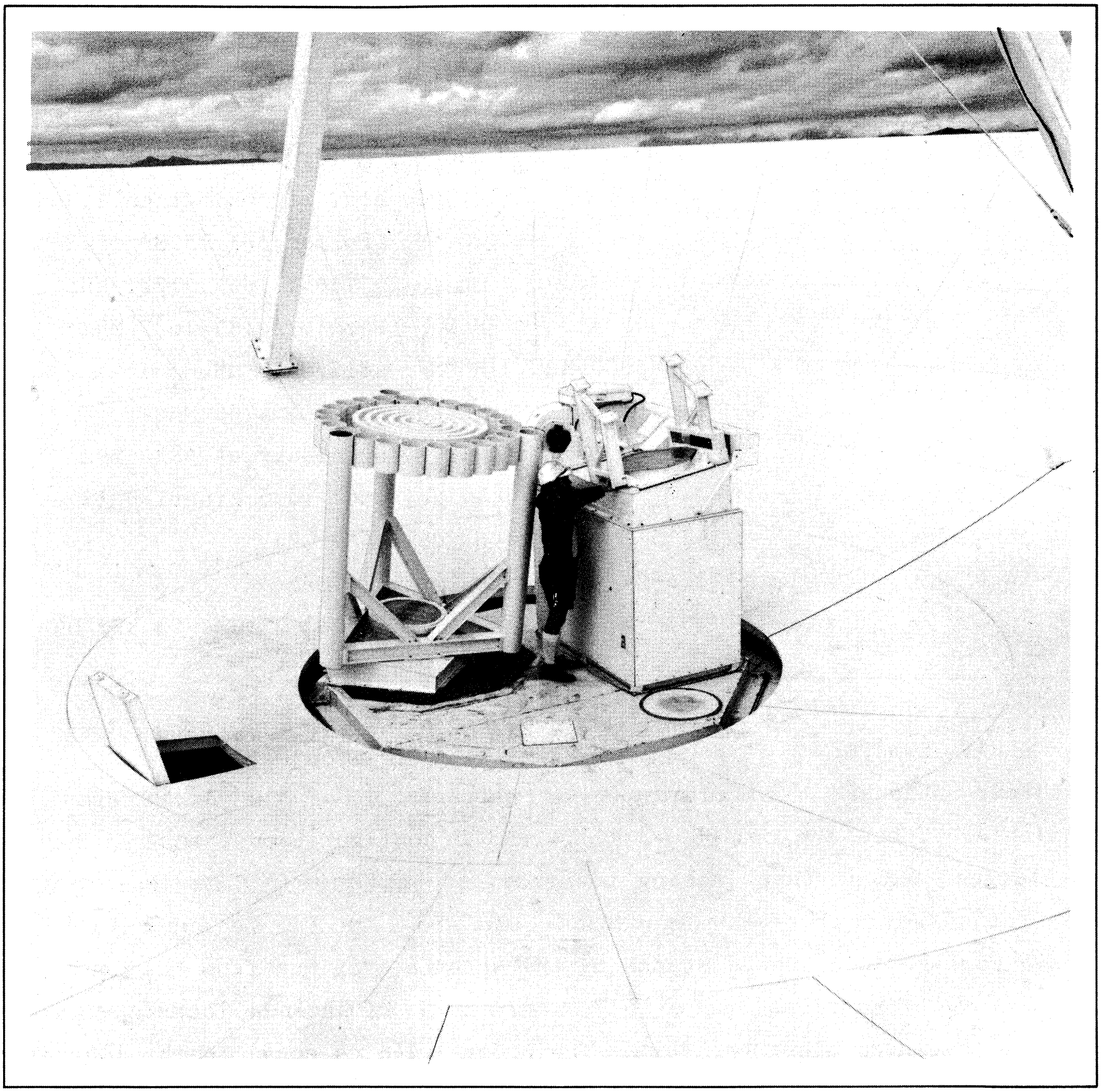

Figure 1-5. Photograph of a VLA feed system with 18-21 cm lens and feed at the left and a man working on the area where 6 cm, 2 cm and 1.3 cm feeds are located at the right.

TABLE 1-2

VLA OBSERVING BANDS AND ASSOCIATED LINES

VLA Band Frequency	VLA Band Wavelength	Protected Band	Atomic and Molecular Lines
1340-1730 MHz	18-21 cm	1400-1427 MHz	Neutral H (Hydrogen) 1420.4 MHz
			H, He, etc. recombination lines
			$HCONH_2$ (Formamide) 1538- 1542 MHz
			OH 1612, 1665, 1667, 1721 MHz
			HCOOH (Formic Acid) 1639 MHz
4500-5000 MHz	6 cm	4990-5000 MHz	$HCONH_2$ 4617-4620 MHz
			OH 4660, 4751, 4766 MHz
			H_2CO (Formaldehyde) 4830 MHz
			H, He, etc. recombination lines
14.4-15.4 GHz	2 cm	15.35-15.4 GHz	H_2CO 14.489 GHz
22.0-24.0 GHz	1.3 cm	23.6-24.0 GHz	H_20 22.235 GHz
			NH_3 (Ammonia) 22.834-23.870 GHz

5. ARRAY GEOMETRY

Four standard configurations of antennas along the array arms are available. These are called A, B, C, and D configurations, with A having the largest extent (but lacking the shortest baselines). The locations of the stations for these configurations are shown in Figure 1-6. Within a single configuration the distance of the antenna stations from the center of the wye is proportional to $m^{1.716}$, where m is an antenna location number, counting outwards along each arm. The power 1.716 is equal to the logarithm to the base 2 of the scale factor between adjacent configurations (3.285). With this choice of power, the m^{th} station on any configuration coincides with the 2 m^{th} station on the next smaller configuration (see Table 1-3), requiring only 72 stations to handle all four configurations. This concept, and the fact that such power-law arrangements give good coverage in the u,v plane for a three-armed array, was due to Y. L. Chow.

Tables 1-4, 1-5 and 1-6 give the locations, and radial distances from the center, for the antenna stations on the southwest, southeast and north arms. Stations affiliated with each configuration are labeled with an "x"

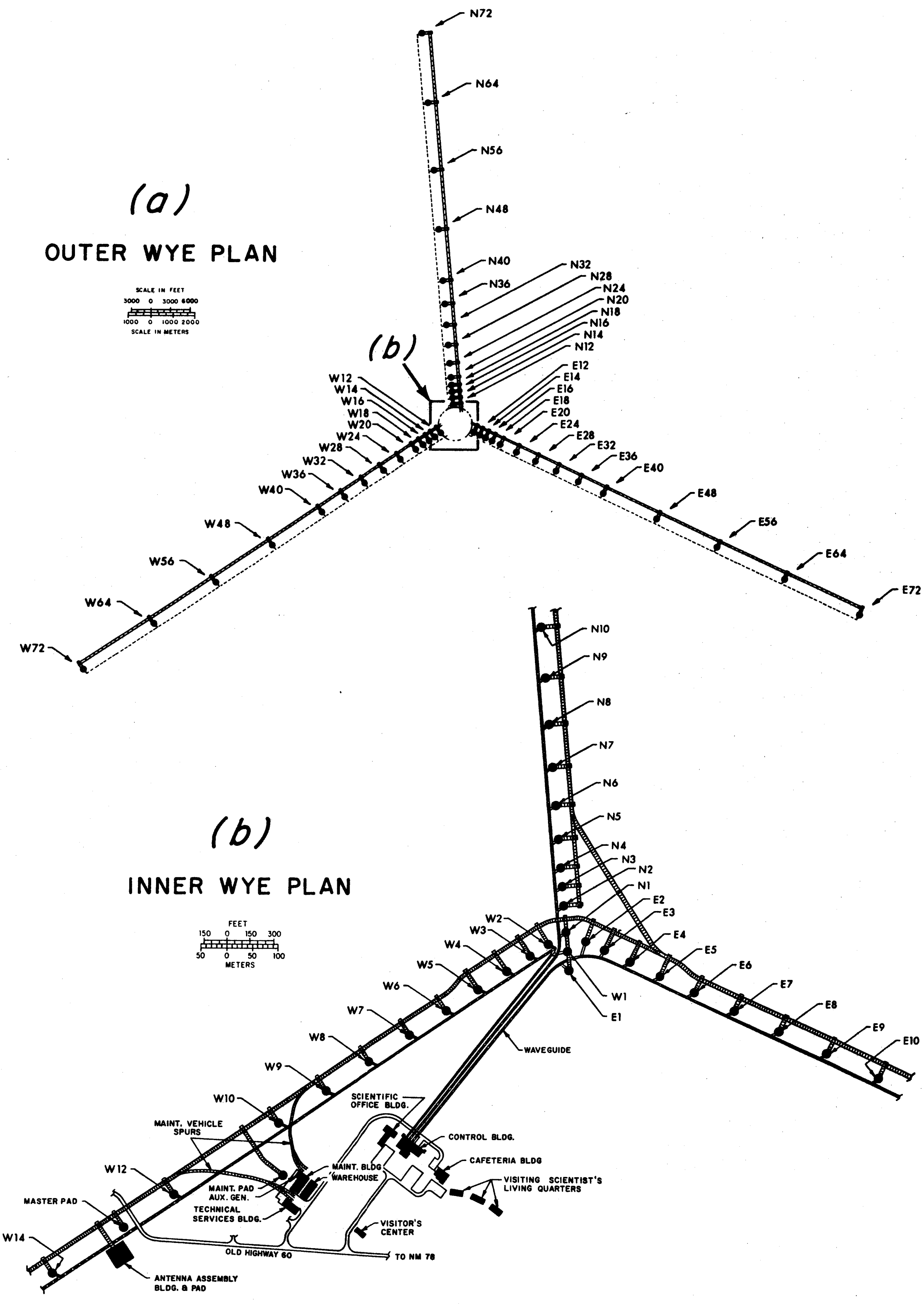

Figure 1-6. The outer (a) and innner (b) parts of the VLA.

in the appropriate columns in the tables. The stations are designated as Nn, En or Wn for the north, southeast and southwest arms. With this system of designation, stations Wn and En are approximately 13.65 $n^{1.716}$ meters from the center of the array, and stations Nn are approximately 12.31 $n^{1.716}$ meters from the center of the array.

TABLE 1-3

RELATIONSHIP BETWEEN CONFIGURATIONS AND STATIONS

Configuration	Station Number (n)		
D	n = 1, 2, 3, 4, 5, 6, 7, 8, 9	= m	
C	n = 2, 4, 6, 8, 10, 12, 14, 16, 18	= 2 m	m = 1,2...,9
B	n = 4, 8, 12, 16, 20, 24, 28, 32, 36	= 4 m	
A	n = 8, 16, 24, 32, 40, 48, 56, 64, 72	= 8 m	

In Tables 1-4, 1-5 and 1-6 the vector (L_x, L_y, L_z) describes a station location in nanoseconds (ns) and R(m) is the radial distance (in meters) from the center of the array to the station position. Baseline vectors, denoted by (B_x, B_y, B_z) are defined by $(B_{jk})_i = (L_k)_i - (L_j)_i$ where j and k are station numbers (k > j by convention) and i = 1, 2, 3, for x, y, z. The coordinates in these tables are accurate to within ±0.04 ns.

A few modifications of the ideal station positions have been made: (1) The north arm was scaled down by 19/21 to avoid a dry lake; (2) the outermost stations on the southeast arm deviate slightly to the north to avoid a ravine; (3) the D configuration station locations are slightly modified to avoid congestion near the array center by (a) putting the n = 1 stations of the southeast and southwest arms on a short southern extension of the north arm called the north arm spur, and (b) modified locations for stations N1 to N4; and (4) station N24 is moved 100 meters north to be farther from Highway US 60.

The azimuths of the arms are:

north arm	354°59'48"
southeast arm	114°59'42"
southwest arm	236°00'05"

The geodetic coordinates of the center of the array are:

latitude	34°04'43.497" north
longitude	107°37'03.819" west.

The height of the center point of the array is 2124 m above sea level and the height variations along the arms lie within ±32 m of this altitude.

TABLE 1-4

STATION POSITIONS FOR THE SOUTHWEST ARM

Station Name	Configuration A	B	C	D	Coordinates with array center as origin L_x(ns)	L_y(ns)	L_z(ns)	R(m)
W1				x	76.69	11.67	-108.36	39.95
W2			x	x	49.29	-123.87	-67.42	44.79
W3				x	96.46	-248.46	-136.94	89.83
W4		x	x	x	156.49	-407.06	-225.51	147.19
W5				x	228.83	-597.84	-331.98	216.18
W6			x	x	311.96	-817.22	-454.39	295.51
W7				x	405.70	-1064.49	-592.36	384.93
W8	x	x	x	x	509.53	-1338.54	-745.23	484.02
W9				x	623.12	-1638.19	-912.51	592.39
W10			x		747.12	-1962.88	-1093.09	709.81
W12		x	x		1021.28	-2683.76	-1494.63	970.49
W14			x		1328.35	-3496.20	-1948.61	1264.29
W16	x	x	x		1667.27	-4396.35	-2452.41	1589.80
W18			x		2040.62	-5381.34	-3002.15	1946.02
W20		x			2446.13	-6447.72	-3596.19	2331.63
W24	x	x			3353.71	-8816.08	-4910.74	3188.05
W28		x			4391.16	-11485.64	-6382.93	4153.44
W32	x	x			5470.50	-14443.13	-8061.25	5222.88
W36		x			6671.47	-17678.17	-9883.19	6392.71
W40	x				7988.65	-21181.36	-11844.80	7659.49
W48	x				10925.70	-28961.66	-16194.06	10473.00
W56	x				14206.44	-37731.09	-21114.62	13643.97
W64	x				17842.85	-47447.29	-26566.65	17157.45
W72	x				21802.57	-58074.16	-32540.96	21000.19

TABLE 1-5

STATION POSITIONS FOR THE SOUTHEAST ARM

Station Name	Configuration A	B	C	D	Coordinates with array center as origin L_x(ns)	L_y(ns)	L_z(ns)	R(m)
E1				x	151.26	23.33	-218.44	79.96
E2			x	x	37.71	135.65	-50.59	44.85
E3				x	73.37	271.95	-103.23	89.94
E4		x	x	x	118.76	445.77	-170.46	147.44
E5				x	173.02	653.27	-250.51	216.07
E6			x	x	235.66	893.16	-343.18	295.42
E7				x	305.29	1163.76	-448.46	384.93
E8	x	x	x	x	381.68	1463.33	-565.35	484.02
E9				x	465.79	1790.89	-692.95	592.38
E10			x		558.29	2145.87	-830.16	709.79
E12		x	x		765.39	2933.01	-1133.62	970.21
E14			x		999.66	3822.35	-1475.27	1264.33
E16	x	x	x		1257.45	4806.65	-1855.04	1589.92
E18			x		1548.02	5883.17	-2264.55	1946.03
E20		x			1868.27	7049.02	-2704.15	2331.68
E24	x	x			2552.45	9638.20	-3698.88	3188.13
E28		x			3331.17	12556.45	-4814.90	4153.44
E32	x	x			4180.34	15789.68	-6060.60	5222.93
E36		x			5118.75	19326.37	-7416.80	6392.82
E40	x				6127.38	23156.24	-8890.33	7659.65
E48	x				8324.92	31661.66	-12190.73	10472.93
E56	x				10813.96	41248.78	-15902.56	13644.00
E64	x				13620.16	51870.75	-19982.12	17157.37
E72	x				16204.22	63678.31	-24269.82	20999.45

TABLE 1-6

STATION POSITIONS FOR THE NORTH ARM

Station Name	Configuration A	B	C	D	Coordinates with array center as origin L_x(ns)	L_y(ns)	L_z(ns)	R(m)
N1				x	2.24	0.05	1.71	0.84
N2			x	x	-100.24	-15.93	152.45	54.91
N3				x	-174.91	-27.56	262.39	94.90
N4		x	x	x	-249.59	-39.15	372.31	134.89
N5				x	-361.68	-56.66	537.09	194.86
N6			x	x	-495.22	-77.43	733.79	266.41
N7				x	-645.82	-100.90	955.52	347.07
N8	x	x	x	x	-812.58	-126.88	1200.98	436.37
N9				x	-995.39	-155.53	1469.71	534.19
N10			x		-1193.00	-186.06	1760.66	640.
N12		x	x		-1632.09	-254.47	2406.72	875.11
N14			x		-2126.47	-331.52	3135.28	1140.07
N16	x	x	x		-2673.19	-416.88	3943.10	1433.62
N18			x		-3271.25	-510.29	4826.72	1754.71
N20		x			-3917.13	-611.39	5784.82	2102.44
N24	x	x			-5538.93	-865.16	8187.02	2974.68
N28		x			-6976.44	-1089.30	10305.16	3745.05
N32	x	x			-8769.76	-1369.81	12961.02	4709.44
N36		x			-10732.66	-1677.65	15864.79	5764.25
N40	x				-12857.81	-2009.03	19009.59	6906.45
N48	x				-17583.09	-2747.09	25991.26	9443.50
N56	x				-22918.88	-3578.90	33852.66	12302.77
N64	x				-28827.03	-4500.61	42565.13	15470.70
N72	x				-35282.55	-5508.69	52098.85	18935.62

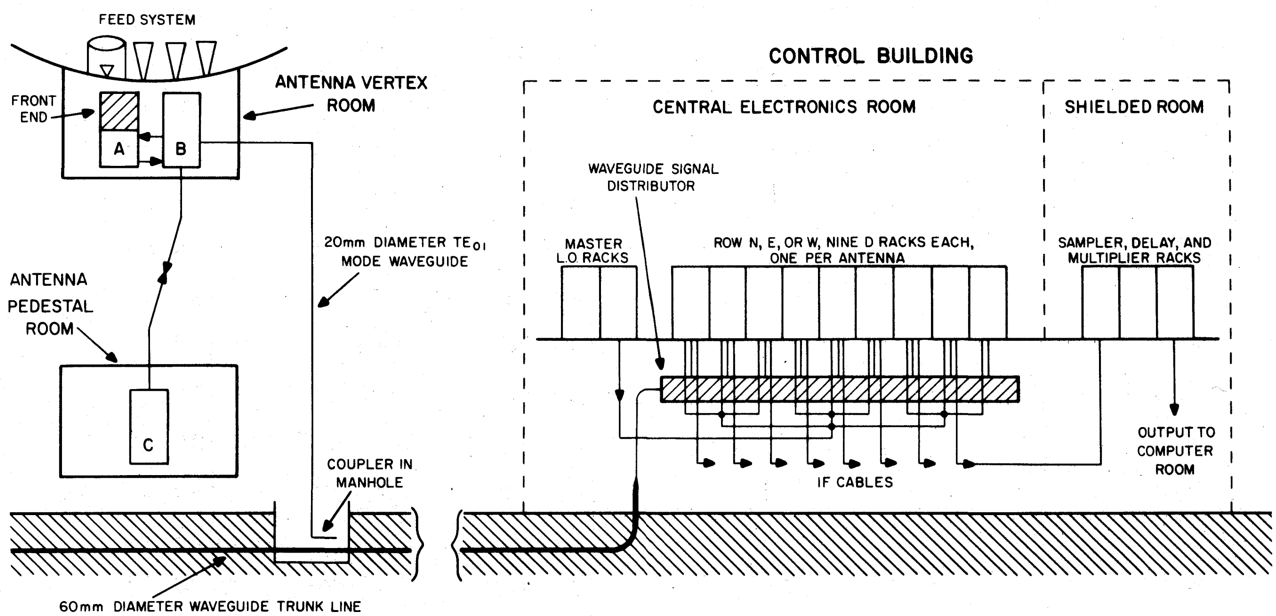

Figure 1-7. Schematic diagram showing the major locations of VLA electronics equipment, including details of the waveguide communications system and the signal distribution system located under the racks in the control building.

6. LOCATION OF MAJOR SYSTEM COMPONENTS

Although we will discuss the electronics and waveguide systems in greater detail in later sections, let us briefly introduce some of the major components of the system.

Figure 1-7 illustrates some of the major components of each antenna, the waveguide communications system and the electronics located at the antennas and in the control building. Rack A contains the front end and cryogenic cooling system for the front ends. Rack B contains portions of the local oscillator (LO) and IF equipment. Both Racks A and B are suspended from the central portion of the main reflector inside a temperature-controlled vertex room. Waveguide from the feeds connect directly to Rack A. Rack C is the antenna control unit (ACU) located in the antenna pedestal room at the base of the antenna. It accepts position commands passed by Rack B and controls the antenna drive motors. Each antenna communicates back and forth to the control building via a 20-mm waveguide connected from Rack B to a buried 60-mm waveguide. Each arm of the array has a single section of buried 60-mm waveguide in which control information and antenna data are transmitted for up to eleven antennas.

Inside the control building the waveguide signals are distributed to Racks D. Each Rack D communicates with the corresponding Rack B at an antenna through the waveguide system. All local oscillator, IF, control and monitor signals are transmitted back and forth by way of this system. IF signals for each antenna are sent from a Rack D, by cable, to the shielded room where the sampler and delay and multiplier racks are located. The resulting cross- correlated signals from the multipliers are transmitted to the computer room where they are processed into ten-second visibility measurements in the on-line computers. The same on-line computer system controls the array by sending signals to each antenna via the waveguide communications system. The computer room in the control building contains, in addition to the on-line computer system, an off-line computer system for subsequent display, editing, correcting, and calibration of visibility data, plus capabilities to prepare maps and display them.

Further details on this system and the remaining equipment not yet mentioned will be discussed in later chapters.

Chapter 2

THE THEORY OF THE INSTRUMENT

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April 1982 Edition

ABSTRACT

The theoretical, geometrical, and mathematical basis of the VLA is discussed. The major goal of this Chapter is to derive or define the basic equations describing the properties of the instrument, particularly the equations of calibration and image construction.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. INTRODUCTION

An astronomer who wishes to use the VLA to study radio sources needs to know the basic principles of interferometry and aperture synthesis. The purpose of this chapter is to provide a basic introduction to these subjects with specific application to the VLA interferometers and aperture synthesis. The approach in this chapter will be dominantly theoretical. Further practical aspects of VLA interferometry and aperture synthesis are discussed in other chapters.

The basic process of interferometry is the cross-correlation of signals from two antennas observing the same source. A pair of antennas operated in this manner is called an interferometer. The signal output is analogous to the interference pattern created by a light wave passing through two slits. With N antennas there are N(N-1)/2 possible interferometers; therefore, there are 351 simultaneous interferometers in the full 27-antenna VLA. Radio interferometric measurements are considerably more complicated than the simple measurement of the radio frequency (RF) power received by the antennas. The cross-correlation of the signals from two antennas produces partial information about not only the intensities of all sources in the beams of the antennas, but also information about their positions in the sky relative to the position at which the interferometers are being "pointed". Because of the importance of time delays, antenna locations, and source position information, we will be very concerned with the geometry and coordinate systems involved in observing.

Any distribution of radio emission in an antenna beam can be considered to be the superposition of a large number of components of different size scales, locations and orientations. Because the relation between intensity distributions and the components can be described in terms of a Fourier integral relationship, it is useful to keep in mind that a single interferometer pair is at any instant measuring a single Fourier component of the apparent angular distribution of sources in the antenna beam. The essential characteristic of aperture synthesis in radio astronomy is the measurement of a large number of Fourier components of a radio source needed to reconstruct an image of the spatial intensity distribution of a source. The changing geometric relationship between the antenna pairs on the rotating earth and the radio source in the sky, allows us to measure N(N-1)/2 different Fourier components (for N antennas) each instant, for many instants. Due to the importance of earth rotation in allowing a large number of Fourier components to be sampled without adding more antennas, or moving antennas around physically, this technique is frequently called earth-rotation aperture synthesis.

The statements made so far about interferometry and aperture synthesis will be readily understood only by those experienced in these areas. Consequently, the purpose of Chapter 2 is to provide a thorough basis for understanding these subjects. We will begin by defining some fundamental concepts and continue by covering most of the things that are essential to an understanding of interferometry and aperture synthesis with the VLA. An excellent reference to most of the subjects in this chapter is the article on "Interferometry and Aperture Synthesis" by E. B. Fomalont and M. H. Wright ["Galactic and Extragalactic Radio Astronomy", ed. G. L. Verschuur and K. I. Kellermann, Springer-Verlag (New York), 1974, Chapter 10].

2. SOME DEFINITIONS

In observing with N(N-1)/2 interferometer pairs, we point each of the N antennas at a particular point in the sky with a specified right ascension (α_o) and declination (δ_o). This position is normally both the antenna pointing position and what we will call the reference position. This reference position is defined as the position in the sky with respect to which all timing and compensation for the delay in arrival of the same wavefront is referred. The position of a general point in the field of view, (α,δ), is frequently described with respect to the reference position in terms of a vector displacement $(\alpha-\alpha_o,\delta-\delta_o) = (x,y,z)$. The z component is along the line of sight. Note that we have used the phrase "field of view" to describe the primary region of the sky to which the antennas are sensitive; this is important because we are not just collecting information about the total radiation in the antenna beam; rather we are collecting information about the strengths and positions of all radio sources in the field of view. We will discuss the field of view mainly in terms of the antenna half-power beamwidth (Θ_{HPBW}) which is approximately

$$\Theta_{HPBW} \simeq 1.5\,\lambda_{cm}\ (\pm 5\%) \quad \text{arcminutes} \tag{2-1}$$

where λ_{cm} is the observing wavelength, and we have used the fact that all the VLA antennas are 25 meters in diameter. Another relevant angle is the beamwidth between first nulls (Θ_{BWFN}) approximately given by

$$\Theta_{BWFN} \simeq 2.4\, \Theta_{HPBW} \simeq 3.6\, \lambda_{cm} \qquad \text{arcminutes} \tag{2-2}$$

A schematic representation of these angles with respect to the antenna beam pattern is shown in Figure 2-1 where we show an antenna beam with its radiation axis aligned with the unit vector $\underset{\sim}{s}_o$, pointing to the reference position (α_o, δ_o) on the celestial sphere. (Unit vectors will be denoted by small letters.) We also show in Figure 2-1 a section of the celestial sphere, the tangent plane at the reference position and a general point on the celestial sphere. This is because, for the VLA operating at its larger dimensions, the deviations of the tangent plane from the celestial sphere will be significant in the outer regions of the antenna field of view. For a unit vector $\underset{\sim}{s}$ pointing at a general point in the field of view, we must in general write $\underset{\sim}{s} = (x,y,z)$ in a Cartesian representation, and only when deviations of the tangent plane from the celestial sphere can be neglected, can the usual

$$\underset{\sim}{s} \simeq [(\alpha-\alpha_o) \cos \delta_o, \delta-\delta_o, 0] \tag{2-3}$$

be written. The more general Cartesian expression for $\underset{\sim}{s}$ will be discussed after coordinate systems have been more explicitly defined.

During normal observing the antennas are pointed under computer control to track the reference position $\underset{\sim}{s}_o$. All observing consists of tracking a particular α_o and δ_o as a function of time. The fundamental time used at the VLA is International Atomic Time, abbreviated IAT, and all other times, including local apparent sidereal time (LAST or LST), are derived from IAT. The hour angle (H) for a source at right ascension α is defined as

$$H = LST - \alpha \tag{2-4}$$

so a point east of the local meridian has a negative H and a source west of the local meridian has a positive H.

All earth-oriented coordinates are referred to with respect to the center of the array at geodetic coordinates

$34^\circ 04' 43''\!.497$ north latitude

$107^\circ 37' 03''\!.819$ west longitude

or a local zenith with a declination $34^\circ 04' 43''\!.497$ on a local meridian at $7^h 10^m 28^s\!.2546$. Local MST (Mountain Standard Time) = GMT - 7^h ≃ UT - 7^h.

For astrometric programs demanding extremely good phase stability, for accurate flux density measurements, and for large dynamic range mapping, more stringent calibration procedures may be necessary.

C. Lists of Phase and Amplitude Calibrators

One can obtain information about phase and amplitude calibrators from the Calibrator Manual. This manual has four sections. You may obtain a printed copy of any section by following the instructions at the beginning of the Calibrator Manual. Calibrators are sometimes not good for all bands, configurations, and purposes. Study the limitations of the calibrators near your sources and carefully choose which you think are optimum. One need not supply positions for sources in the Calibrator Manual because they will read in by the OBSERV program (from a calibrator information file) when the calibrator name is given.

D. Planning u-v Coverage

The number of antennas available at a particular frequency may vary from day to day. Because of malfunctions one or two antennas may be down during any particular observation. The maximum possible u-v plane coverage for a 27-element array is shown in Figure 5-1. Several synthesized beam shapes are shown in Figure 5-2. With the "CLEAN" and self calibration programs one may not need extensive u-v coverage to obtain quality maps. One of the most important considerations in choosing the amount of observing time is signal-to-noise ratio (SNR). Once the SNR is greater than 10 or so on a map feature of interest, the CLEAN algorithm can remove the sidelobes of the beam produced by limited u-v coverage. To successfully apply self calibration, which can remove some phase errors, one must have a good SNR, on cell-to-cell basis in the u-v plane, and not just a good SNR on a feature in the final map. The definition of a good SNR in the u-v data for self calibration is complicated. Very extended features can cause problems both for CLEAN and self calibration. An inexperienced observer should contact a VLA staff scientist for advice.

The maximum and minimum sidelobe levels of a synthesized beam are major indicators of image quality. These levels for the 27-element observing situations corresponding to Figure 5-1 are listed Table 5-1. In addition, Table 5-2 shows sidelobe levels for various tracking ranges for a source with 30° declination.

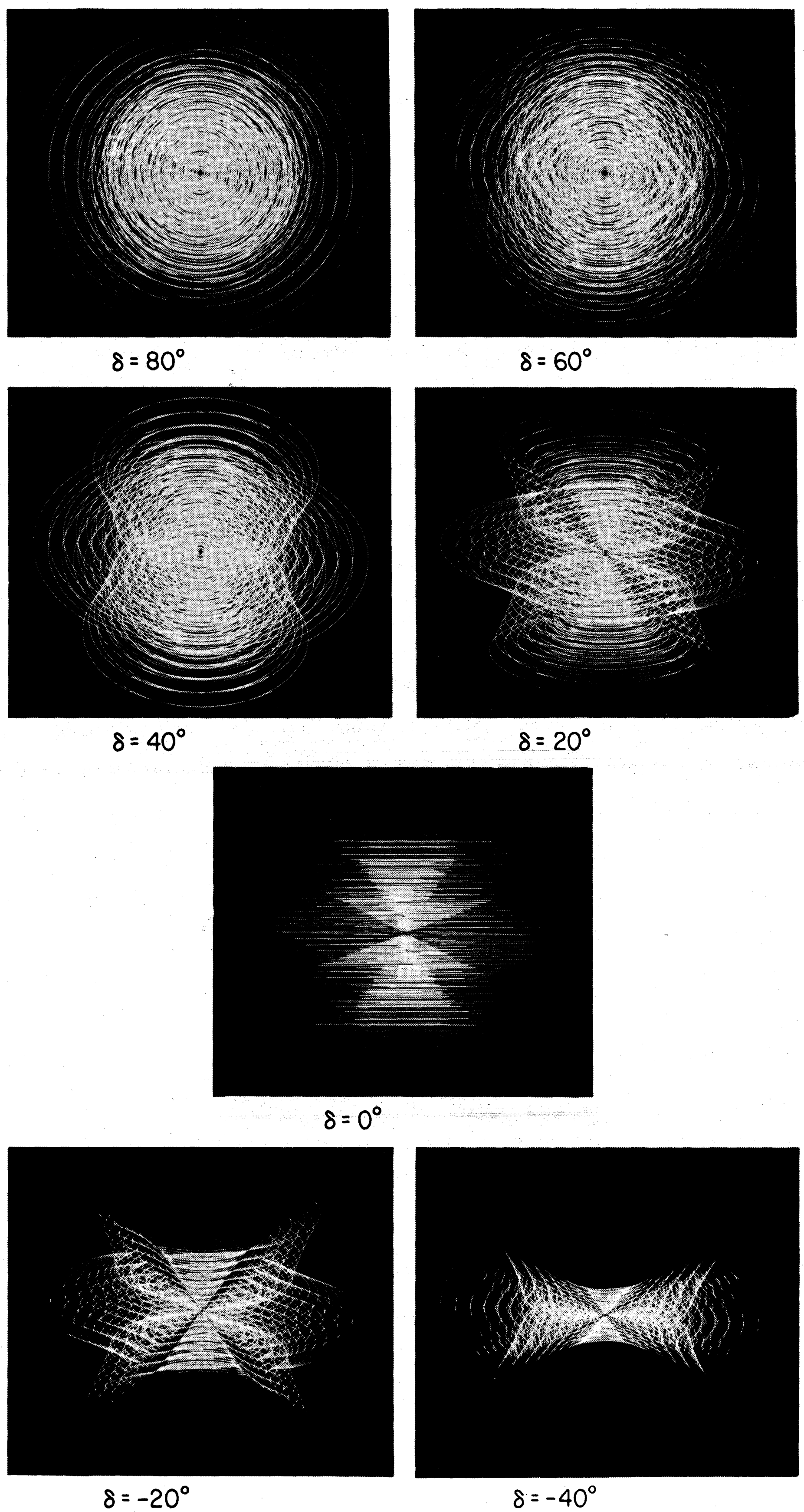


Figure 5-1. The possible u-v plane coverage for the 27-antenna VLA for declinations of 80°, 60°, 40°, 20°, 0°, -20°, and -40°.

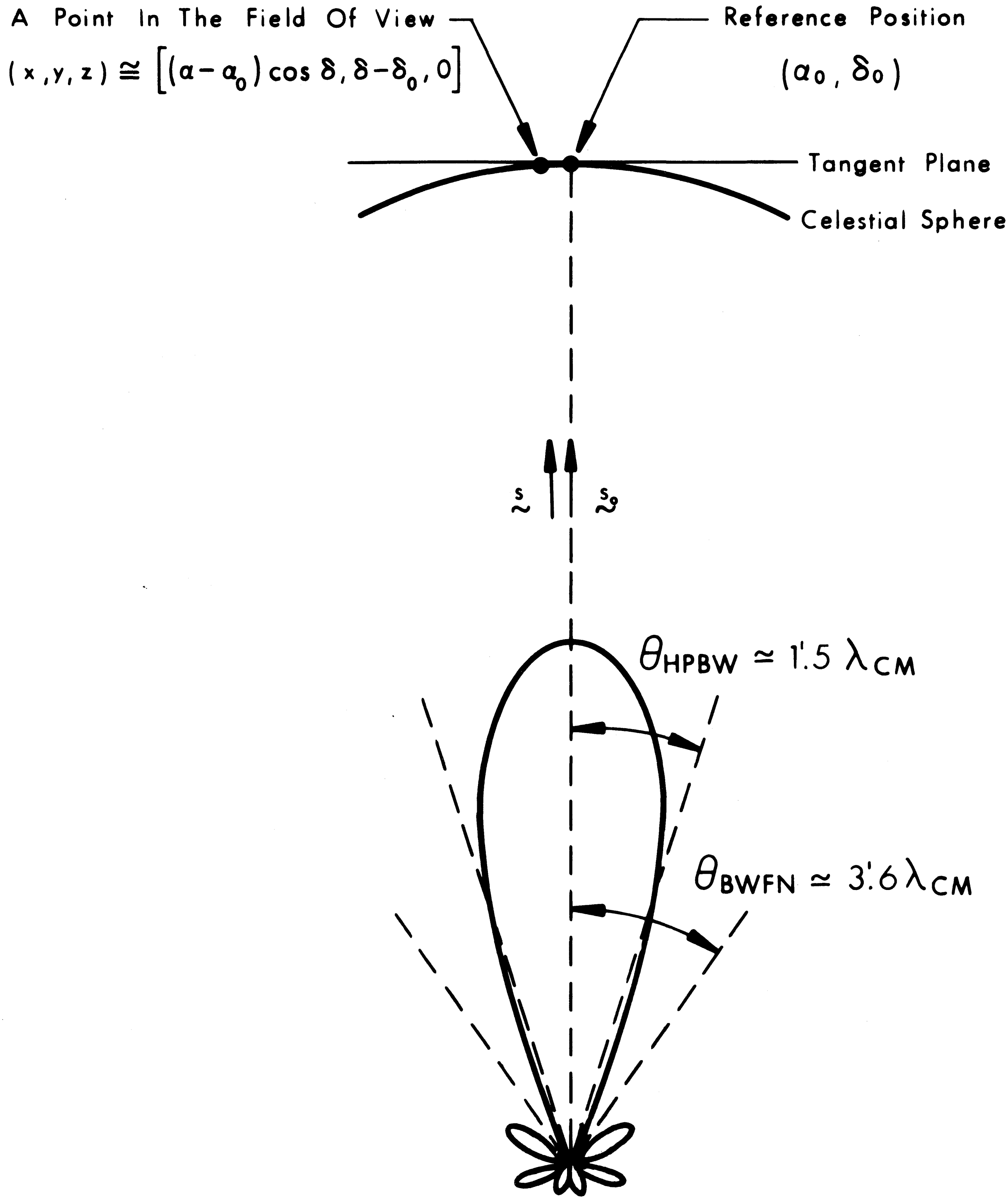


Figure 2-1. A schematic diagram showing the relation between an antenna beam pattern, pointed at the reference position, and positions on the celestial sphere and its tangent plane.

3. INTERFEROMETER RESPONSE TO A POINT SOURCE

We begin with a discussion of the special case where VLA antennas track a region of the sky containing a strong point source which completely dominates the radiation received by the antennas. Let us define

$\underset{\sim}{s}_o$ = unit vector pointing along the radiation axis of each telescope to the reference position (α_o,δ_o)

$\underset{\sim}{s}$ = unit vector pointing to the position of a point source at (α,δ)

$\Delta\underset{\sim}{s}$ = $(\underset{\sim}{s}-\underset{\sim}{s}_o)$ = vector displacement on celestial sphere $\{\simeq[(\alpha-\alpha_o)\cos\delta_o,\ \delta-\delta_o, 0]$ on tangent plane$\}$

ν,λ,ω = frequency, wavelength and angular frequency of radiation

ν_o,λ_o,ω_o = frequency and angular frequency used for radio frequency (RF) to intermediate frequency (IF) conversion

$\underset{\sim}{L}_j$ = vector position of the j^{th} antenna with respect to the center position of the array, units in seconds of time

$\underset{\sim}{B}_{jk}$ = $\underset{\sim}{L}_k - \underset{\sim}{L}_j$ = baseline vector between the j^{th} and k^{th} antennas where $j < k$, units in seconds of time

In Figure 2-2 we show a schematic representation of two VLA antennas intercepting a wavefront from a point source at $\underset{\sim}{s}$ while tracking a position $\underset{\sim}{s}_o$. The fundamental basis of interferometry is the fact that wavefronts which leave a point source at the same time arrive at slightly different times at different telescopes. In particular, for an orientation as shown in Figure 2-2, a wavefront reaches the j^{th} antenna at a time

$$\tau_{jk} = \underset{\sim}{B}_{jk}\bullet\underset{\sim}{s} = (\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet\underset{\sim}{s} \qquad (2\text{-}5)$$

later than it arrives at the k^{th} antenna. This corresponds to a phase difference $\omega\tau_{jk}$, thus the phase of wavefronts from the point source at s is given by $\omega\underset{\sim}{B}_{jk}\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o)$ since phase is measured with respect to the reference position. The maximum antenna separation of 35 km for the full A-array VLA means the delays will be from 0 to ~120 microseconds.

The process by which incoming signals are converted to measurements of the amplitude and phase of a wavefront is very complicated for the VLA because of the complex electronics system. However, in order to stress the more important aspects of this, let us discuss this process in terms of a couple of simple models. Those who do not wish to follow this discussion can proceed to Equation 2-15, taking the results on faith.

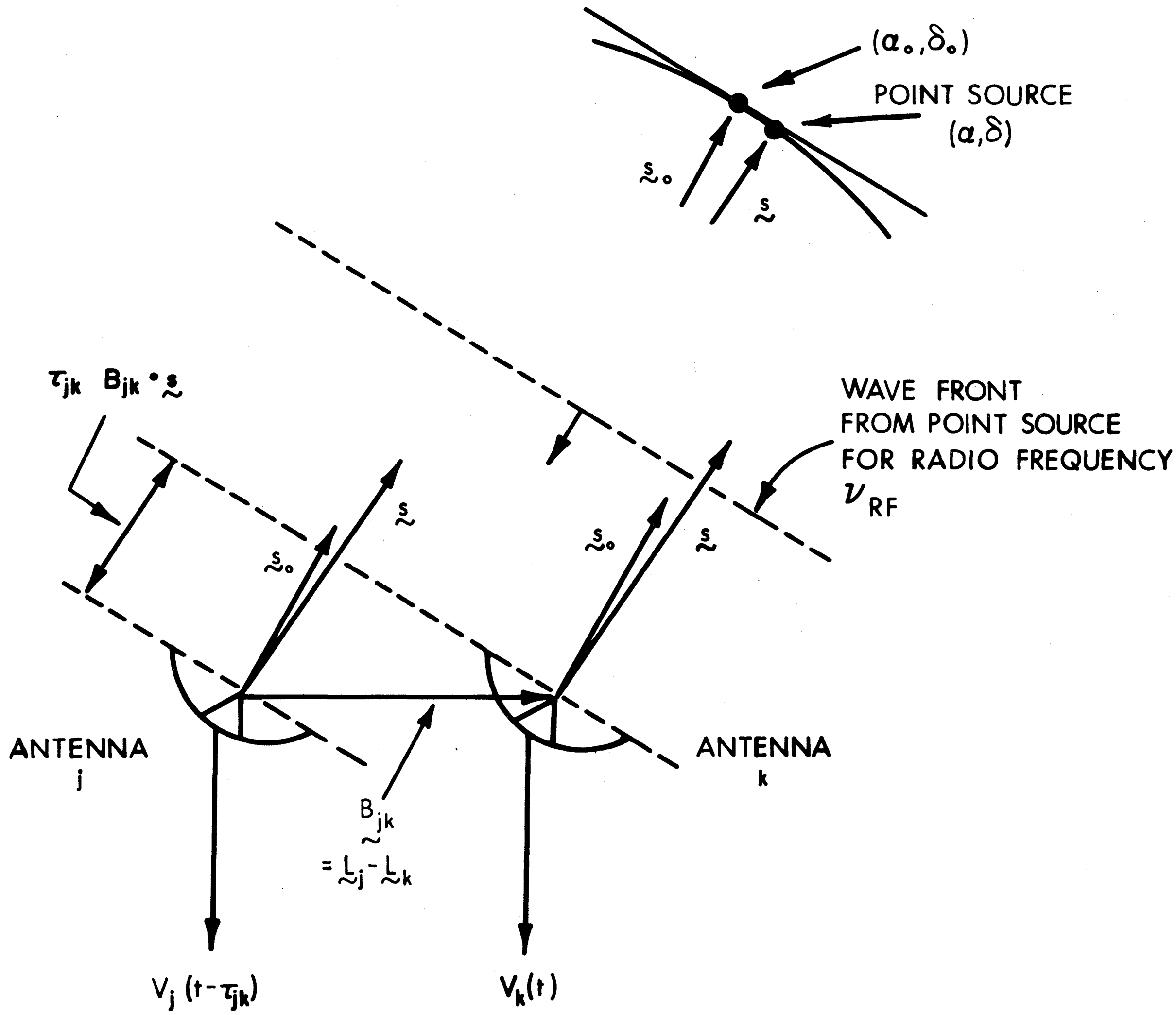


Figure 2-2. The geometry of a single interferometer pair with respect to wavefronts arriving from a point (α,δ) on the celestial sphere.

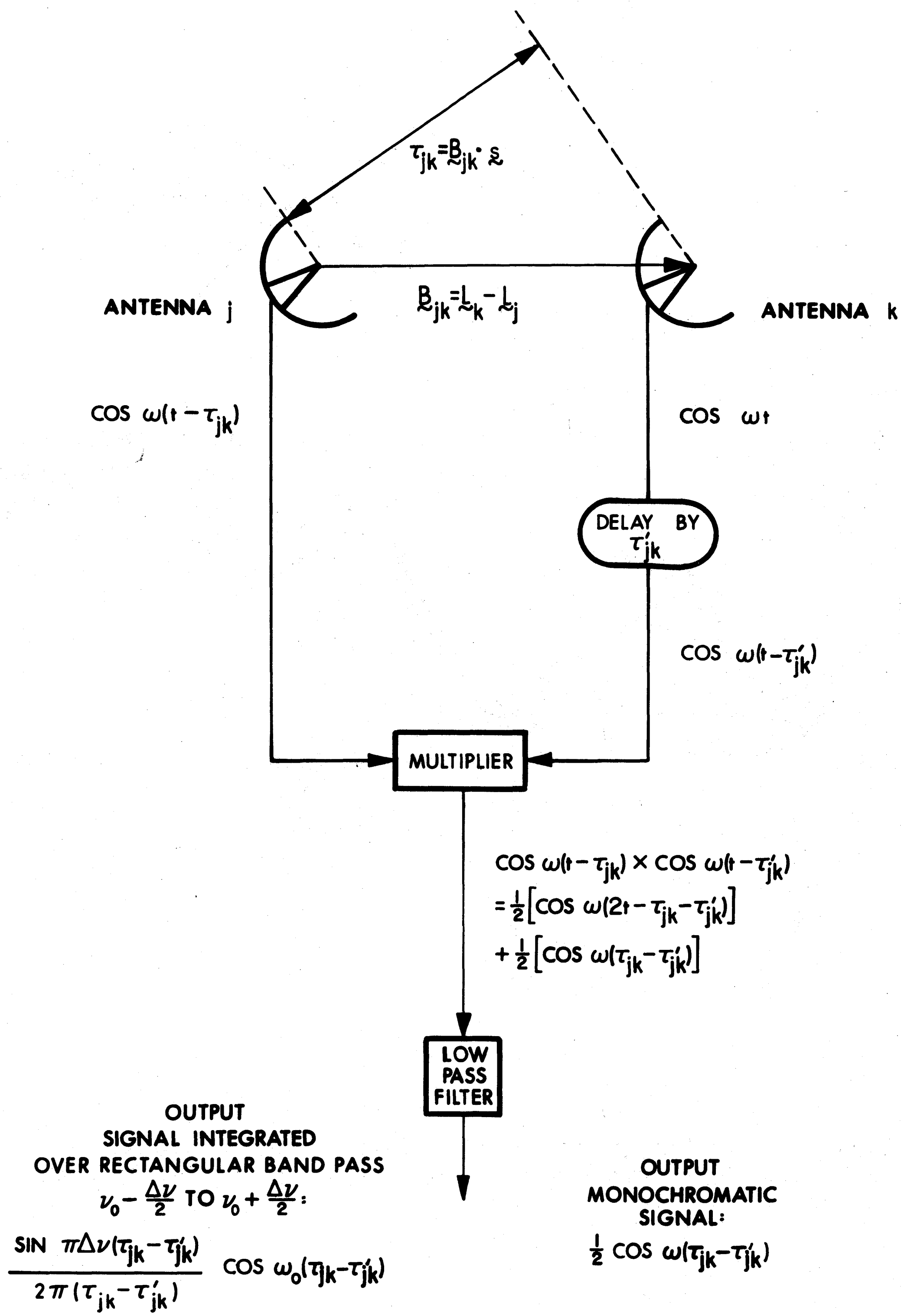


Figure 2-3. A simplified block diagram of the processing of pure RF signals from an interferometer pair.

Let E be the electric field strength of the incoming wavefront schematized in Figure 2-2, and $G_j(\nu)$ and $G_k(\nu)$ be the multiplicatively accumulative amplifier power gains for frequencies between ν and $\nu + \Delta\nu$ for telescopes j and k. These gains will represent everything that affects the amplitudes of the voltages propagating in the system. The output voltages for telescopes j and k, due to radiation in the RF range ν to $\nu + \Delta\nu$, when the same wavefront is producing the voltage response, can be represented in a quasimonochromatic form as

$$V_k(t) = [\tfrac{1}{2} G_k(\nu)\Delta\nu]^{\frac{1}{2}} E \cos \omega t \tag{2-6}$$

and

$$V_j(t) = [\tfrac{1}{2} G_j(\nu)\Delta\nu]^{\frac{1}{2}} E \cos \omega(t-\tau_{jk}) \tag{2-7}$$

where the factors of $\frac{1}{2}$ represent the fraction of the assumed unpolarized signal received by a single feed.

The representation of the cross-correlation output for antennas j and k is much more complicated than one would get by multiplying Equations (2-6) and (2-7). In order to illustrate this, let us first consider an unrealistically simplified model of how the signals from the two antennas could be processed. This model is shown in Figure 2-3 where cross-correlation (multiplication and filtering) is performed with the time dependent factors only after a simple delay compensation τ'_{jk}. All frequencies are RF. The multiplier output contains the sum of high- and low-frequency components, of which only the low frequencies are desired. A low-pass filter suppresses the high frequencies and producing a filter output proportional to $\cos \omega(\tau_{jk}-\tau'_{jk})$ for a single monochromatic component. However, the antenna electronics actually pass a range of frequencies corresponding to a designated passband. The actual output voltages are, therefore, obtained by integrating the monochromatic output signal over the range $\nu_o - \Delta\nu/2$ to $\nu_o + \Delta\nu/2$ (assuming uniform signal in this range and zero signal elsewhere) to obtain an output voltage from the low-pass filter proportional to

$$\text{sinc } [\Delta\nu(\tau_{jk}-\tau'_{jk}] \cos \omega_o(\tau_{jk}-\tau'_{jk})$$

where sinc x = (sin πx)/x. A schematic representation of this idealized output signal is shown in Figure 2-4 for the case where $\underset{\sim}{s} = \underset{\sim}{s}_o$. We see that, if $(\tau_{jk}-\tau'_{jk})$ can be kept small enough, the signal can be kept on the strongest positive maximum of the envelope.

To show why we can simply integrate the monochromatic output over frequency to get the broadband output, we repeat the above procedure on a more generalized level. The signal from the radio source will be designated as m(t). Thus the two signals to the multiplier will be $m(t-\tau_{jk})$ and $m(t-\tau'_{jk})$. Multiplying these two signals in the time domain is the same as convolving the Fourier transform of each signal in the frequency domain. Mathematically,

$$F\{m(t-\tau_{jk})m(t-\tau'_{jk})\} = \{\exp[-i2\pi\nu\tau_{jk}]\ M(\nu)\}*\{\exp[i2\pi\nu\tau'_{jk}]\ M(\nu)\}$$

where $M(\nu)$ is the Fourier transform of m(t), and the asterisk designates convolution. The phase terms are obtained with the shift theorem. Writing out the convolution gives

$$\exp[-i2\pi\nu(\tau'_{jk}-\tau_{jk})] \int_{-\infty}^{\infty} M(\nu')M(\nu-\nu')\ \exp[-i2\pi\nu'(\tau_{jk}-\tau'_{jk})]\ d\nu'$$

The celestial signal is stochastic and can ideally be thought of as white noise over the bandwidth of the instrument. The expectation operator of the multiplier output can be carried inside the integral to the product of M functions because no other factor is stochastic. The expectation of $M(\nu')M(\nu-\nu')$ is zero everywhere except where $\nu = \nu'$ since the frequency components are not correlated with each other. Let $E[M(\nu)M(\nu)] = I$ (an even function). Assuming the frequency response of the expectation process is unity over the bandwidth allows us to write the output as

$$I\ \exp[-i2\pi\nu(\tau_{jk}-\tau'_{jk})]\ 2 \int_{\nu_o-\Delta\nu/2}^{\nu_o+\Delta\nu/2} \cos\ 2\pi\nu'(\tau_{jk}-\tau'_{jk})\ d\nu'.$$

and we now have an integral expression which is the same as that previously found by simply integrating the sinusoidal fringe expression over the bandwidth. The factor out front is an arbitrary phase shift. The important concept demonstrated here is that for an incoherent signal, a convolution of that signal with itself in the frequency domain reduces to an integral over the product with no frequency shift. We will use this concept again in future developments.

Sep p 2-33

Extended radio sources, which have components at a position other than $\underset{\sim}{s}_o$, are distorted in the mapping process. If $\tau'_{jk} = \tau_{jk}$ for $\underset{\sim}{s} = \underset{\sim}{s}_o$, outer source components do not have the proper delay compensation. Thus they will be attenuated. For the maximum baseline of 35 km the angular width between first nulls is 1.1 arcmin, which is defined as the field of view for 50-MHz bandwidth. Effects of this loss on the mapping process will be discussed later in this chapter.

The delay τ_{jk} can be as big as 120 μsec for a 35-km baseline, and for 1% accuracy we need to keep timing errors in delay compensation less than $0.01/\nu_o$, which is 0.5 ps (picoseconds) at 20 GHz. Timing accuracy of this order, 1 part in 2×10^{12}, is too hard to achieve, so a different approach is necessary. By mixing the RF signals from each antenna with an LO signal, one can convert the signals to intermediate frequencies (IF) before delay and multiplication. Phase is preserved in mixing so accuracy of timekeeping in delays need be only of the order of $0.01/\Delta\nu$ (for a baseband system) which is 0.2 nanosec for $\Delta\nu \sim 50$ MHz.

In actuality the VLA has a phase shifting network plus a delay network as shown in Figure 2-5. The phase shifters $\phi_j(t)$ and $\phi_k(t)$ in the LO signal paths keep the output signal within the time range of the central fringe (largest cycle) shown in Figure 2-4. The process of constantly changing the phases to "stop" the fringes is called lobe rotation since it is in effect moving the lobes of an antenna array. The "fine tuning" of the delay system to put the output signal on the peak of the central fringe is accomplished by the delays τ'_j and τ'_k in the IF paths.

In Figure 2-5 we show phase shifting in the RF signal and delay in the IF signal paths for each antenna This is representative of the fact that the cross-correlated signals from each antenna pair will automatically have the correct delay compensation since delaying and phase shifting are done with respect to an arbitrary position at the center of the array for all N antennas. This is the first instance of the dominantly antenna-based treatment of VLA signal processing that the reader will encounter throughout this Introduction.

Figure 2-5 omits the many amplification stages in the system and the imperfections that may affect the signal phase. However, it does illustrate the essential aspects of the way phase information is handled for a plane wave observed as $\cos(\omega t-\tau_{jk})$ at the j^{th} antenna and $\cos \omega t$ at the k^{th} antenna. The conversion of these signals to IF frequencies is accomplished

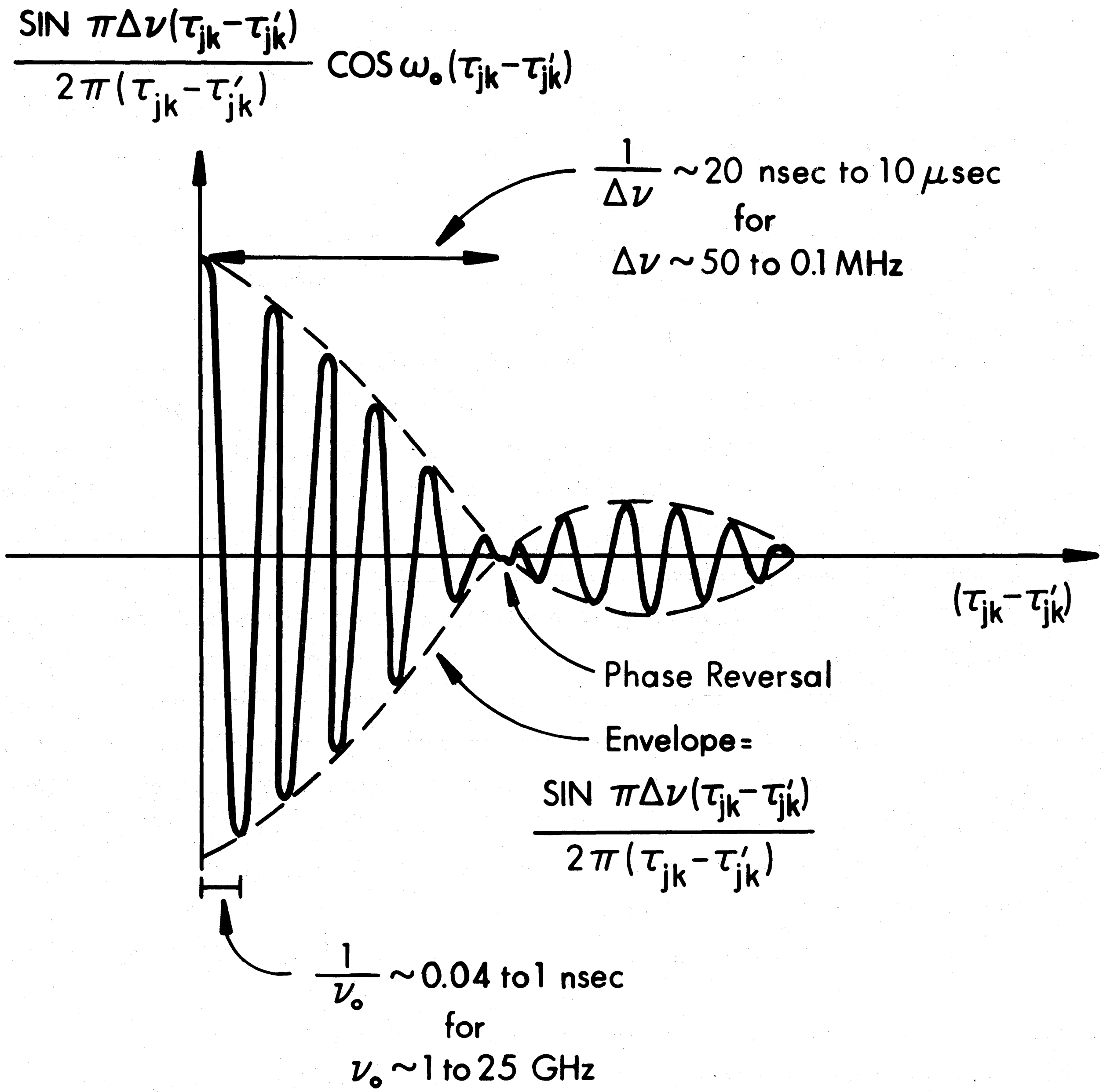
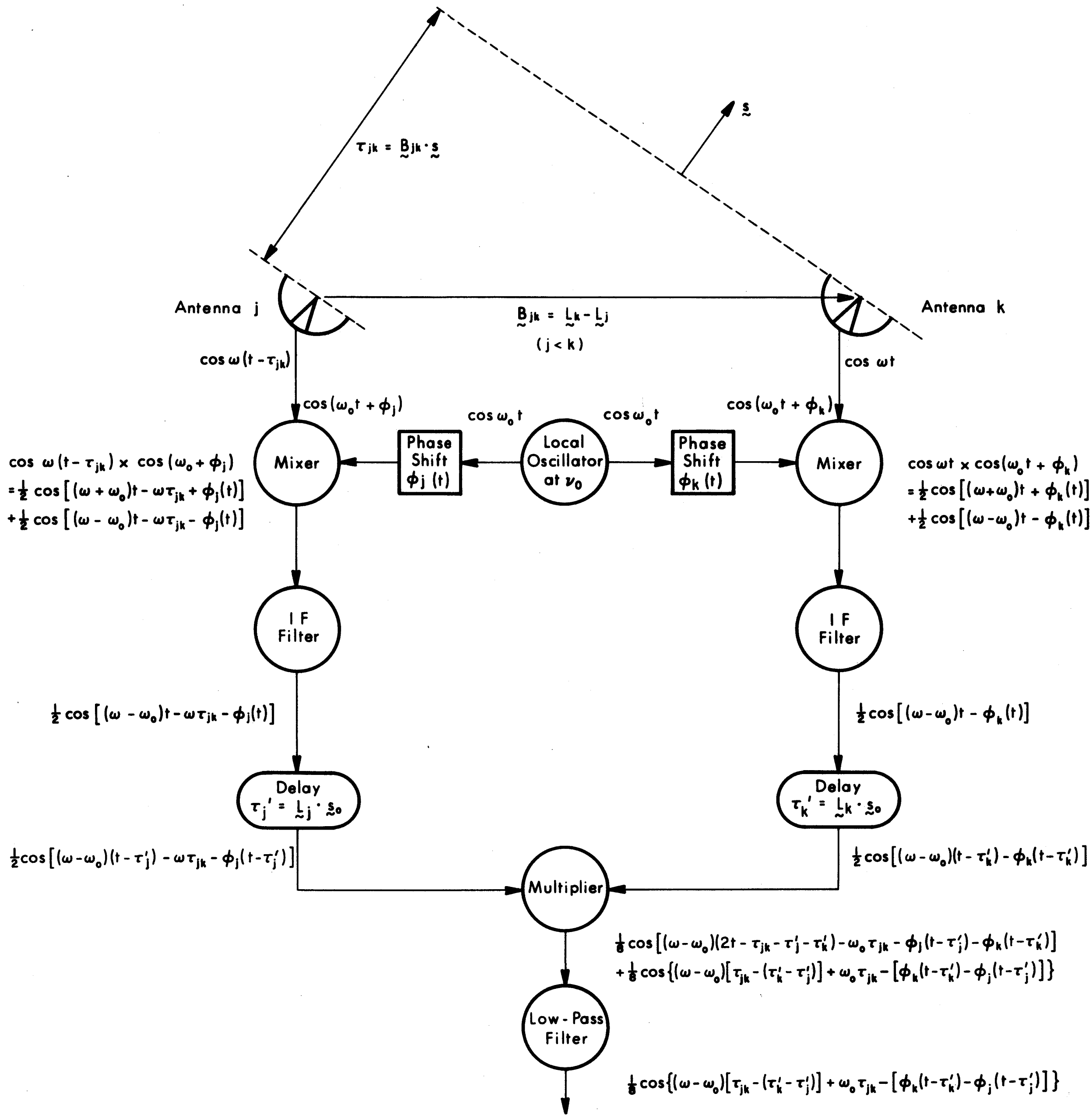


Figure 2-4. The theoretical signal output from the system shown in Figure 2-3. The location of the first null of the envelope defines one-half of the field of view.



$$R_\nu^{jk}(t) = A''_{j\nu_0} A''_{k\nu_0} a_j(\nu-\nu_0)\, a_k(\nu-\nu_0) \cos\{(\omega-\omega_0)[\tau_{jk}-(\tau_k'-\tau_j')] + \omega_0\tau_{jk} - [\phi_k(t-\tau_k') - \phi_j(t-\tau_j')]\}$$

OR

$$R_{jk}(t) = \int_0^\infty R_\nu^{jk}(t)\,d\nu = A_j'' A_k'' f_{jk}[\tau_{jk}-(\tau_k'-\tau_j')] \cos[\omega_0(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_0) + \phi_k^{CORR}(t) - \phi_j^{CORR}(t)]$$

Figure 2-5. A simplified schematic of the signal path for a VLA interferometer pair.

by mixing them with an LO frequency ν_o. By mixing with a phase shifted signal $\cos(\omega_o t+\phi_j)$ for the j^{th} antenna and $\cos(\omega_o t+\phi_k)$ for the k^{th} antenna, one introduces not only the delay discussed previously, but also any other antenna-dependent phase corrections that can be computed and applied in real time. After filtering to eliminate all but the IF frequencies, the two signals proportional to $\cos[(\omega-\omega_o)t-\omega\tau_{jk}-\phi_j(t)]$ and $\cos[(\omega-\omega_o)t-\phi_k(t)]$ are time delayed by $\tau_j' = \underset{\sim}{L}_j \bullet \underset{\sim}{s}_o$ and $\tau_k' = \underset{\sim}{L}_k \bullet \underset{\sim}{s}_o$. After multiplication together and passage through a low-pass filter, the IF signal response at frequency ν is proportional to

$$\cos\{(\omega-\omega_o)[\tau_{jk}-(\tau_k'-\tau_j')] + \omega_o\tau_{jk} - [\phi_k(t-\tau_k')-\phi_j(t-\tau_j')]\} .$$

Attaching the amplitude to this, the instantaneous response at frequency ν can then be written as

$$R_\nu^{jk}(t) = A''_{j\nu o}\, A''_{k\nu o}\, \alpha_j(\omega-\omega_o)\alpha_k(\omega-\omega_o) \bullet \cos\{(\omega-\omega_o)[\tau_{jk}-(\tau_k'-\tau_j')] + \omega_o\tau_{jk} + [\phi_k(t-\tau_k')-\phi_j(t-\tau_j')]\} \quad (2\text{-}8)$$

where

$$A''_{j\nu o} = [\tfrac{1}{2}\, G_j(\nu_o)\Delta\nu]^{\frac{1}{2}}\, E \quad (2\text{-}9)$$

[the amplitude from Equation (2-6) at frequency ν_o] and $\alpha_j(\omega-\omega_o)$ is the band-pass function for the j^{th} antenna. It is normalized such that $\int\alpha_j(\omega-\omega_o)d(\omega-\omega_o) = 1$. The total signal response is obtained by integrating $R_\nu^{jk}(t)$ over all frequencies. Letting $\omega' = \omega - \omega_o$ and $\Delta\tau = [\tau_{jk}-(\tau_k'-\tau_j')]$, the phase dependent factor can be expanded as

$$\cos[\omega'\Delta\tau]\cos[\omega_o\tau_{jk}+(\phi_k-\phi_j)] + \sin[\omega'\Delta\tau]\sin[\omega_o\tau_{jk}+(\phi_k-\phi_j)] \quad .$$

If the band-passes are sufficiently symmetrical, only the even-function term contributes in the integral over frequency and one obtains

$$R_{jk}(t) = A''_j A''_k f[\tau_{jk}-(\tau_k'-\tau_j')]\cos[\omega_o\tau_{jk}+\phi_k(t-\tau_k')-\phi_j(t-\tau_j')] \quad (2\text{-}10)$$

where

$$f_{jk}[\tau_{jk}-(\tau_k-\tau_j)] = \int_{\text{IF range}} \alpha_j(\omega')\alpha_k(\omega')\cos(\omega'\Delta\tau)d\omega' \quad (2\text{-}11)$$

is the so-called <u>fringe-washing</u> <u>function</u> which is unity for identical, symmetrical band-pass under conditions of good delay tracking. Under these conditions, which should be valid for normal VLA operation, the output signal response is

$$R_{jk}(t) = A''_j A''_k \cos \{\omega_o \tau_{jk} + [\phi_k(t-\tau'_k)-\phi_j(t-\tau'_j)]\} \quad . \qquad (2\text{-}12)$$

Using $\tau_{jk} = (\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet\underset{\sim}{s}$, $\tau_j = \underset{\sim}{L}_j\bullet\underset{\sim}{s}_o$, and noting that the general form of the phase shift applied before RF to IF conversion is

$$\phi_j(t) = \omega_o \underset{\sim}{L}_j \bullet \underset{\sim}{s}_o - n(2\pi) + \phi_j^{corr}(t) \qquad (2\text{-}13)$$

where $\phi_j^{corr}(t)$ represents any phase corrections applied at this stage. Equation (2-12) then becomes

$$R_{jk}(t) = A''_j A''_k \cos \{\omega_o (\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o) + [\phi_k^{corr}(t)-\phi_j^{corr}(t)]\}. \qquad (2\text{-}14)$$

In the above equation, A''_j is a constant proportional to the square root of the flux density of the point source being tracked for the i^{th} antenna system. In practice, when measuring and processing the interferometer response output, it is most convenient to deal with the amplitude and phase of a complex representation of the response function; thus, Equation (2-14) becomes

$$V'' = A''_{jk}\, e^{i\phi_{jk}} = A''_j A''_k \exp \{i\omega_o (\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o) + i[\phi_k^{corr}-\phi_j^{corr}+\phi_k^o-\phi_j^o]\} \quad (2\text{-}15)$$

where we now have system phase constants ϕ_i^o for the i^{th} antenna. The measured

$$A''_{jk} \text{ and } \phi''_{jk} = \phi''_k-\phi''_j \qquad (2\text{-}16)$$

are raw amplitude and phase measured as a function of time.

4. SYSTEM CORRECTION AND CALIBRATION

Because the correction and calibration of data from the VLA interferometers play such a major role in using the instrument, we will adopt a notation to describe these processes. Let the raw signal derived from the correlator output by the on-line computer system be described by double-primed quantities, such as

$$V''_{jkp} = A''_{jkp} \exp (i\phi''_{jkp}) \qquad (2\text{-}17)$$

where p represents the polarization of the visibility data. The V''_{jkp} data will have had the phase corrections (ϕ_j^{corr} and ϕ_k^{corr}) applied as part of the RF to IF conversion process.

The on-line, real time computer system can apply further corrections and calibration, as will be discussed in more detail later, before sending the visibility data on to the off-line computer system. We denote data corrected and calibrated on-line by single-primed quantities, such as

$$V'_{jkp} = A'_{jkp} \exp (i\phi'_{jkp}) \quad . \tag{2-18}$$

These data are passed from the on-line computer system via fixed-head disk and magnetic tape to the off-line computer system where further corrections and calibration are applied. Let us denote data that have been corrected and calibrated by the off-line system by unprimed quantities as

$$V_{jkp} = A_{jkp} \exp (i\phi_{jkp}) \quad . \tag{2-19}$$

Each VLA antenna has two feeds of orthogonal polarizations for each frequency. The 18-21 cm, 6, 2, and 1.25 cm band feeds are normally followed by circular polarizers, but linear polarizers can be inserted in the signal path to convert to linear polarization. We will be concerned with circular polarizations and will use the symbols L and R to represent left and right, respectively.

Any electromagnetic wave can be represented as left and right circularly-polarized components. Thus

$$\begin{aligned} E_L &= E_\ell \, e^{i\omega t} \\ E_R &= E_r \, e^{-i(\omega t+\Theta)} \end{aligned} \tag{2-20}$$

where Θ is the phase difference between the two components. There are various ways of representing the information in a polarized wave, but the most common one in radio astronomy is Stokes parameters which are defined as follows:

$$\begin{aligned} I &= E_L E_L^* + E_R E_R^* = E_\ell^2 + E_r^2 \\ Q &= E_L E_R^* + E_R E_L^* = 2E_\ell E_r \cos \Theta \\ U &= i(E_L E_R^* - E_R E_L^*) = 2E_\ell E_r \sin \Theta \\ V_c &= E_L E_L^* - E_R E_R^* = E_\ell^2 - E_r^2 \end{aligned} \tag{2-21}$$

The asterisk denotes complex conjugation. The advantage of this representation is that each product in the parenthesis corresponds to a quantity measurable with the interferometer.

Inverting the expressions we get

$$
\begin{aligned}
E_L E_L^* &= \tfrac{1}{2}(I + V_c) = V_{jkLL} \\
E_R E_R^* &= \tfrac{1}{2}(I - V_c) = V_{jkRR} \\
E_L E_R^* &= \tfrac{1}{2}(Q - iU) = V_{jkLR} \\
E_R E_L^* &= \tfrac{1}{2}(Q + iU) = V_{jkRL}
\end{aligned}
\qquad (2\text{-}22)
$$

where the L and R subscript notation has been attached to the interferometer response, V_{jk}. Now that we have these relationships between the calibrated polarization data, we will derive the polarization version of the raw correlator visibilities V'_{jkp}.

The complex voltage, before cross-correlation of the j^{th} telescope, can be described as

$$
\begin{aligned}
R_j &= G_{jR}\bullet(E_R e^{-i\phi_p} + D_{jR}E_L e^{i\phi_p}) \\
L_j &= G_{jL}\bullet(E_L e^{i\phi_p} + D_{jL}E_R e^{-i\phi_p})
\end{aligned}
\qquad (2\text{-}23)
$$

where G_{jR} and G_{jL} are complex gains describing all the amplification and phase modification aspects of the j^{th} antenna, D_{jR} and D_{jL} describe the coupling between polarizations. ϕ_p is the parallactic angle which can be obtained from

$$\phi_p = \tan^{-1}[\cos\lambda_{lat}\sin H/(\sin\lambda_{lat}\cos\delta - \cos\lambda_{lat}\sin\delta\cos H)] \qquad (2\text{-}24)$$

where λ_{lat} is the VLA latitude. The parallactic angle (shown in Figure 2-6) is the angle between the source meridian and the elevation great circle of the VLA alt-az antennas.

An alternate technique for describing the instrumental polarization is to introduce Stokes parameters for the antennas. However, the above approach is more straightforward for instrumental calibration.

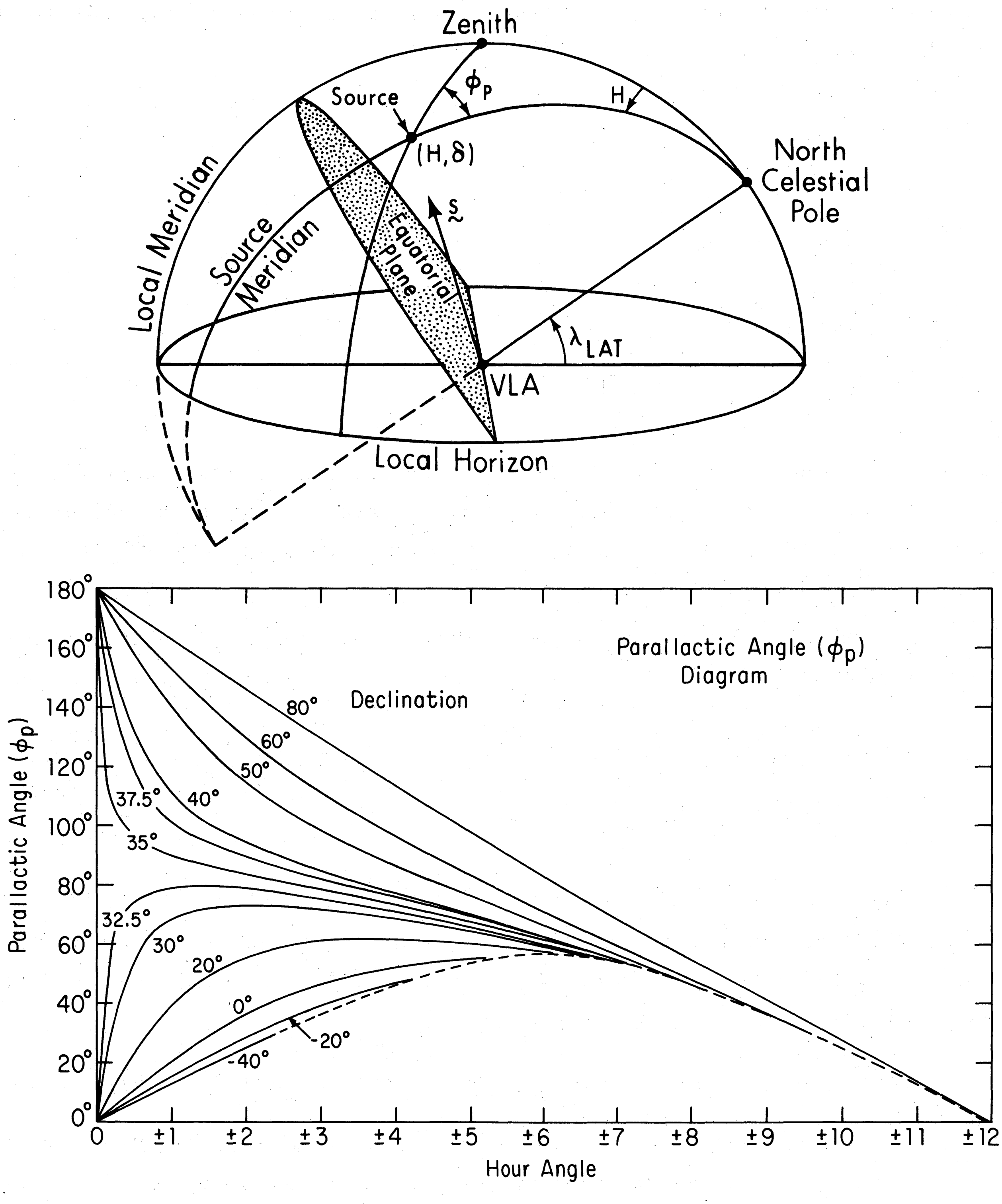


Figure 2-6. Parallactic angle ϕ_p is shown as the angle between the source meridian and the elevation great circle.

The measured correlator outputs are then represented as

$$V''_{jkLL} = L_j L_k^*$$

$$V''_{jkRR} = R_j R_k^*$$

$$V''_{jkLR} = L_j R_k^*$$

and

$$V''_{jkRL} = R_j L_k^* \tag{2-25}$$

carrying out the multiplication for V''_{jkRR}, we get

$$V''_{jkRR} = G_{jR} \bullet G_{kR}^* \bullet (E_R E_R^* + E_L E_L^* D_{jR} e^{2i\phi_p} + E_R E_L^* D_{kR}^* e^{-2i\phi_p} + D_{jR} D_{kR}^* E_L E_L^*)$$

and for V''_{jkLR} we get

$$V''_{jkLR} = G_{jL} \bullet G_{kR}^* \bullet (E_L E_R^* e^{2i\phi_p} + E_L E_L^* D_{kR}^* + E_R E_R^* D_{jL} + E_R E_L^* D_{jL}^* D_{kR} e^{-2i\phi_p}) \quad .$$

In practice, the D's are less than 10% and the linear polarization of sources is typically 10% or less; therefore, $E_R E_L^*$ and $E_L E_R^*$ are 10% or less of $E_L E_L^*$ and $E_R E_R^*$. We can, therefore, neglect second and higher-order terms to obtain, after also using Equation (2-23),

$$V''_{jkLL} = G_{jL} \bullet G_{kL}^* \bullet V_{jkLL} \tag{2-26}$$

$$V''_{jkRR} = G_{jR} \bullet G_{kR}^* \bullet V_{jkRR} \tag{2-27}$$

$$V''_{jkLR} = G_{jL} \bullet G_{kR}^* \bullet (V_{jkLR} e^{2i\phi_p} + V_{jkLL} D_{kR}^* + V_{jkRR} D_{jL}) \tag{2-28}$$

$$V''_{jkRL} = G_{jR} \bullet G_{kL}^* \bullet (V_{jkRL} e^{-2i\phi_p} + V_{jkRR} D_{kL}^* + V_{jkLL} D_{jR}) . \tag{2-29}$$

Equations (2-27) - (2-30) describe how a set of four complex constants per antenna, G_{jR}, G_{jL}, D_{jR}, and D_{jL}, are sufficient to completely describe the relation between the true visibilities, V_{jkp}, and the raw instrumental visibilities, V''_{jkp}. If one is not interested in linear polarization, only the V''_{jkRR} and V''_{jkLL} visibilities are relevant and the two complex constants, G_{jR} and G_{jL}, are sufficient.

In practice, one observes point-source calibrators with known values of I, Q, U, V_c so the V_{jkp}'s can be obtained from the right-hand equalities in Equations (2-21). Then from measured V''_{jkp} one can solve Equations (2-26) - (2-29) for G_{jR}, G_{jL}, D_{jR}, and D_{jL}. Once these are known, we define

$$g_{jR} = 1/G_{jR}$$

and

$$g_{jL} = 1/G_{jL} \qquad (2\text{-}30)$$

and Equations (2-26) - (2-29) can be rearranged to give

$$V_{jkLL} = g_{jL} g^{*}_{kL} V''_{jkLL} \qquad (2\text{-}31)$$

$$V_{jkRR} = g_{jR} g^{*}_{kR} V''_{jkRR} \qquad (2\text{-}32)$$

$$V_{jkLR} = (g_{jL} \bullet g^{*}_{kR} V''_{jkLR} - D_{jL} V_{jkRR} - D^{*}_{kR} V_{jkLL}) e^{-2i\phi_p} \qquad (2\text{-}33)$$

$$V_{jkRL} = (g_{jR} \bullet g^{*}_{kL} V''_{jkRL} - D_{jR} V_{jkLL} - D^{*}_{kL} V_{jkRR}) e^{2i\phi_p} \qquad (2\text{-}34)$$

as a set of equations by which V''_{jkp} data can be transformed into corrected and calibrated V_{jkp} data.

In practice, the VLA data processing system has both on-line and off-line application of corrections and calibration. Let us denote the on-line correction and calibration parameters as

$$g'_{jR},\ g'_{jL},\ D'_{jR},\ D'_{jL}$$

and reserve double-primed parameters

$$g''_{jR},\ g''_{jL},\ D''_{jR},\ D''_{jL}$$

for off-line correction and calibration parameters. However, since corrections like that of parallactic angle are not made twice, we assume that, if ϕ_p is applied in the on-line system, $\phi_p = 0$ in the off-line system, and vice versa.

The on-line computer system correction and calibration process can then be described as

$$V'_{jkLL} = g'_{jL} g'^{*}_{kL} V''_{jkLL} \qquad (2\text{-}35)$$

$$V'_{jkRR} = g'_{jR} g'^{*}_{kR} V''_{jkRR} \qquad (2\text{-}36)$$

$$V'_{jkLR} = (g'_{jL} \bullet g'^{*}_{kR} V''_{jkLR} - D'_{jL} V''_{jkRR} - D'^{*}_{kR} V'_{jkLL}) e^{-2i\phi_p} \qquad (2\text{-}37)$$

$$V'_{jkRL} = (g'_{jR} \bullet g'^{*}_{kL} V''_{jkRL} - D'_{jR} V''_{jkLL} - D'^{*}_{kL} V'_{jkRR}) e^{2i\phi_p} \qquad (2\text{-}38)$$

and the off-line computer system correction and calibration process can be described as

$$V_{jkLL} = g''_{jL} g''^{*}_{kL} V'_{jkLL} \quad (2\text{-}39)$$

$$V_{jkRR} = g''_{jR} g''^{*}_{kR} V'_{jkRR} \quad (2\text{-}40)$$

$$V_{jkLR} = (g''_{jL} g''^{*}_{kR} V'_{jkLR} - D''_{jL} V_{jkRR} - D''^{*}_{kR} V_{jkLL}) e^{-2i\phi_p} \quad (2\text{-}41)$$

$$V_{jkRL} = (g''_{jR} g''^{*}_{kL} V'_{jkRL} - D''_{jR} V_{jkLL} - D''^{*}_{kL} V_{jkRR}) e^{2i\phi_p}. \quad (2\text{-}42)$$

The corrected and calibrated V_{jkp}, for a point source at a position s which has Stokes parameters I, Q, U, V_c, will be described by

$$V_{jkLL} = (I + V_c + I_{noise} + V_{c,noise}) \exp[i\omega_o(\underset{\sim}{L}_k - \underset{\sim}{L}_j)\bullet(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}] \quad (2\text{-}43)$$

$$V_{jkRR} = (I - V_c + I_{noise} - V_{c,noise}) \exp[i\omega_o(\underset{\sim}{L}_k - \underset{\sim}{L}_j)\bullet(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}] \quad (2\text{-}44)$$

$$V_{jkLR} = (Q - iU + Q_{noise} - iU_{noise}) \exp\ [i\omega_o(\underset{\sim}{L}_k\ \underset{\sim}{L}_j)\bullet(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}] \quad (2\text{-}45)$$

$$V_{jkRL} = (Q + iU + Q_{noise} + iU_{noise}) \exp\ [i\omega_o(\underset{\sim}{L}_k - \underset{\sim}{L}_j)\bullet(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}]\ . \quad (2\text{-}46)$$

In Equations (2-44) to (2-47) we have for the first time taken note of the fact that noise will be present in completely corrected and calibrated data by introducing a phase noise function (ϕ_{noise}) and a noise function for each Stokes parameter. In most equations these will not be included, but the user should be aware of their presence in all data.

In theory, the determination of calibration constants and their application to uncalibrated data to achieve calibration is very straightforward. Observations of point sources with known values of $I = S_\nu$, Q, U, and V_c, which are relatively constant, are used in conjunction with Equations (2-26) - (2-30) and (2-21) to determine the complex functions

$$g_{jR},\ g_{jL},\ D_{jR},\ D_{jL}$$

as parameters that remain constants over reasonable time scales (hopefully, days or longer). Noncalibrator source data observed over the same time scale that the calibration constants are known and stable are then calibrated using Equations (2-31) - (2-34).

see also p 5-10

X

5. AMPLITUDE AND PHASE NOISE

Let us briefly discuss the amplitude and phase noise introduced by the electronics system. If we define

$\Delta\nu$ = IF bandwidth

T_{sys} = system noise temperature

D_{ant} = diameter of each antenna (= 25 m)

ε_a = aperture efficiency

ε_c = 3 level correlator efficiency $\simeq$ 0.82,

then the theoretical rms noise fluctuation in the amplitudes for a single antenna-receiver pair is

$$\sigma = 4(2^{\frac{1}{2}})k_B T_{sys}/[\pi\varepsilon_c\varepsilon_a D^2_{ant}(\Delta\nu\ \tau)^{\frac{1}{2}}]$$

$$= 2.2\times10^{-4} T_{sys}/\{\varepsilon_a[(\Delta\nu_{MHz}/50)(\tau_{sec}/10)]^{\frac{1}{2}}\}\ \text{Jy} \qquad (2\text{-}47)$$

where k_B is the Boltzmann constant (1.38×10^{-23} joule K^{-1}) and t is the length of observing time involved. Using Equation (2-47) and the nominal values of T_{sys} and ε_a for each standard VLA frequency, one predicts the rms noise fluctuations listed in Table 2-1 for a single ten-second record.

For N antennas,

$$\sigma = 2.2\times10^{-4} T_{sys}/\{\varepsilon_a[(\Delta\nu_{MHz}/50)(\tau_{sec}/10)N(N-1)/2]^{\frac{1}{2}}\} \qquad (2\text{-}48)$$

in which the noise decreases as the reciprocal square root of the number of antenna pairs.

TABLE 2-1

Amplitude Noise for Ten Seconds of Data for a Single Antenna Pair

Band	ε_a	T_{sys}	A_{noise} (Theoretical)
18-21 cm	50%	60 K	$0.026\ (50/\Delta\nu_{MHz})^{\frac{1}{2}}$ Jy
6 cm	65%	50 K	$0.017\ (50/\Delta\nu_{MHz})^{\frac{1}{2}}$ Jy
2 cm	54%	300 K $\times\frac{1}{2}$ now	$0.12\ (50/\Delta\nu_{MHz})^{\frac{1}{2}}$ Jy
1.3 cm	46%	360 K	$0.17\ (50/\Delta\nu_{MHz})^{\frac{1}{2}}$ Jy

Next we turn to the probability distributions for both amplitude and phase of the fringes. The observed quantity consists of the signal S and the noise N vectorily added. We let

S	=	signal with constant amplitude
A	=	measured amplitude = S + N
N	=	noise = $Re^{i\theta}$
θ	=	phase noise = $\phi - \phi_{true}$
ϕ_{true}	=	constant phase of signal
ϕ	=	measured phase

To determine the joint probability density function for the fringe amplitude and phase, we assume that the true fringe amplitude, S, is a constant and that the rectangular components of the noise, R cos θ and R sin θ, are each Gaussian distributed with zero mean and variance σ^2. The joint probability distribution in rectangular coordinates is

$$P(\xi,\eta) = (2\pi\sigma^2)^{-1} \exp\{-(\xi + S)^2/(2\sigma^2) - \eta^2/(2\sigma^2)\}.$$

This is transformed to polar coordinates by setting $\xi = R\cos\theta$, $\eta = R\sin\theta$, and multiplying $P(\xi,\eta)$ by the Jacobian, which in this case is A. Thus, the joint probability density function in polar form is

$$P(A,\theta) = (A/2\pi\sigma^2) \exp\{-[A\cos\theta + S)^2/(2\sigma^2)]-[(A^2\sin^2\theta)/(2\sigma^2)]\} \quad . \quad (2\text{-}49)$$

To find P(A) we integrate Equation (2-49) over θ which gives

$$P(A) = \int_0^{2\pi} P(A,\theta)d\theta = (A/\sigma^2) \exp[-(A^2 + S^2)/(2\sigma^2)]I_o(AS/\sigma^2) \qquad (2\text{-}50)$$

This is known as the Rice-Nakagami distribution in which $I_o(x)$ is the modified Bessel function of the first kind, of order zero. It is unity when the argument is zero (no signal present). Plots of P(A) as a function of A/σ are shown in Figure 2-7 for various values of signal-to-noise ratio, S/σ. Note that as S/σ increases, P(A) approaches a Gaussian distribution.

The probability density function for the phase is determined in a manner similar to finding p(A). Thus

$$P(\theta) = \int_0^{\infty} P(A,\theta)dA = (1/2\pi) \exp[-S^2/(2\sigma^2)]\{1 + G\pi^{\frac{1}{2}} \exp(G^2)[1 + \text{erf } G]\}$$

where erf is the error function and $G = S\cos\theta/(\sigma 2^{\frac{1}{2}})$.

Without the signal S, the measured system output would have a uniform phase distribution and a Rayleigh amplitude distribution. Clearly, these distributions are altered by the presence of a signal.

The probability distribution of the phase, $P(\theta)$ is plotted in Figure 2-8 as a function of $\theta = \phi - \phi_{true}$ for $S/\sigma = 0, 1, 2, 3$, and 5. We see that, in the absence of a signal, the phases are uniformly distributed. As the signal-to-noise ratio increases, the phase probability distribution has less and less deviation from the true phase, as seen from Figure 2-8 and the following table:

S/σ	$(\phi - \phi_{true})_{P/P_{max}=\frac{1}{2}}$
1	$\pm 55°$
2	$\pm 35°$
3	$\pm 22°$
4	$\pm 13°$

For large values of S/σ (≥ 2),

$$(\phi - \phi_{true})_{P/P_{max}=\frac{1}{2}} \simeq \pm 65°/(S/\sigma) \quad . \tag{2-51}$$

Examination of Figures 2-6 and 2-7 reveals the basic reasons why the presence of a weak source will always show up most easily in the phase information. The difference between the phase distributions for $S/\sigma = 0$ and 1 are much more obvious than the difference between the associated amplitude distributions.

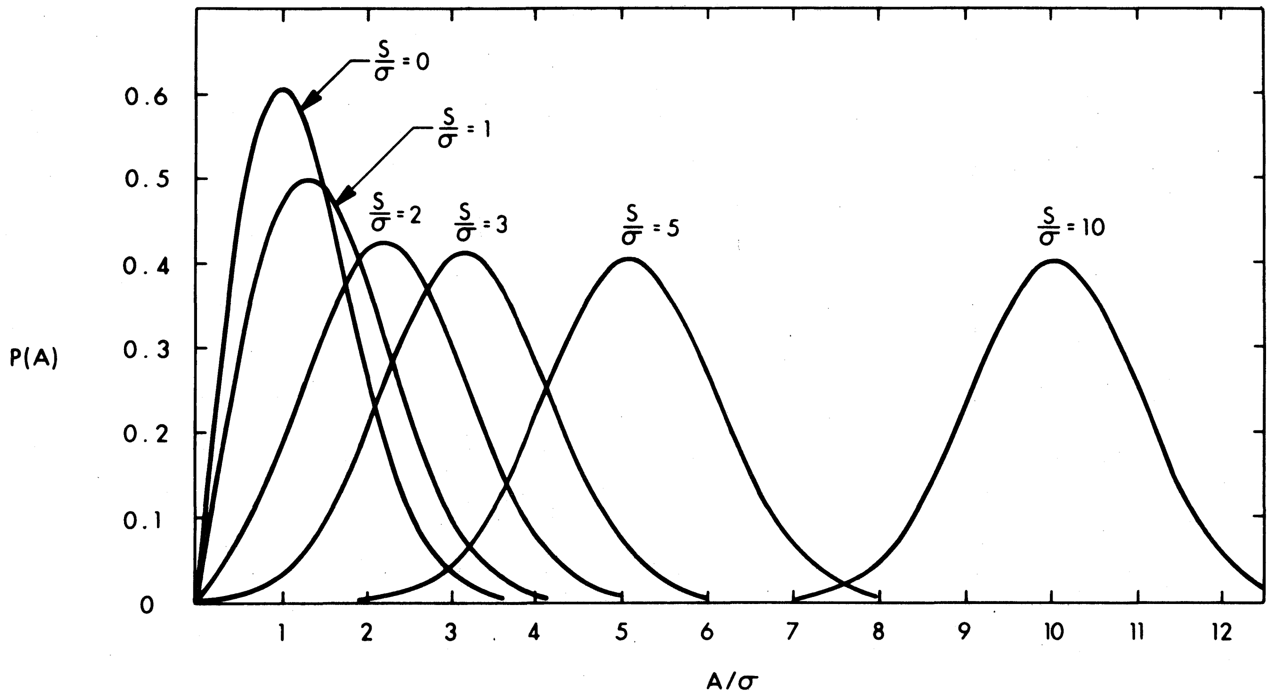


Figure 2-7. The probability distribution of measured amplitudes is plotted as a function of apparent signal-to-noise for a number of values of true signal-to-noise ratio.

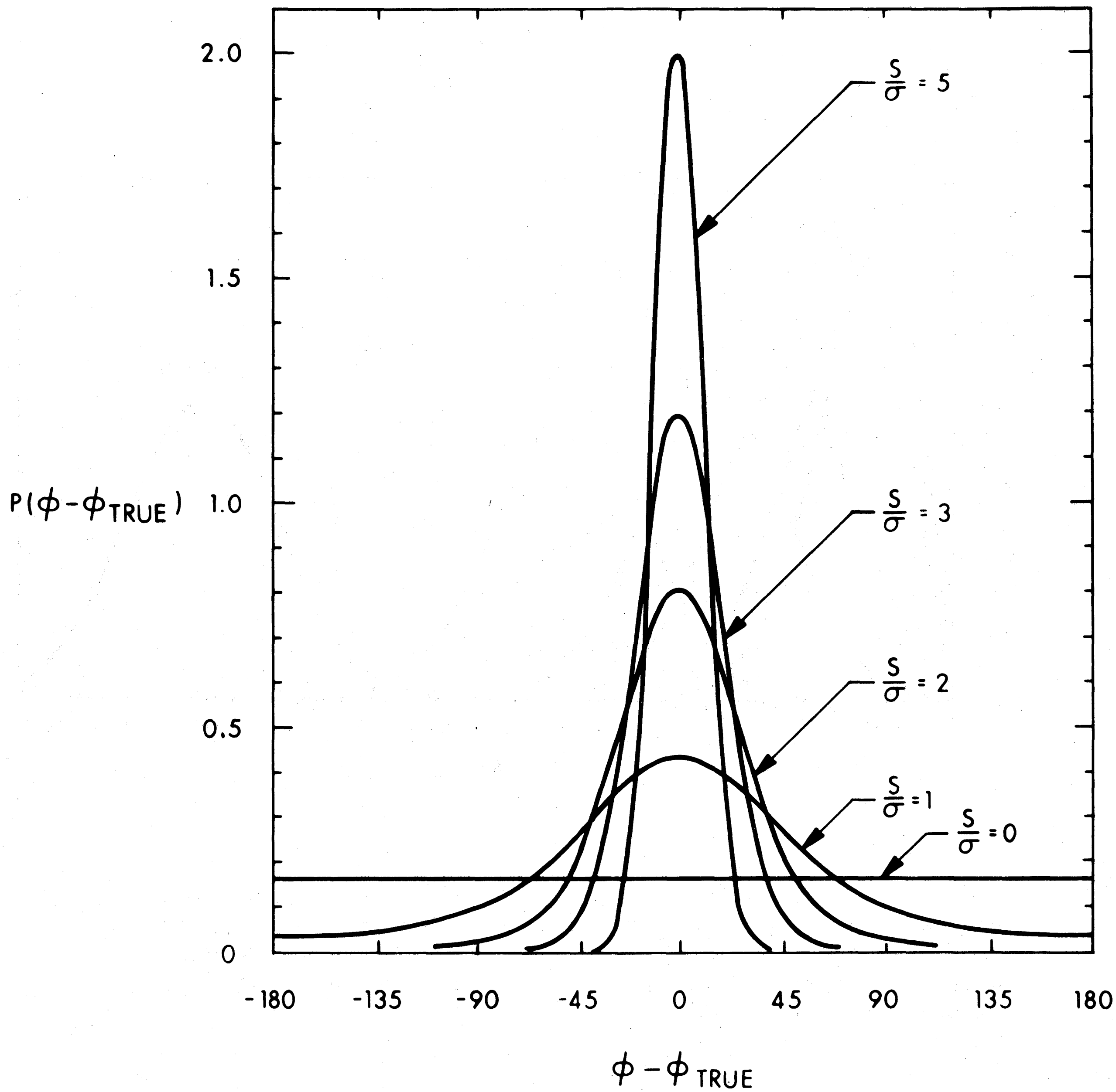


Figure 2-8. The probability distribution of measured phases is plotted as a function of (ϕ - ϕ_{true}) for a number of values of signal-to-noise ratio.

6. GEOMETRY AND COORDINATES

In the foregoing discussions in this section we concentrated on general concepts and avoided detailed discussions of geometry and coordinates. Let us now discuss these explicitly so further equations can be considered in greater detail.

There are only two basic coordinate systems involved in the VLA. One is an earth-oriented, topocentric system that we will call the x_e-y_e-z_e system, and the other is a sky-oriented system that we will call x_s-y_s-z_s. Both systems are right-handed. Figure 2-9 shows the geometry and relationship between these systems.

In the earth-oriented system the z_e axis points to the north pole and the y_e axis points east. The origin of this system is the position arbitrarily defined as the center of the Y for the VLA. The geometry of the two coordinate systems and one pair of antennas is shown in Figure 2-9. An example of station positions $\underset{\sim}{L}_j$ and $\underset{\sim}{L}_k$, with the resultant baseline vector $\underset{\sim}{B}_{jk}$, is also shown for the case of the j^{th} antenna on station W56 and the k^{th} antenna on station E72, where $j < k$. In the x_e-y_e-z_e system the standard polar angular coordinates (Θ,ϕ) are related to declination and hour angle as shown, except $\phi = H$ for LST > α and $\phi = 360° - H$ for LST < α (the latter is shown on Figure 2-9).

The sky-oriented coordinate system as shown in Figure 2-9 is defined such that the z_s-axis extends along the vector $\underset{\sim}{s}_o$ corresponding to the reference position so that x_s-y_s are in the tangent plane to the celestial sphere at this point, with the x_s-axis pointing east as seen from the center of the wye and the y_s-axis pointing north.

In the earth-oriented system,

$$\underset{\sim}{s} = \begin{bmatrix} \cos H \cos \delta \\ -\sin H \cos \delta \\ \sin \delta \end{bmatrix}_e \qquad (2\text{-}52)$$

so that

$$\underset{\sim}{s}_o = \begin{bmatrix} \cos H_o \cos \delta_o \\ -\sin H_o \cos \delta_o \\ \sin \delta_o \end{bmatrix}_e$$

where $H_o = \text{LST} - \alpha_o$. In the earth-oriented system, the station position of

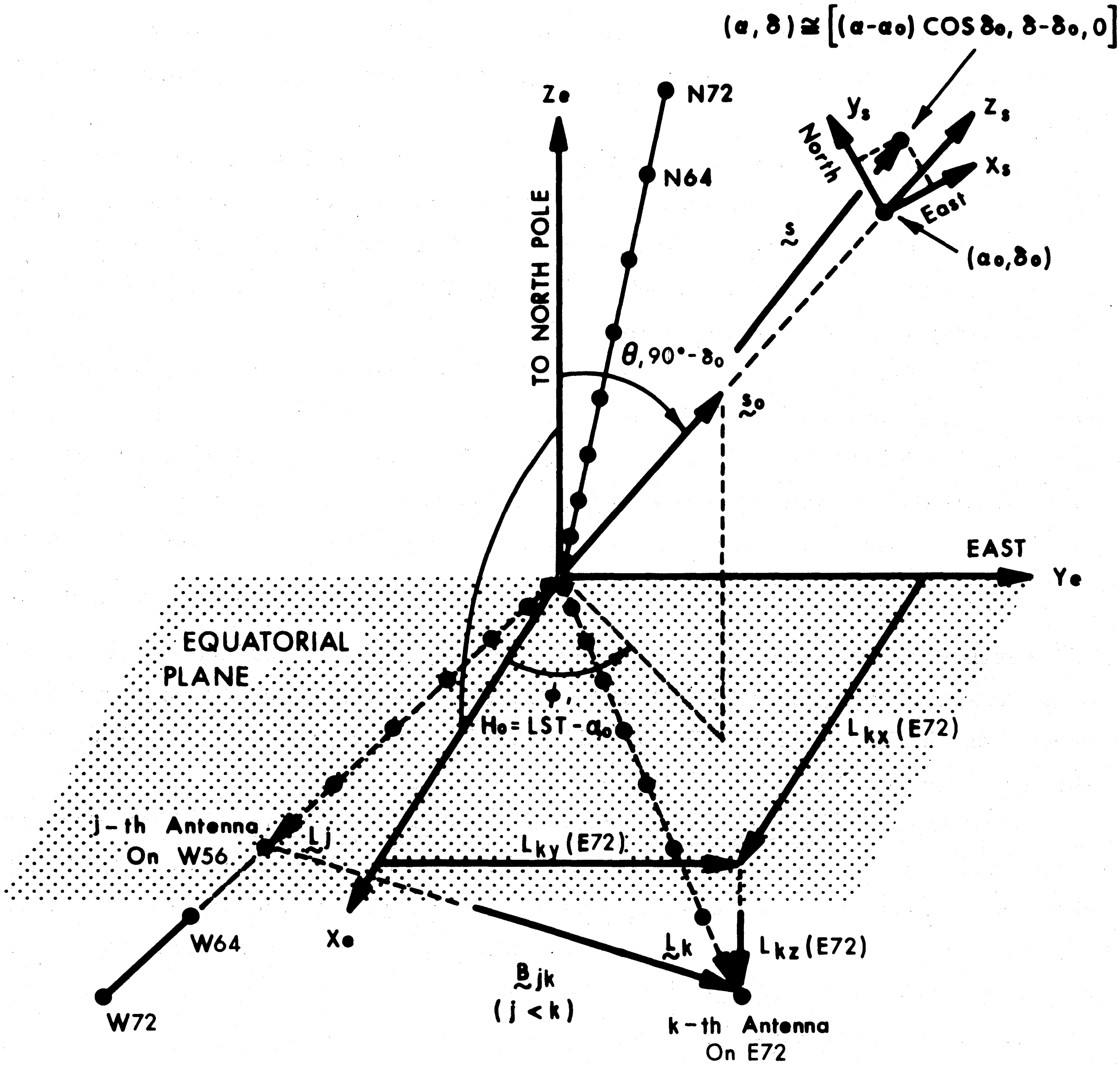


Figure 2-9. Geometrical relationships between the earth-oriented coordinate system (x_e, y_e, z_e) and the sky-oriented system (x_s, y_s, z_s). $\underset{\sim}{L}_j$ and $\underset{\sim}{L}_k$ are vectors from the VLA wye center to two antennas on separate arms.

the j^{th} antenna, as shown in Figure 2-9, is given by the appropriate dot products of coordinate unit vectors

$$\underset{\sim}{L}_j = (L_{jx}, L_{jy}, L_{jz})_e \quad . \tag{2-53}$$

The transformation matrix from the earth-oriented system to the sky-oriented system is given in general by

$$M_{earth\text{-}sky} = \begin{bmatrix} \underset{\sim}{x}_e \bullet \underset{\sim}{x}_s & \underset{\sim}{y}_e \bullet \underset{\sim}{x}_s & \underset{\sim}{z}_e \bullet \underset{\sim}{x}_s \\ \underset{\sim}{x}_e \bullet \underset{\sim}{y}_s & \underset{\sim}{y}_e \bullet \underset{\sim}{y}_s & \underset{\sim}{z}_e \bullet \underset{\sim}{y}_s \\ \underset{\sim}{x}_e \bullet \underset{\sim}{z}_s & \underset{\sim}{y}_e \bullet \underset{\sim}{z}_s & \underset{\sim}{z}_e \bullet \underset{\sim}{z}_s \end{bmatrix} \tag{2-54}$$

The dot products appearing in each element are most easily determined from Figure 2-10 which is an altered presentation of the coordinate systems shown in Figure 2-9. The result is

$$M_{earth\text{-}sky} = \begin{bmatrix} \sin H & \cos H & 0 \\ -\sin\delta\cos H & \sin\delta\sin H & \cos\delta \\ \cos\delta\cos H & -\cos\delta\sin H & \sin\delta \end{bmatrix} \quad . \tag{2-55}$$

The projection of the baseline vector $\underset{\sim}{L}_j$ onto the plane of the sky tangent to $\underset{\sim}{s}$ is a very significant vector. The length of the projection determines the resolution of the baseline (longer baseline ~ better resolution), and the orientation of the projection determines the direction in which we have the resolution. u and v are the designations used for the east-west and north-south components of the projected baseline, respectively. An additional component, w, is a measure of the relative distance between the source and array center and between the source and any antenna. The u, v, w coordinates for an antenna-oriented description are determined from the transformation matrix, Equation (2-55), and the earth-oriented description of $\underset{\sim}{L}_j$. Thus

$$\underset{\sim}{L}_j = \begin{bmatrix} u_j \\ v_j \\ w_j \end{bmatrix} = \begin{bmatrix} \sin H & \cos H & 0 \\ -\sin\delta\cos H & \sin\delta\sin H & \cos\delta \\ \cos\delta\cos H & -\cos\delta\sin H & \sin\delta \end{bmatrix} \begin{bmatrix} L_{jx} \\ L_{jy} \\ L_{jz} \end{bmatrix}_e \tag{2-56}$$

Executing the matrix product gives

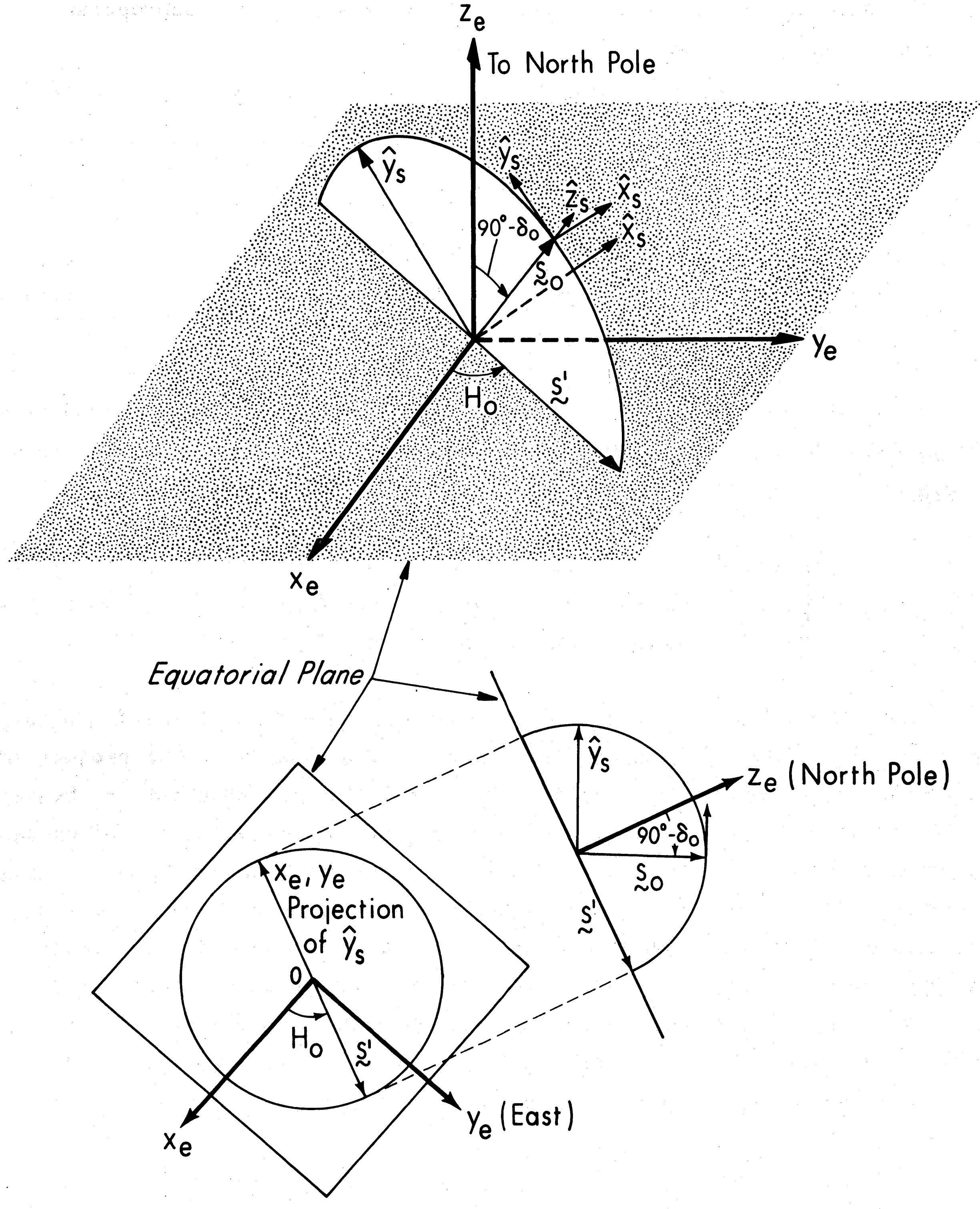


Figure 2-10. Geometrical presentation of earth and sky coordinate systems arranged for convenient determination of Equation (2-55).

$$u_j = L_{jx} \sin H + L_{jy} \cos H \tag{2-57}$$

$$v_j = \sin \delta(-L_{jx} \cos H + L_{jy} \sin H) + L_{jz} \cos \delta \tag{2-58}$$

for the projection of the antenna position vector on the tangent plane of the sky and

$$w_j = \cos \delta(L_{jx} \cos H - L_{jy} \sin H) + L_{jz} \sin \delta \tag{2-59}$$

for the delay in time between the arrival of a wavefront from (α,δ) at the j^{th} antenna and at the center of the array.

Another necessary matrix relates a position (x, y, z,) in the sky-oriented system to the celestial coordinates (α,δ). If a surface segment of a sphere is projected onto a plane tangent to the sphere in the $\underset{\sim}{s}_o$ direction we have

$$\underset{\sim}{s} - \underset{\sim}{s}_o = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_s = \begin{bmatrix} \cos \delta \sin (\alpha-\alpha_o) \\ -\sin \delta_o \cos \delta \cos (\alpha-\alpha_o) + \cos \delta_o \sin \delta \\ \cos \delta_o \cos \delta \cos (\alpha-\alpha_o) + \sin \delta_o \sin \delta - 1 \end{bmatrix} \tag{2-60}$$

Figure 2-11 illustrates the tangent-plane geometry used in deriving Equation (2-60). Relationships for sin (Θ) sin (A) and sin (Θ) cos (A) are determined from the law of cosines and law of sines applied to a spherical triangle defined by (α_o,δ_o), (α,δ) and the north celestial pole.

For the case in which Θ is small $\underset{\sim}{s} - \underset{\sim}{s}_o$ can be approximated as

$$\underset{\sim}{s} - \underset{\sim}{s}_o = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_s \simeq \begin{bmatrix} (\alpha-\alpha_o) \cos \delta_o \\ (\delta-\delta_o) \\ 0 \end{bmatrix} . \tag{2-61}$$

The purpose of most of this discussion has been preparatory to writing explicit expressions for the vector projection $(\underset{\sim}{L}_k - \underset{\sim}{L}_j) \bullet (\underset{\sim}{s} - \underset{\sim}{s}_o)$, i.e.,

$$(\underset{\sim}{L}_k - \underset{\sim}{L}_j) \bullet (\underset{\sim}{s} - \underset{\sim}{s}_o) = (u_k - u_j, v_k - v_j, w_k - w_j) \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$= u_{jk}x + v_{jk}y + w_{jk}z \tag{2-62}$$

$$= ux + vy + wz$$

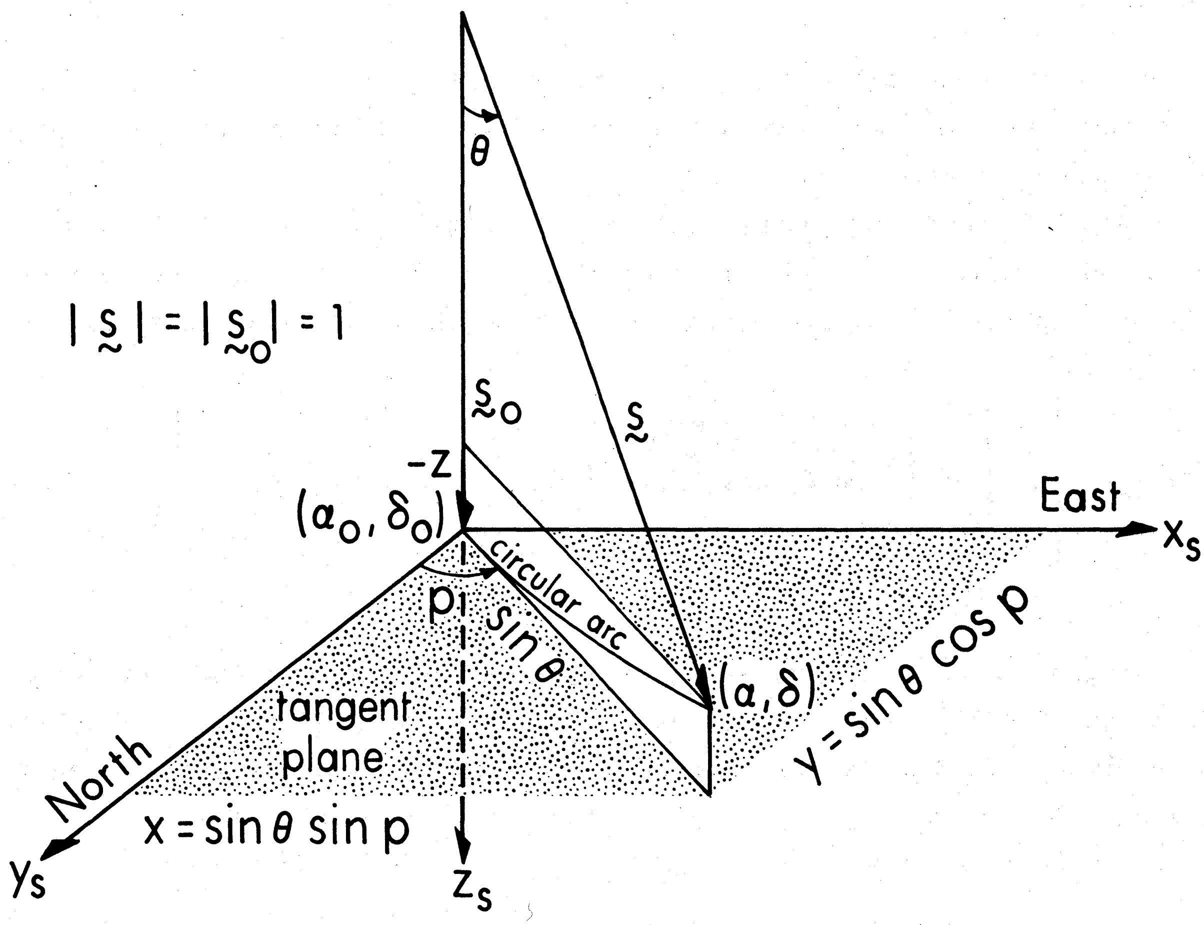


Figure 2-11. Inverted presentation of (x_s, y_s, z_s) coordinate system shown in Figure 2-9. Note that the line-of-sight path along s does not extend to the tangent plane.

where $u_{jk} = u_k - u_j$, $v_{jk} = v_k - v_j$, and $w_{jk} = w_k - w_j$. The units of u,v,w are seconds of time. We have adopted a convention that will be used frequently whereby the lack of subscripts indicates the j-k pair; that is, $(u, v, w,) = (u_{jk}, v_{jk}, w_{jk})$. For the case in which the tangent plane approximation to the celestial sphere is valid, we have

$$(\underset{\sim}{L}_k - \underset{\sim}{L}_j) \bullet (\underset{\sim}{s} - \underset{\sim}{s}_o) \simeq u_{jk}x + v_{jk}y = ux + vy. \tag{2-63}$$

Because we will need to be careful about when we use Equation (2-62) and when the approximate Equation (2-63) is sufficient, let us evaluate the conditions under which the wz term can be neglected. From Figure 2-11 it can be seen that

$$z = \cos\theta - 1 \simeq -\theta^2/2 \tag{2-64}$$

so one can evaluate the importance of the zw term by putting it in terms of a phase

$$\phi_z = \omega_o w\theta^2/2 \tag{2-65}$$

where ω_o is the angular radio frequency. Letting w = B/c, and putting B in units of a 35-kilometer baseline and Θ in arcminutes

$$\phi = (53/\lambda cm)(B_{km}/35)\ \theta^2_{arcmin} \quad \text{degrees} \quad . \tag{2-66}$$

B_{km} will range up to 35 and Θ will typically range up to either $\Theta_{HPBW/2}$ (c.f., Equation 2-1) or one-half the delay beamwidth caused by use of finite band-passes,

$$\Theta_{delay} \simeq 1.2(50/\Delta\nu_{MHz})(35/B_{km}) \quad \text{arcminutes} \tag{2-67}$$

depending upon which is smaller. For the two cases

$$\Theta^{max} = \Theta_{HPBW}/2 \quad \Theta_{delay}/2,\ \phi^{max}_z = 38\ \lambda cm(B_{km}/35) \quad \text{degrees} \tag{2-68}$$

and

$$\Theta^{max} = \Theta_{delay}/2 \quad \Theta_{HPBW}/2,\ \phi^{max}_z = (18/\lambda cm)(35/B_{km})(50/\Delta\nu_{MHz}) \text{ degrees} \tag{2-69}$$

7. VISIBILITY FUNCTION FOR A POINT SOURCE

Let I, Q, U, and V_c be the Stokes parameters for a point source located at a position $\underset{\sim}{s}$ which is observed with a reference position $\underset{\sim}{s}_o$. Combining Equations (2-43) through (2-46) with Equation (2-62), the four corrected, calibrated correlator visibilities for this point source can be written as

$$V_{jkLL} = (I + V_c) \exp [i\omega_o(ux + vy + wz)] \tag{2-70}$$

$$V_{jkRR} = (I - V_c) \exp [i\omega_o(ux + vy + wz)] \tag{2-71}$$

$$V_{jkLR} = (Q - iU) \exp [i\omega_o(ux + vy + wz)] \tag{2-72}$$

and

$$V_{jkRL} = (Q + iU) \exp [i\omega_o(ux + vy + wz)] \tag{2-73}$$

neglecting noise effects, where $(\underset{\sim}{s}-\underset{\sim}{s}_o) = (x,y,z)$, and $(\underset{\sim}{L}_k-\underset{\sim}{L}_j) = (u,v,w)$ in units of time. If we denote the visibility functions for the four Stokes parameters by V_{jkI}, V_{jkQ}, V_{jkU}, and V_{jkV} , then

$$V_{jkI} = S_\nu \exp [i\omega_o(ux + vy + wz)] \tag{2-74}$$

$$V_{jkQ} = Q \exp [i\omega_o(ux + vy + wz)] \tag{2-75}$$

$$V_{jkU} = U \exp [i\omega_o(ux + vy + wz)] \tag{2-76}$$

and

$$V_{jkV_c} = V_c \exp [i\omega_o(ux + vy + wz)] \tag{2-77}$$

where we explicitly identify the I Stokes parameter with the flux density S_ν. Under many circumstances we can neglect wz compared with (ux + vy), but we will carry the extra term in what follows even in those cases in which it is negligible. We will also frequently consider only the I Stokes parameter visibility, V_{jkI}, both because it is the most important and because from Equations (2-74) to (2-75) the functional forms of the others are the same. Equation (2-77) is strictly true only when the source does not have a large linear polarization. The treatment of polarization in this chapter, starting with Equation (2-34), will not handle the exceptional case of a highly elliptically polarized source.

8. VISIBILITY FUNCTION FOR AN EXTENDED SOURCE

We can now derive the equations for the visibility produced by observations of an extended source. We assume measured visibilities have been corrected and calibrated. Our derivation is based upon the principle that any infinitesimal region of the sky can be treated as a point source of radiation as far as any single interferometer pair is concerned. Let (α,δ) be the location of an infinitesimal solid angle $d\Omega$. By definition, the flux density S_ν for any source with an intensity distribution $I_\nu(\alpha,\delta)$ for the first Stokes parameter is given by

$$S_\nu = \iint_{\text{source}} I_\nu(\alpha,\delta)\,d\Omega \tag{2-78}$$

where $d\Omega = \cos\delta\ d\alpha\ d\delta$. Therefore, radiation from the infinitesimal solid angle $d\Omega$ can be considered to make an infinitesimal contribution to the flux density. If we further define $P(\alpha-\alpha_o,\delta-\delta_o)$ to be the normalized antenna power pattern, the contribution of the solid angle $d\Omega$ to the visibility function is given by the following generalization of Equation (2-74):

$$dV_{jkI}(\alpha,\delta) = P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)\ \exp\left[i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o)\right]d\Omega \tag{2-79}$$

where for convenience we now drop the frequency subscripts. Integrating Equation (2-79) over the antenna beam, we get the integrated or total visibility

$$V_{jkI} = \iint P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)\ \exp\left[i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o)\right](\cos\delta)d\alpha d\delta. \tag{2-80}$$

The equations for V_{jkQ}, V_{jkU}, and V_{jkV} are altered accordingly with the $I(\alpha,\delta)$ distribution functions replaced by the spatial distribution function of the appropriate Stokes parameters.

Equation (2-80) is the complex Fourier transform of the apparent intensity distribution $P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$. It is because of this that <u>we can describe any single complex visibility measurement as a single Fourier component of $P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$.</u> Since Equation (2-80) is a Fourier integral, we can invoke all that we know about Fourier transforms to analyze and interpret interferometric data. In particular, we know how, in principle, to determine $P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$ from VLA data by the Fourier inversion integral

$$\cos\delta\, P(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta) = \iiint V_I \exp[-i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\bullet(\underset{\sim}{s}-\underset{\sim}{s}_o)]dudvdw. \quad (2\text{-}81)$$

The reader will note that Equation (2-80) is a two-dimensional integral over the celestial sphere, whereas Equation (2-81) is, in principal, a three-dimensional integral. Indeed, converting from (α,δ) to (x,y,z) using Equation (2-60) through (2-62) one transforms Equation (2-80) into

$$V_I(u,v,w) = \iint P(x,y)I(x,y) \exp[-i\omega_o(ux+vy+wz)]dxdy \quad (2\text{-}82)$$

where the integral is evaluated for $z \simeq -(\frac{1}{2})(x^2+y^2)$ on the celestial sphere, and Equation (2-81) becomes

$$P(x,y,z)I(x,y,z) = \iiint V_I(u,v,w) \exp[i\omega_o(ux+vy+wz)]dudvdw. \quad (2\text{-}83)$$

Equation (2-83) needs the additional constraint $z \simeq -(\frac{1}{2})(x^2+y^2)$ to get the "correct" radiation distribution on the celestial sphere.

In practice, one makes a finite number of discrete measurements of $V_I(u,v,w)$ for finite integration times, so Equation (2-83) will be rewritten as the following summation equation:

$$\begin{aligned} P(x,y)I(x,y) = &\sum_{\substack{\text{measured}\\ u,v,w}} [V_I(u,v,w)\exp[-\omega_o(ux+vy+wz) \\ &\qquad +V_I^*(u,v,w)\exp[+\omega_o(ux+vy+wz)]\ \Delta u\Delta v\Delta w \\ + &\sum_{\substack{\text{unmeasured}\\ u,v,w}} [V_I(u,v,w)\exp[-\omega_o(ux+vy+wz) \\ &\qquad + V_I^*(u,v,w)\exp[+\omega_o(ux+vy+wz)]\ \Delta u\Delta v\Delta w. \end{aligned} \quad (2\text{-}84)$$

In Equation (2-84) we have invoked the Hermitian properties of V_I, $V_I(-u,-v,-w) = V_I^*(u,v,w)$, that are required for the left-hand side of Equations (2-83) and (2-84) to be real. We have also conceptually separated measured and unmeasured visibilities.

9. SPECTRAL LINE VISIBILITY

The visibility function for a spectral line system can be easily developed as an extension of the material in Section 8. We start with Equation (2-82) by adding a delay τ to the exponential function giving

$$\iint P(x,y)\, I(x,y) \exp -i[2\pi\nu\tau+2\pi\nu(ux+vy+wz)]\, dx\, dy.$$

In the system this delay is located with the other delays shown in the oval in Figure 2-5. It is alternately positioned in one antenna path and then the other so that we effectively have positive and negative lags.

Next, we integrate over the bandwidth to give

$$V_I(u,v,w,\tau) = \iiint P(x,y,\nu) I(x,y,\nu) b(\nu) \bullet \exp -i[2\pi\nu\tau+2\pi\nu(ux+vy+wz)]\, dx dy d\nu \quad (2\text{-}85)$$

where $b(\nu)$ is the frequency passband function.

Following the correlators, a synchronous computer and array processor calculate the Fourier transform of the visibility with respect to the delay τ. Since both positive and negative lags are used in the system only the real part of the visibility function is necessary. This will be shown below. The real part of the visibility function can be represented as

$$\begin{aligned} \mathrm{Re}\{V_I(u,v,w,\tau)\} = {} & \tfrac{1}{2}\iiint P(x,y,\nu)\, I(x,y,\nu)\, b(\nu) \\ & \bullet \exp\{-i[2\pi\nu\tau + 2\pi\nu(ux+vy+wz)]\}\, dx\, dy\, d\nu \\ & + \tfrac{1}{2}\iiint P(x,y,\nu)\, I(x,y,\nu)\, b(\nu) \\ & \bullet \exp\{+i[2\pi\nu\tau + 2\pi\nu(ux+vy+wz)]\}\, dx\, dy\, d\nu. \end{aligned}$$

Now take the Fourier transform with respect to τ and re-arrange the integrals to integrate on τ first. Note that the limits on all integrals are over the entire range of the functions in the integrand.

$$\int_{-\infty}^{\infty} \mathrm{Re}\{V_i(u,v,w,\tau)\} e^{i2\pi\nu'\tau}\, d\tau$$

$$= \tfrac{1}{2} \iint P(x,y,\nu)\, I(x,y,\nu)\, b(\nu) e^{i2\pi\nu(ux+vy+wz)} \int_{-\infty}^{\infty} e^{-i2\pi(\nu-\nu')\tau}\, d\tau\, dx\, dy\, d\nu$$

$$+ \tfrac{1}{2} \iint P(x,y,\nu)\, I(x,y,\nu)\, b(\nu) e^{+i2\pi\nu(ux+vy+wz)} \int_{-\infty}^{\infty} e^{+i2\pi(\nu+\nu')\tau}\, d\tau\, dx\, dy\, d\nu$$

The two integrals over τ give $\delta(\nu-\nu')$ and $\delta(\nu+\nu')$ respectively. Thus it is simple to integrate next with respect to ν. The result is

$$\int_{-\infty}^{\infty} \mathrm{Re}\{V_I(u,v,w,\tau)\} e^{i2\pi\nu\tau} d\tau$$

$$= \tfrac{1}{2} \iint_{-\infty}^{\infty} P(x,y,\nu)\ I(x,y,\nu)\ b(\nu)\ e^{-i2\pi\nu(ux+vy+wz)} dx\ dy$$

$$+ \tfrac{1}{2} \iint_{-\infty}^{\infty} P(x,y,-\nu)\ I(x,y,-\nu)\ b(\nu)\ e^{+i2\pi\nu(ux+vy+wz)} dx\ dy$$

Where the prime on ν has been dropped. $P(x,y,\nu)$ and $I(x,y,\nu)$ are even functions since their time domain counterparts are real functions. Hence our result reduces to

$$\int_{-\infty}^{\infty} \mathrm{Re}\{V_I(u,v,w,\tau)\} e^{i2\pi\nu\tau} d\tau = \iint P(x,y,\nu)\ I(x,y,\nu)\ b(\nu) e^{-i2\pi\nu(ux+vy+wz)} dx\ dy \qquad (2\text{-}86)$$

The right hand side of Equation (2-86) appears to be the same as the right hand side of Equation (2-82). The difference is that Equation (2-82) is the visibility at the center radio frequency and Equation (2-86) is the visibility at one of the frequencies determined by the Fourier transform on τ. Thus the Fourier transform of the real part of V_I contains all the necessary visibility information for mapping the source at frequency ν. Theoretically Equation (2-86) is an infinite continuous visibility function over all frequencies. In practice we would have a finite number of discrete frequencies determined by the number of lags in the system. Information on the number of available frequency channels versus bandwidth is given in Chapter 3. One additional requirement for spectral line work which is not necessary for continuum work is that the bandpass function $b(\nu)$ must be determined. Calibration procedures for this are discussed in Chapter 12.

10. U-V PLANE COVERAGE

The values of (u,v,w) for which measurements of V_I are made determine the quality of radio image reconstruction from visibility measurements. This is mostly a question of u-v coverage, and for the purposes of this section we will not consider the effects of w.

The ideal circumstance would be complete and uniform sampling of all (u,v) within a circular region in the so-called u-v plane. In practice,

$$u = u_k - u_j = (L_{kx} - L_{jx}) \sin H + (L_{ky} - L_{jy}) \cos H \quad (2\text{-}87)$$

and

$$v = v_k - v_j = \sin \delta \, [-(L_{kx} - L_{jx}) \cos H + (L_{ky} - L_{jy}) \sin H] + (L_{kz} - L_{jz}) \cos \delta , \quad (2\text{-}88)$$

and from these equations one can show that, for a particular antenna pair, u and v are related to each other by

$$(u/a)^2 + (v - v_o)^2/b^2 = 1 \quad (2\text{-}89)$$

which is the equation for an ellipse, where

$$a = [(L_{kx} - L_{jx})^2 + (L_{ky} - L_{jy})^2]^{\frac{1}{2}} , \quad (2\text{-}90)$$

$$b = a \sin \delta , \quad (2\text{-}91)$$

and

$$v_o = (L_{kz} - L_{jz}) \cos \delta . \quad (2\text{-}92)$$

The u-v ellipse for a particular antenna pair has a center located at (u=0, $v=v_o$), with a major axis a, a minor axis b, and an eccentricity cos δ. The size of each u-v ellipse is, to first order, proportional to the physical separation between antennas, $\underset{\sim}{B}_{jk} = \underset{\sim}{L}_k - \underset{\sim}{L}_j$. The u-v plane coverage formed by the 351 ellipses of the full 27 antenna VLA for A, B, C, or D configurations is shown for δ = 80°, 60°, 40°, 20°, 0°, -20°, and -40° in Figure 2-12. These ellipses are for continuous, elevation-limit-to-elevation-limit tracking for δ < 64° and 24^h tracking for δ > 64°. Each measured (u-v) ellipse and the conjugate (-u,-v) ellipse are plotted, making 702 ellipses or segments of ellipses for each case in Figure 2-12.

Examination of Figure 2-12, with an eye to selecting the circular region of measurement to be used in reconstructing radio images, allows one to evaluate the location and severity of the problem of unmeasured u-v.

11. RADIO IMAGE RECONSTRUCTION BY DIRECT TRANSFORM

A direct transform of measured visibilities into a radio image map can be obtained by neglecting the portion of Equation (2-84) dealing with nonmeasured visibilities and approximating P(x,y)I(x,y) by

$$P(x,y)I(x,y) \approx \frac{\sum\limits_{\substack{\text{measured}\\u,v}} [V_I e^{-i\omega_o(ux+vy+wz)} + V_I^* e^{i\omega_o(ux+vy+wz)}]W(u,v)T(u,v)}{\sum\limits_{\substack{\text{measured}\\u,v}} W(u,v)T(u,v)} \qquad (2\text{-}93)$$

where $\Delta u\Delta v\Delta w$ has been replaced by an arbitrary weighting function W(u,v) and an arbitrary tapering function T(u,v). Taking W(u,v) = 1 results in the so-called "natural" weighting, while taking W(u,v) = 1/N(u,v) results in the so-called "uniform" weighting, where N(u,v) is a function describing the relative density of measurements in the u-v plane. The tapering function T(u,v) allows an additional relative degree of emphasis of low resolution measurements vs. high resolution measurements. The most frequently used taper function is a Gaussian,

$$T(u,v) = \exp\left[-(u/u_{taper})^2 - (v/v_{taper})^2\right] \qquad (2\text{-}94)$$

where u_{taper} and v_{taper} are free parameters usually taken to be the same.

12. POINT SOURCE IMAGES FOR THE FULL VLA

We know the visibility function for a point source from Equation (2-74). A point source exactly at the reference position will have $V_I = S_\nu$ where S_ν is the flux density. Because of this, one can evaluate the quality of a VLA radio image for any specified u-v coverage by calculating

$$P(x,y)I(x,y) \approx \frac{\sum\limits_{\substack{\text{measured}\\u,v,w,}} 2S_\nu \cos[\omega_o(ux+vy+wz)]W(u,v)T(u,v)}{\sum\limits_{\substack{\text{measured}\\u,v,w}} W(u,v)T(u,v)} \qquad (2\text{-}95)$$

which is obtained from Equation (2-93) for a point source at the reference position.

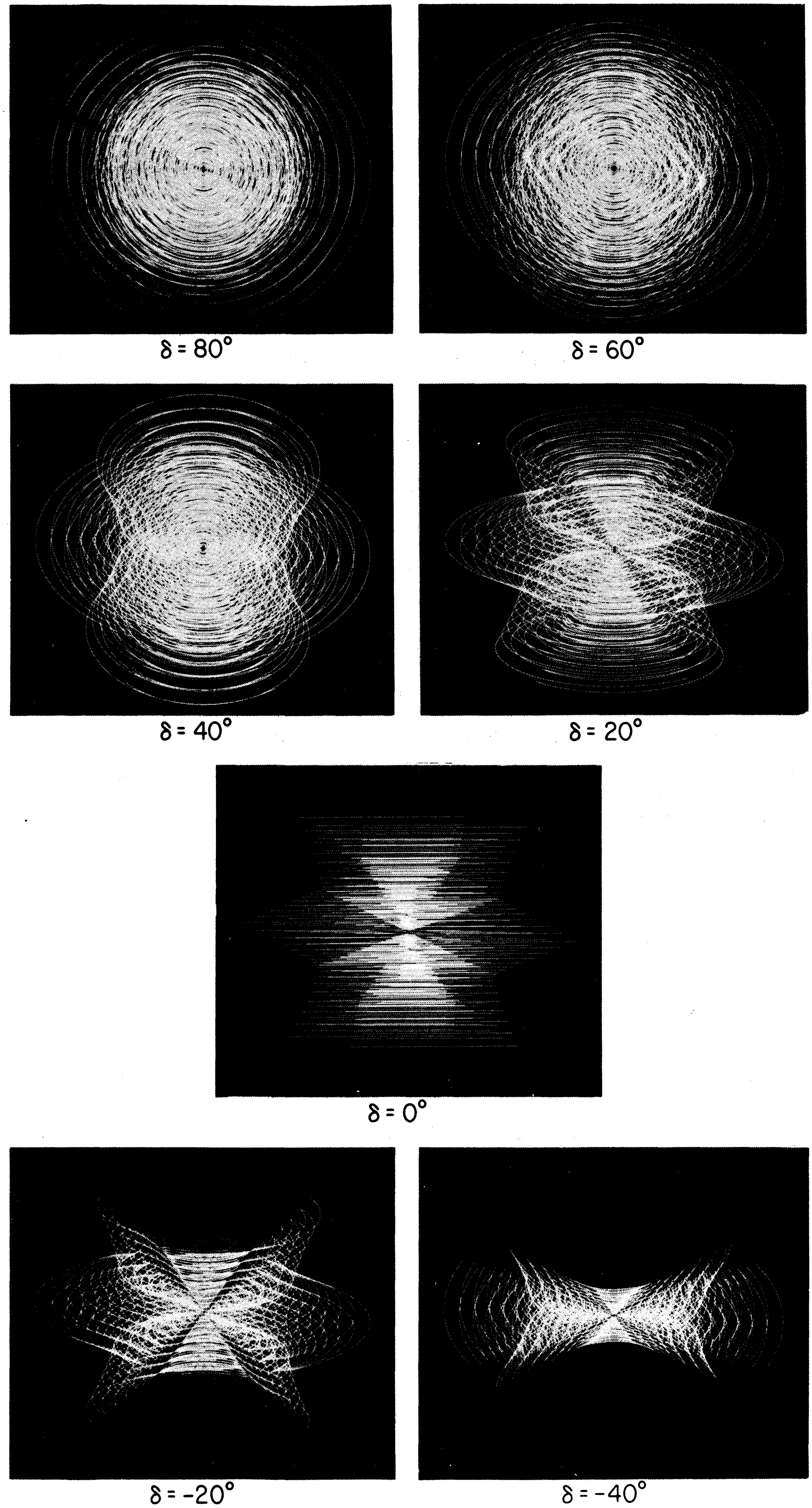


Figure 2-12. The possible u-v plane coverage for the 27-antenna VLA for declinations of 80°, 60°, 40°, 20°, 0°, -20°, and -40°.

Point source image responses are sometimes called the synthesized beam or dirty beam, and sometimes called the point spread function. The synthesized beams made from uniform weighting mapping, for 27 antennas with full coverage tracking of sources as $\delta = 60°$, $30°$, $0°$, and $-30°$, are then shown in Figure 2-13. The central beams in Figure 2-13 are truncated to the 10% level.

The VLA with 27 antennas produces 351 baselines. The instantaneous u-v plane coverage, made up of the 702 points produced at any instant, is always in the form of a six-pointed star, with varying distortions for different declinations and hour angles. Figure 2-14 shows an instantaneous u-v plane distribution and synthesized beam for a source at $\delta = 30°$, $H = 0$. The principal sidelobe level in this map, made with uniform weighting, is 27%. More extensive observing of sources at this declination will result in improved beam shape and lower sidelobes. For example, Table 2-2 shows the decrease of maximum sidelobe level in the inner one-fourth and outer three-fourths of the beam as data on a source at $\delta = 30°$ increases.

Figure 2-15 shows the change in beam shape for the $\delta = 30°$ buildup map, showing the map with fifteen minutes, one hour, two hours, six hours, and twelve hours of integration time.

Table 2-2

Sidelobe Levels for $\delta = 30°$ Buildup Map

H_{start}	H_{stop}	H_{range}	Inner 1/4 Maximum Sidelobe Level	Outer 3/4 Maximum Sidelobe Level
-6^h	$-5^h\,45^m$	15^m	27%	12%
-6^h	$-5^h\,30^m$	30^m	16	4
-6^h	-5^h	1^h	9	4
-6^h	-4^h	2^h	8	3
-6^h	-3^h	3^h	7	2
-6^h	-2^h	4^h	5	2
-6^h	0^h	6^h	3	2
-6^h	$+6^h$	12^h	3%	<1%

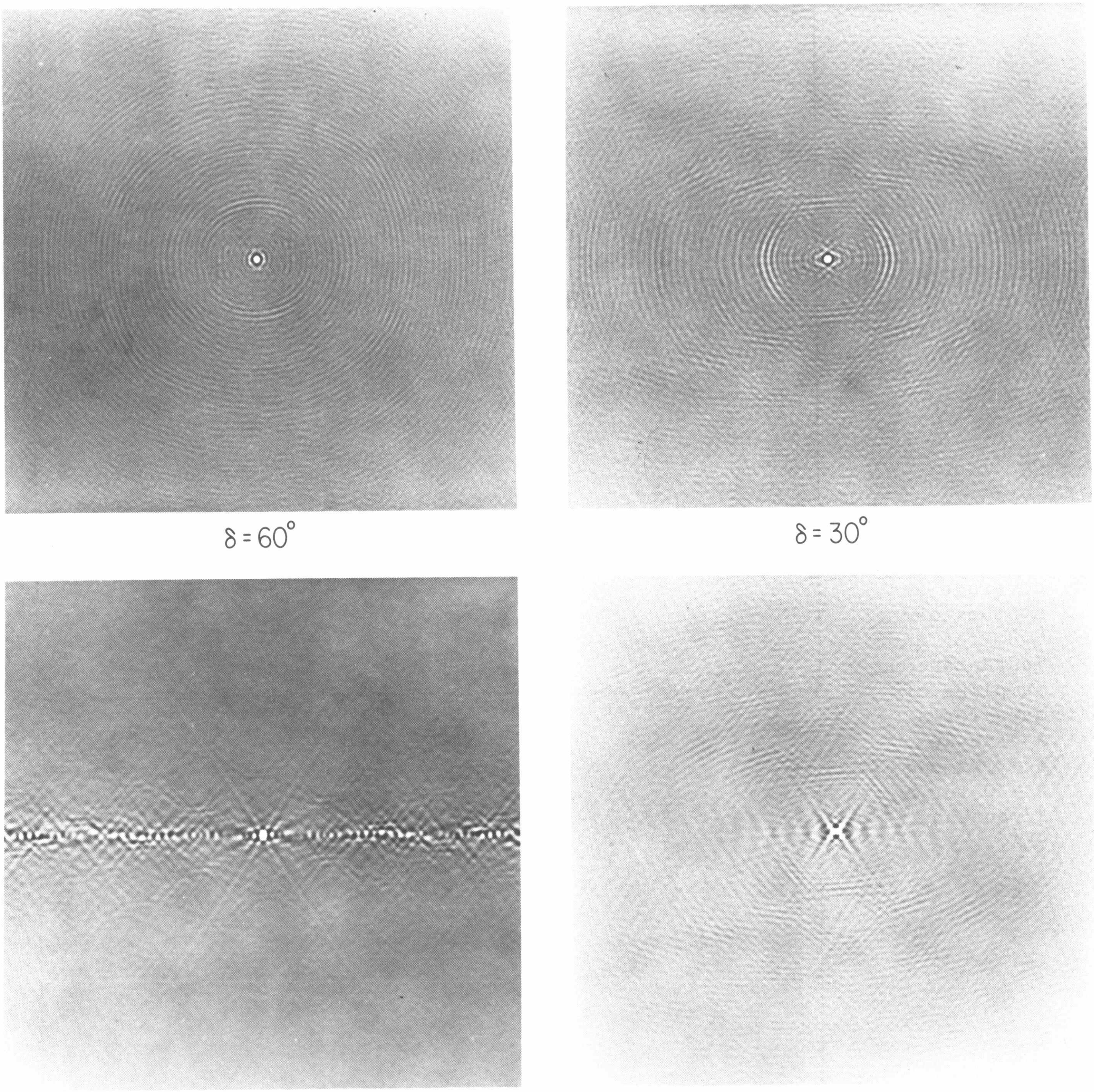
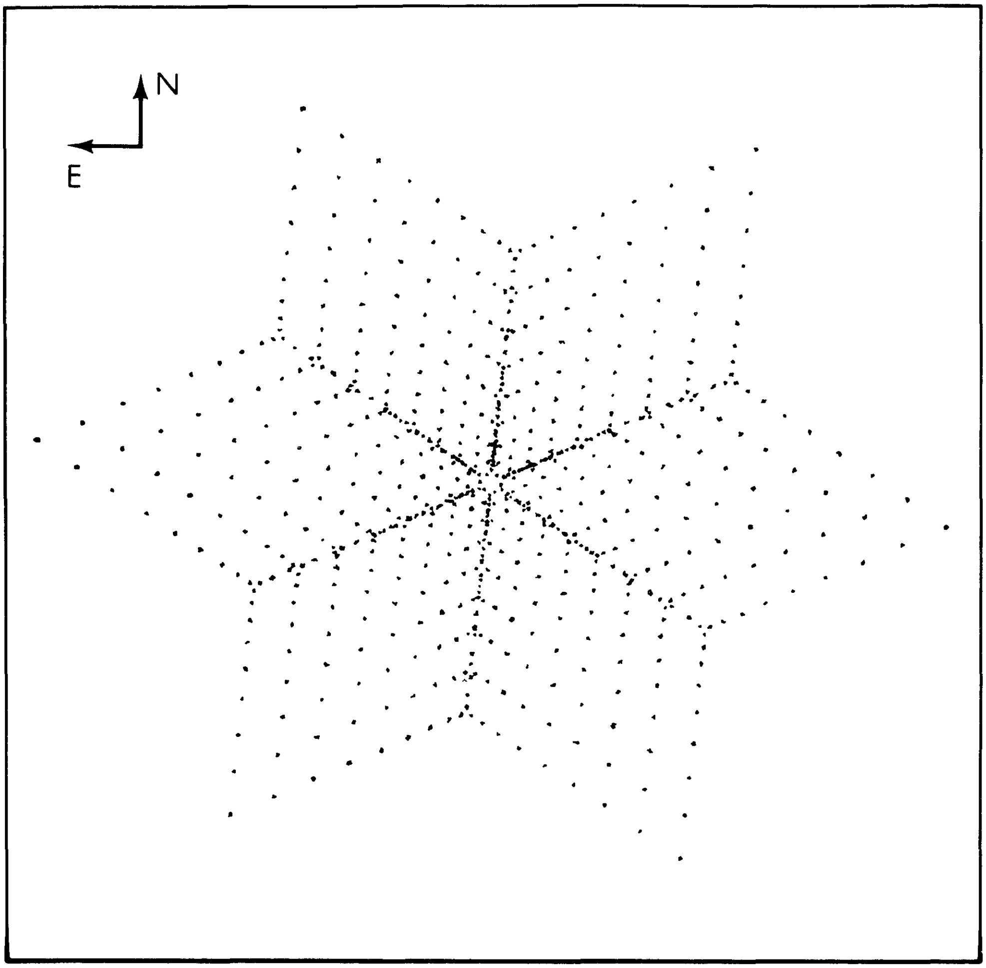


Figure 2-13. The synthesized beams for full tracking coverage of the 27-antenna VLA for a number of declinations. The main beam has been truncated to the 90% level to allow sidelobe patterns to be more visible.



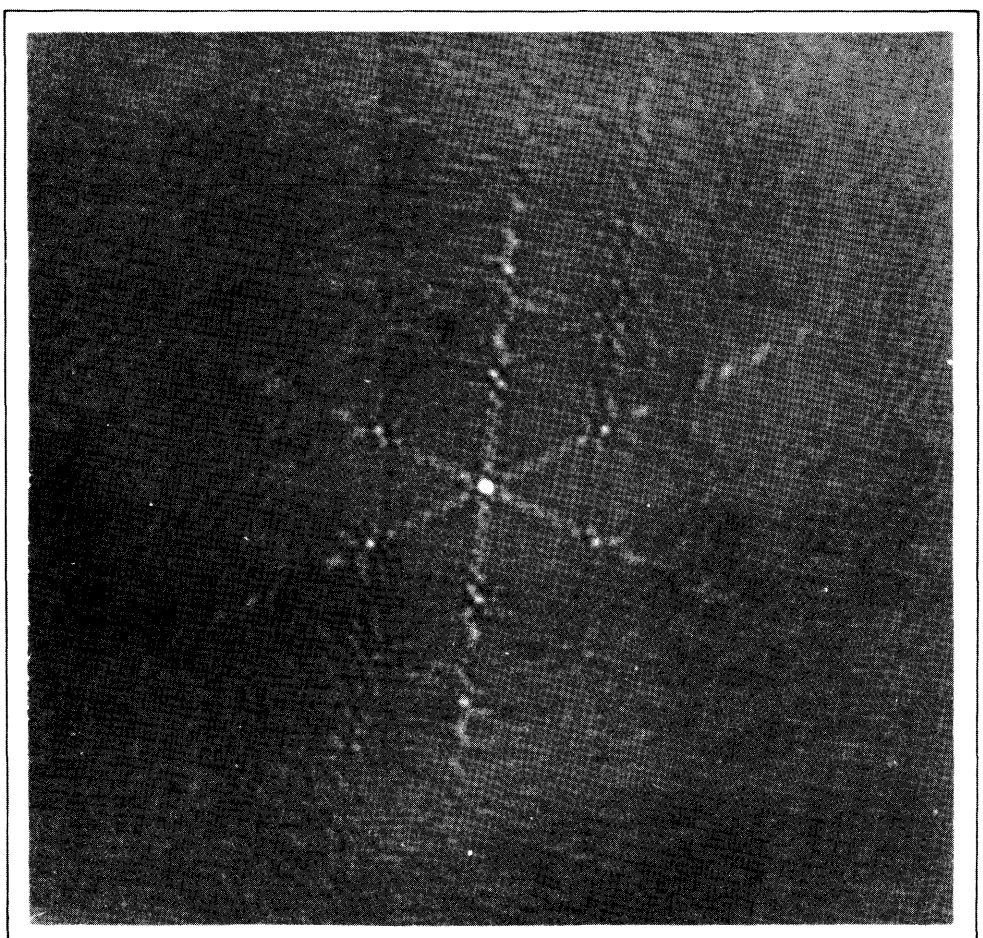


Figure 2-14. The u-v plane coverage and synthesized beam for an instantaneous sampling of data for a source at $\delta = 30°$ and $H = 0$ for a 27-antenna VLA.

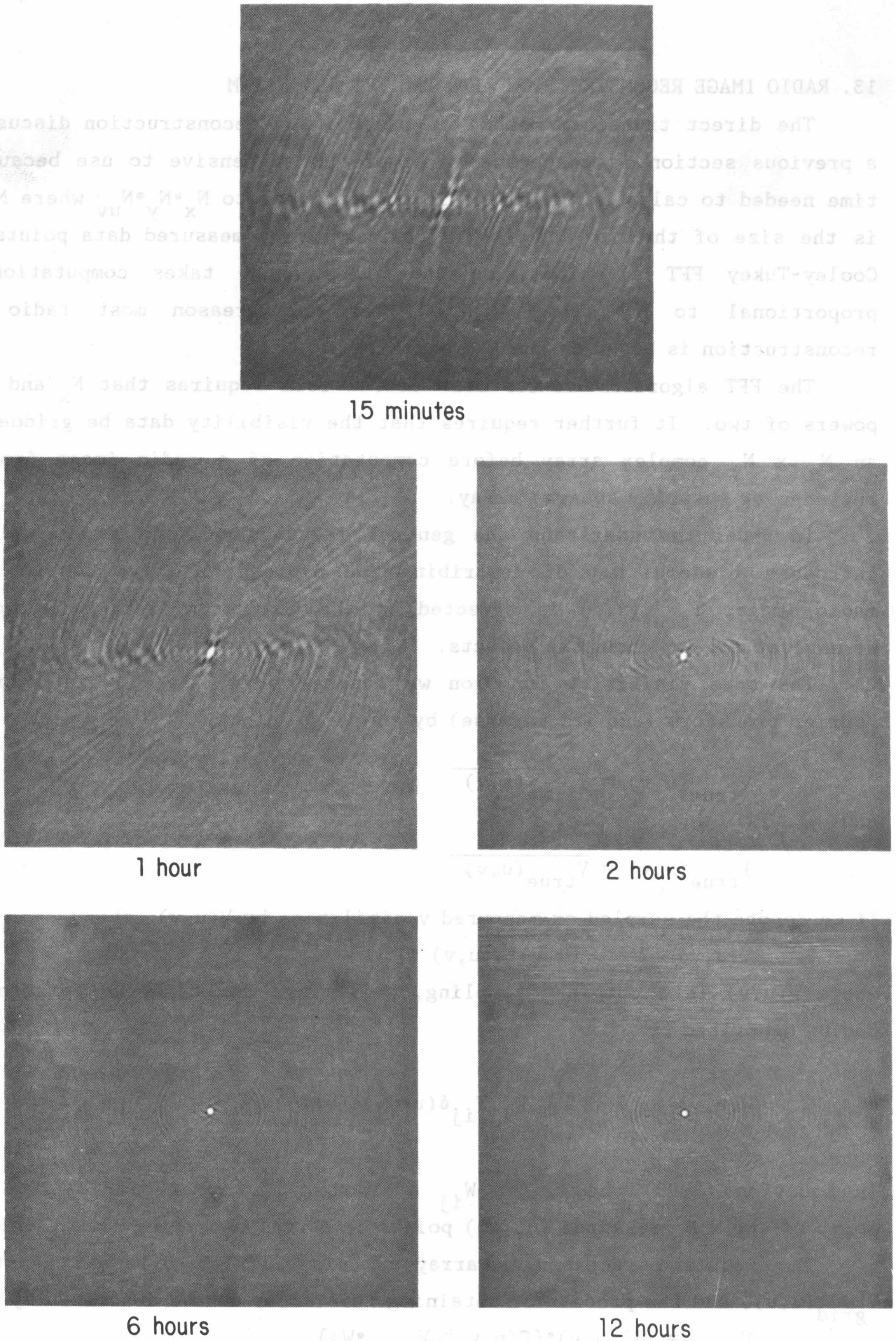


Figure 2-15. The changing synthesized beam patterns for a buildup map made from data continuously added to maps of a source at $\delta = 30°$, observed from $H = -6^h$ to $H = +6^h$ with a 27-antenna VLA.

13. RADIO IMAGE RECONSTRUCTION WITH THE FFT ALGORITHM

The direct transform method of radio image reconstruction discussed in a previous section is conceptually simple but expensive to use because the time needed to calculate an image is proportional to $N_x \bullet N_y \bullet N_{uv}$ where $N_x \times N_y$ is the size of the map and N_{uv} is the number of measured data points. The Cooley-Tukey FFT algorithm, on the other hand, takes computation time proportional to $N_x N_y \log (N_x N_y)$. For this reason most radio image reconstruction is based on the FFT algorithm.

The FFT algorithm in its most useful form requires that N_x and N_y are powers of two. It further requires that the visibility data be gridded into an $N_x \times N_y$ complex array before computation of a radio image from this rectangular (usually square) array.

In order to understand the general features of this process, let us introduce a useful way of describing the process in terms of how a true radio image, $I_{true}(x,y)$ is affected by the major computational processes. We neglect all instrumental effects.

The true visibility function we denote by $V_{true}(u,v)$, and denote the Fourier transform (and its inverse) by an overhead bar,

$$V_{true}(u,v) = \overline{I_{true}(x,y)} \tag{2-96}$$

and

$$I_{true}(x,y) = \overline{V_{true}(u,v)} \quad . \tag{2-97}$$

If we denote the sampled or measured visibilities by V(u,v), then

$$V(u,v) = V_{true}(u,v) \bullet W(u,v) \quad , \tag{2-98}$$

where W(u,v) is a combined sampling, weighting, and tapering function that can be described by

$$W(u,v) = \sum_{i=1}^{N_u} \sum_{j=1}^{N_v} W_{ij} T_{ij} \delta(u-u_i)\delta(v-v_j) \quad . \tag{2-99}$$

In Equation (2-99) the weight W_{ij} and taper T_{ij} are those for the i,j-th point of the $N_u N_v$ measured (u_i,v_j) points in a real observing situation.

The required rectangular array of visibilities will be denoted by $V_{grid}(u,v)$, and the process of obtaining this array can be described by

$$V_{grid} = III(u,v) \bullet \{C(u,v) * (V_{true} \bullet W)\} \tag{2-100}$$

where * indicates convolution (in two dimensions in this case) and

$$III(u,v) = \sum_{\ell=1}^{N_x} \sum_{m=1}^{N_y} \delta(u-u_\ell)\delta(v-v_m) \qquad (2\text{-}101)$$

is a two-dimensional sampling (shah) function which has nonzero values only on the grid points (u_ℓ, v_m) of a rectangular array of size N_x x N_y, where both N_x and N_y are powers of two. The purpose of the convolution function, C(u,v), is to smooth the irregularly sampled data so that the result can be uniformly sampled by III(u,v).

The radio image or map is obtained from the Fourier transform of V_{grid}, so from Equations (2-97) and (2-100) we get

$$I(x,y) = \overline{III} * \{\bar{C} \bullet (\bar{W} * I_{true})\} \quad . \qquad (2\text{-}102)$$

We used the convolution theorem for Fourier transforms

$$\overline{A*B} = \bar{A} \bullet \bar{B} \qquad (2\text{-}103)$$

and its close relative

$$\overline{A \bullet B} = \bar{A} * \bar{B} \quad . \qquad (2\text{-}104)$$

The point spread function or synthesized beam is found by setting $I_{true}(x,y)$ = $\delta(x)\delta(y)$ in Equation (2-102)

$$I_{beam}(x,y) = \overline{III} * \{ \bar{C} \bullet \bar{W} \} \quad . \qquad (2\text{-}105)$$

The function W is a type of point spread function obtained purely from the sampling, weighting, and tapering of original measurements. The function $I_{beam}(x,y)$ is a modified point spread function including the effects of convolution before gridding and the gridding process itself.

The Fourier transform of the shah function is again a shah function with adjacent delta functions separated by the reciprocal of the separation in the untransformed domain. Thus if the separation between two adjacent delta functions is four units in the uv plane, the separation is one-fourth unit in the xy plane. The result of convolving III with C W is to replicate C W about each delta function. If the sampling interval is too large in the uv plane (called undersampling), the consequentially smaller sampling interval in the xy plane will cause adjacent replications of C W to overlap. This effect is called aliasing because high frequencies can impersonate low frequencies in this overlap area. The effects of aliasing caused by real sources are reduced when the mapped area corresponds to the main antenna beam, outside of which, sensitivity to sources is greatly reduced. In addition, the convolution with C during the process of gridding causes a point outside the mapped area to be reduced in intensity by the ratio $C(x_a,y_a)/C(x_m,y_m)$ when aliased into the map at the point (x_m,y_m). The ideal case where this ratio is zero would be obtained if C(u,v) were a two-dimensional sinc function, but the computing time would be very large. Under many practical circumstances C(u,v) can be taken to be a two-dimensional Gaussian with the convolution applied only over a small range of u-v points, which results in a considerable reduction in aliasing. The simplest convolution function is the so-called box convolution where all data within half a cell of a grid point are complex averaged into a single visibility. Aliasing badly attenuated when box convolution is used.

14. MAP SIZES AND THE NUMBER OF POINTS PER SYNTHESIZED BEAM

An aperture with a diameter B will have a half-power beamwidth (HPBW) given by

$$\Theta_{HPBW} = 1.24\ (\lambda/B)\ \text{radians} \quad . \qquad (2\text{-}106)$$

Let us denote the number of points per synthesized beam by N_{pts} and the size of a radio map by $N_x \times N_y$. For a map size equal to Θ_{HPBW} of a VLA antenna, the number of linear points in a map can then be derived from N_{pts} times the ratio of Θ_{HPBW} for a VLA antenna (Equation (2-1)) and the Θ_{HPBW} for a synthesized aperture of size B_{km} (Equation (2-106)), e.g.,

$$N_x = 34\ N_{pts}\ B_{km} \quad . \qquad (2\text{-}107)$$

The values of N_{pts} that are desirable range from a minimum of 2 to a display or map cleaning oriented value of 4 or 5. In practice, Equation (2-107) is basically for a synthesized aperture with uniform weighting and no tapering. Natural weighting and tapering broaden the synthesized beam so that smaller map sizes (N_x,N_y) will suffice for a particular N_{pts}. Table 2-3 gives the map sizes for N_{pts} = 2 and 4 for the arm length of each configuration.

In practice, N_x and N_y must be powers of 2, so that reasonable maps of 4 or more points per beamwidth will be made for apertures in the A, B, C and D configurations by taking N_x or N_y equal to 8192, 2048, 1024, and 128. The trade-offs in mapping regions larger than the antenna HPBW, selecting different values of N_{pts}, or choosing u-v plane apertures larger or smaller than array arm lengths are obvious.

Table 2-3

Map Sizes for Different Configurations

Configuration	Arm Length, km	N_x or N_y	
		$N_{pts} = 2$	$N_{pts} = 4$
A	21	2560	5121
B	6.4	780	1560
C	1.95	237	475
D	0.60	36	72

15. GRIDDING, CELL SIZES, AND THE SAMPLING THEOREM

Let us denote cell spacings or cell sizes of radio maps by $(\Delta x, \Delta y)$ and of gridded u-v plane apertures by $(\Delta u, \Delta v)$. The angular size of field of view for a map is then $(N_x \Delta x, N_y \Delta y)$ and the size of the gridded u-v aperture $(N_x \Delta u, N_y \Delta v)$. The use of the FFT algorithm in radio image reconstruction imposes a constraint between the cell sizes in the u-v plane and the angular size of a map because of the sampling theorem. For an overall u range of $N_x \Delta u \nu_o = u_c$ in radians (u_c is called the cutoff frequency) we must sample in the x domain at an interval of $1/(2u_c)$. Thus we have

$$\Delta u = 1/(2N_x \Delta x \nu_o) \tag{2-108}$$

and similarly

$$\Delta v = 1/(2N_y \Delta y \nu_o) \tag{2-109}$$

where ν_o is the observing frequency, Δu and Δv are in units of time, and Δx and Δy are in units of radians. The relation between a gridded u-v plane for the full VLA observing source at $\delta = 40°$ and the corresponding radio map of a point source is shown in Figure 2-16.

If we select $B_{km} \times B_{km}$ to be the size of the u-v plane aperture we grid for mapping, then $N_y \Delta v c = N_x \Delta u\, c = 10^5\, B_{km}$ with c in cm/s, and Equations (2-108) and (2-109) can be used to obtain

$$\Delta x = \Delta y = 1.03'' \lambda_{cm}/B_{km} \tag{2-110}$$

for the map cell size.

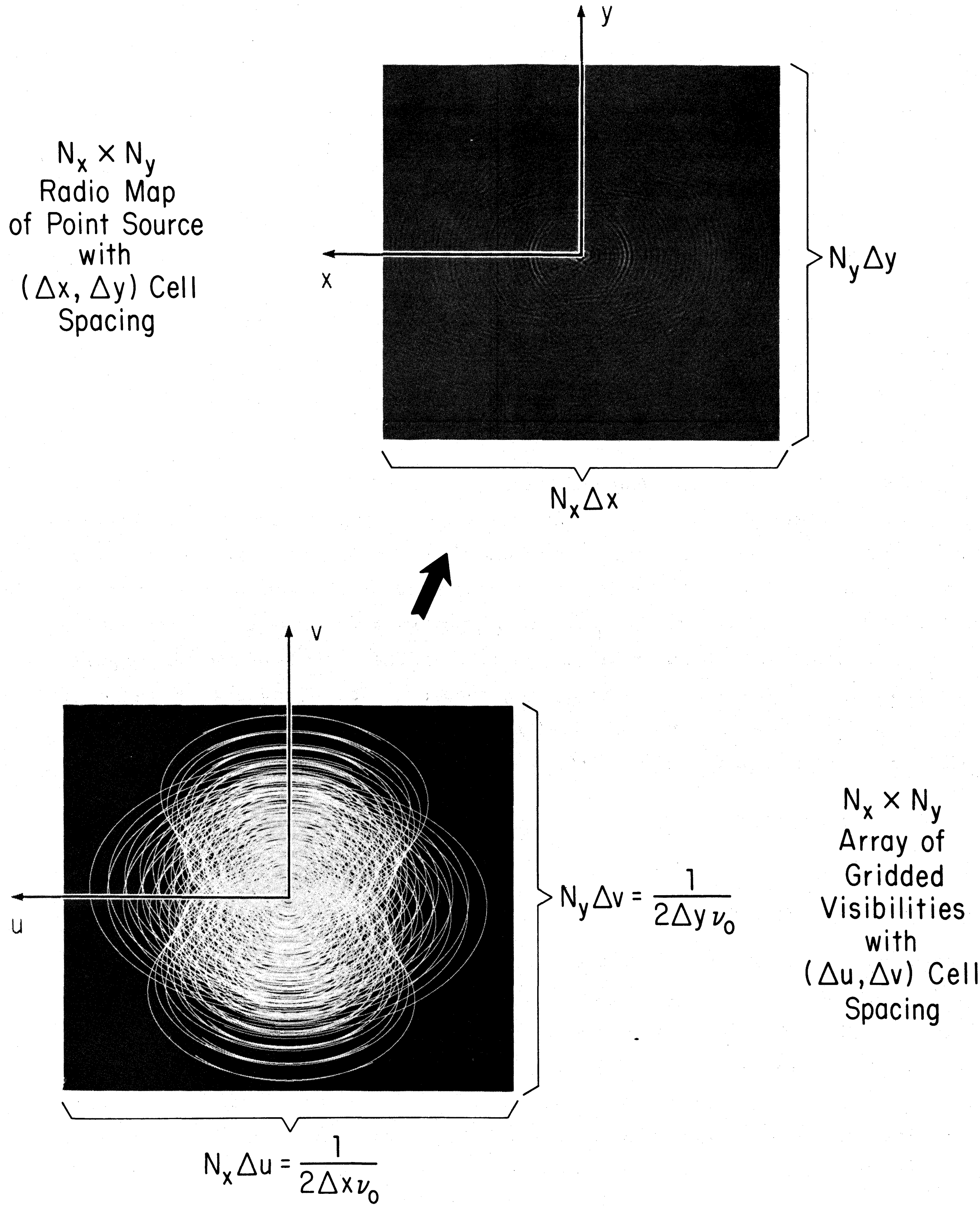


Figure 2-16. The relation between a gridded u-v plane, for the 27-antenna VLA observing a source at $\delta = 40°$, and the corresponding point source image map.

16. BANDWIDTH EFFECT (Radial Smearing)

A. Visibility Function for Finite Bandwidth

In Section 3 we discussed the effect of the bandwidth on the fringe amplitude if there were no delay tracking. For any map point not at the phase center, the delay tracking will not properly compensate for the geometric delay in the signal arrival time. In this section we want to discuss the effect of the bandwidth on the overall map.

Insight to the bandwidth effect can most easily be obtained from analyzing a point source located an angular distance (x_p, y_p) from the map center. Fourier transforming $\delta(x-x_p, y-y_p)$ gives $e^{-i2\pi\nu(ux_p+vy_p)}$ for the complex visibility. u and v are in units of seconds of time and carry no frequency dependence. To bring in the frequency response of the system let $\alpha_j(\nu)$ represent the frequency dependence for all the electronics from the antenna up to the correlator. As explained in Section 3 we can multiply and integrate (rather than convolve) the frequency dependent functions from two antennas since we are observing an incoherent signal. Consequently, the observed brightness for the (j,k) pair is

$$B_{jk}(ux_p+vy_p) = \int_{-\infty}^{\infty} \alpha_j(\nu)\alpha_k(\nu)e^{-i2\pi\nu(ux_p+vy_p)}d\nu \quad . \qquad (2\text{-}111)$$

For convenience $\alpha_j(\nu)\alpha_k(\nu)$ will be replaced by $b_{jk}(\nu)$. Equation (2-111) then becomes

$$B_{jk}(ux_p+vy_p) = \int_{-\infty}^{\infty} b_{jk}(\nu)e^{-i2\pi\nu(ux_p+vy_p)}d\nu \qquad (2\text{-}112)$$

which is a Fourier transform of $b_{jk}(\nu)$.

B. Radial Nature of Bandwidth Smearing

Our next step is to transform B_{jk} to the x,y plane. The integral is

$$b(x,y) = \iint_{-\infty}^{\infty} B_{jk}(ux_p+vy_p)e^{i2\pi\nu_o(ux+vy)}\,du\,dv$$

where ν_o is the center frequency. The generality of this derivation can be continued more easily if x,y coordinates are converted to polar coordinates $-r\sin\theta$, $r\cos\theta$ to give $b(x,y,x_p,y_p) =$

$$\iint_{-\infty}^{\infty} B_{jk}[r_p(-u\sin\theta_p + v\cos\theta_p)]e^{i2\pi r\nu_o(-u\sin\theta + v\cos\theta)}\,du\,dv$$

where θ is defined counterclockwise from the y-axis as a position angle. u and v can now be rotated to simplify the integral. Let

$$u' = -u \sin \theta_p + v \cos \theta_p \tag{2-113a}$$

$$v' = v \sin \theta_p + u \cos \theta_p \tag{2-113b}$$

which gives for the unprimed coordinates

$$u = v' \cos \theta_p - u' \sin \theta_p \tag{2-114a}$$

$$v = u' \cos \theta_p + v' \sin \theta_p . \tag{2-114b}$$

Substituting these expressions into the integral gives

$$b(r,\theta,r_p,\theta_p) = \iint_{-\infty}^{\infty} B(r_p u') e^{i2\pi r \nu_o [\cos(\theta_p - \theta)u' + \sin(\theta_p - \theta)v']} \, du' \, dv' .$$

The u',v' variables are now separated so each may be integrated seperately. Applying the similiarity theorem to the u' integration and recognizing the Dirac delta in the v' integration gives

$$b(r,\theta,r_p,\theta_p) = (1/r_p) \, B[\nu_o (r/r_p) \cos(\theta_p - \theta)] \, \delta[r\nu_o \sin(\theta_p - \theta)] \quad . \tag{2-115}$$

The point source has been elongated in a radial direction from the map center in the shape of the frequency bandpass function. Perpendicular to this, in the azimuthal (θ) direction, there is no spreading or smearing.

C. Computation of Bandwidth Smearing in Map Plane

The previous result can be generalized to any map by multiplying together all appropriate factors in the u,v plane. Assuming all baselines have the same bandpass function, we get

$$V(u,v) = W(u,v)\, T(u,v)\, B(u,v)\, S(u,v)\, V_{true}(u,v) \tag{2-116}$$

where $V_{true}(u,v)$ is the Fourier transform of the true brightness distribution, S in the sampling function, and W and T are the weighting and tapering functions. The mapped brightness distribution is then

$$I(x,y) = w(x,y)*(t(x,y)*(b(r,\theta)*(s(x,y)*I_{true}(x,y)))) \tag{2-117}$$

where s, w, and t are the transforms $\bar{S}$, $\bar{W}$, and $\bar{T}$, respectively, $b(r,\theta)$ is expression (2-115), and the asterisk denotes two dimensional convolution. We see that the true brightness distribution is convolved with the bandpass spread function, $b(r,\theta)$. This causes all features to be elongated in a radial direction from the map (phase) center.

We can carry out a basic evaluation of the effect of various bandwidths by considering the case of a point source located at a $y_p = 0$ and arbitrary y_p, and the result will be completely general for radial distances $\Theta = x_p = r_p$. We assume uniform weighting over a u-v plane sampling that will be taken to be uniform for all $|u| \le u_{max}$ and $|v| \le v_{max}$. The beam at radius Θ is then

$$I_{beam}(r,\Theta;\Delta\nu) = b(r,\theta) * I_{beam}(r,\Theta;\Delta\nu=0) \qquad (2\text{-}120)$$

Computations based upon Eqn. (2-120) have been carried out by R. Perley in VLA Scientific Memorandum No. 138 for a number of assumptions concerning the taper and the bandwidth function. For un-distorted beams given by

$$I_{beam}(r,\Theta;\Delta\nu=0) = \mathrm{sinc}[\eta(r-\Theta)/\Theta_{HPBW}] \text{ , no taper, uniform sampling}$$

and (2-121a)

$$I_{beam}(r,\Theta;\Delta\nu=0) = \exp[-(\gamma(r-\Theta)/\Theta_{HPBW})^2] \text{ , gaussian taper, uniform sampling}$$

where $\eta = 3.79$ and $\gamma = 1.665$. If one defines functions α and β by

$$\alpha = (\Delta\Theta/\Theta_{HPBW}) \qquad (2\text{-}122)$$

$$\beta = (\Delta\nu/\nu_o)(\Theta/\Theta_{HPBW}) \qquad (2\text{-}123)$$

where $\Delta\Theta = (r - \Theta)$, and let I_o be the un-smeared central intensity, then the radially smeared beams for three cases are as given in Table 2-4.

Table 2-4

Radial Beam Shapes for Different Finite Bandwidth Models

Bandwidth	Taper	$I_{beam}(\alpha,\beta)/I_o$
square	none	$\{ Si[\eta(\alpha + \beta/2)] - Si[\eta(\alpha - \beta/2)] \}$
square	gaussian	$[\pi^{\frac{1}{2}}/(2\beta\gamma)] \{ erf[\gamma(\alpha + \beta/2)] - erf[\gamma(\alpha - \beta/2)] \}$
gaussian	gaussian	$\exp[-(\alpha\gamma)^2/(1 + \beta^2)] / (1 + \beta^2)^{\frac{1}{2}}$

In Table 2-4 we we have used the standard functions

$$erf(x) = (2/\pi^{\frac{1}{2}}) \int_0^x \exp(-t^2)\, dt$$

and

$$Si(x) = \int_0^x \sin(t)/t\, dt \quad .$$

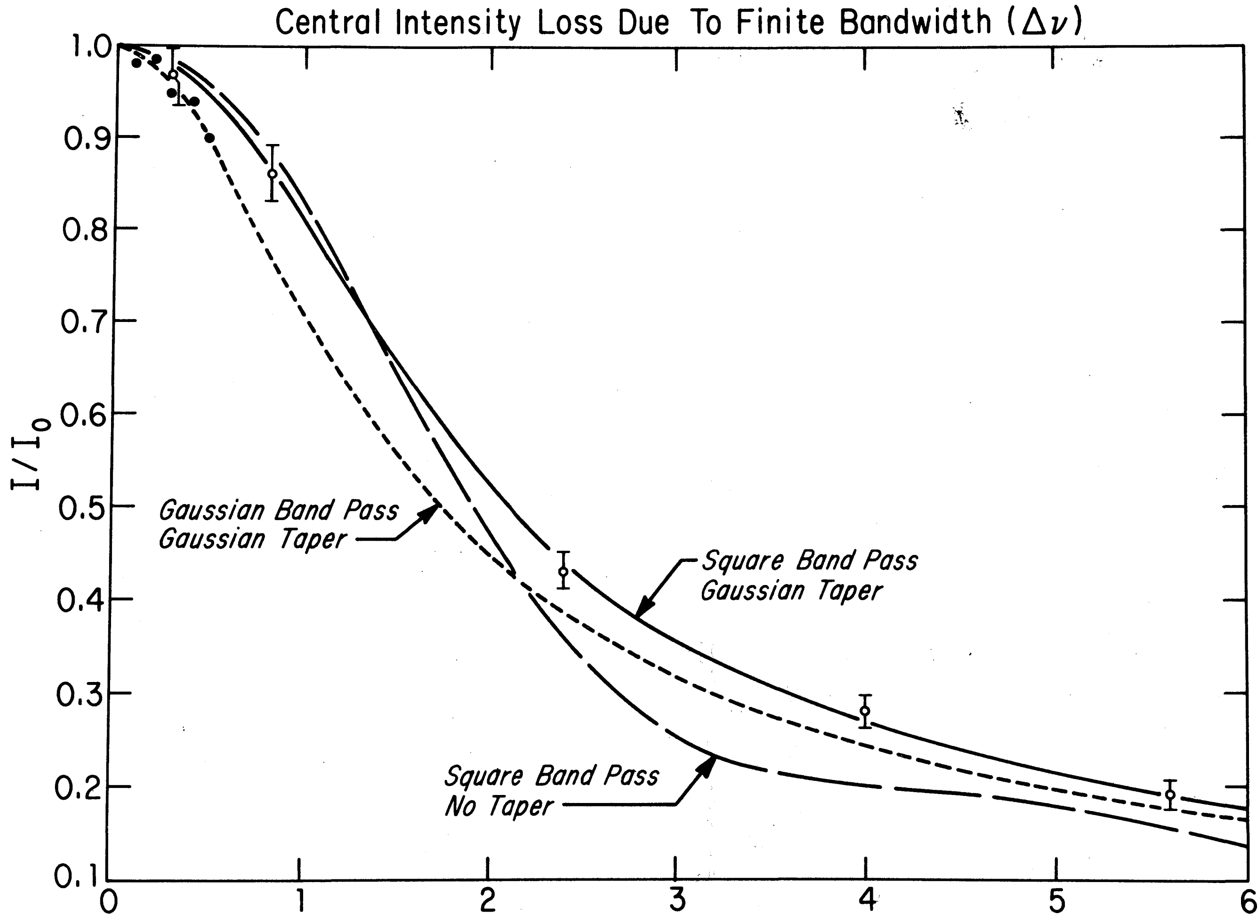
Figures 2-17, 2-18, and 2-19 show plots of I_{beam}/I_o vs. β, I_{beam}/I_o vs. α (beam shape) for various values of β, and the ratio of radial to azimuthal beam width as a function of β, respectively.

Plotted in Figures 2-17 and 2-19 are empirical measurements of the effects of finite bandwidth made for the A-array (open circles) and the C-array (filled circles). We see that the A-array data, which are most subject to band-width smearing effects, are fit quite well by the model assuming a square frequency band-pass and a gaussian taper.

In Figures 2-18 and 2-19 we also indicate an array-dependent expression for β, i.e.

$$\beta = 1.6\ (\theta/1')(\Delta\nu/50\text{MHz})(1/3.285)^{n-1} \qquad (2\text{-}124)$$

where n = 1, 2, 3, and 4 for the A, B, C, and D arrays, respectively.



$$\beta = \frac{\Delta\nu}{\nu}\,\frac{\theta}{\theta_{HPBW}} = 1.6\left(\frac{\theta}{1'}\right)\left(\frac{\Delta\nu}{50\ \mathrm{MHz}}\right)\left(\frac{1}{3.285}\right)^{n-1}$$

Figure 2-17. Central intensity loss (due to finite bandwidth $\Delta\nu$) plotted as a function of $\beta = \beta(\Theta, \Delta\nu, n)$, where Θ is angular displacement from the phase center and n = 1, 2, 3, and 4 for the A, B, C, and D configurations.

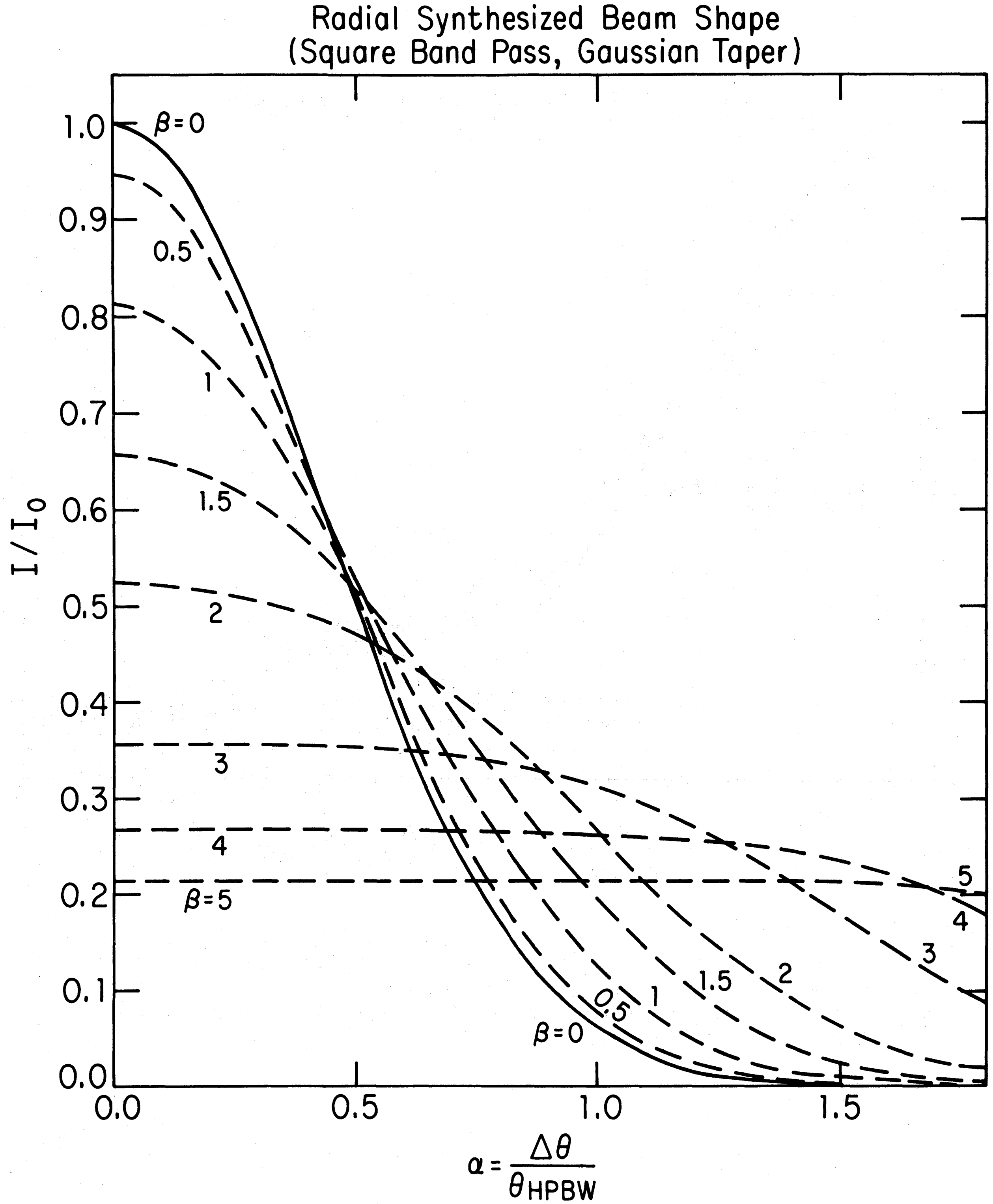


Figure 2-18. Beam shape due to finite bandwidth for a number of values of $\beta = \beta(\Theta, \Delta\nu, \text{configuration})$.

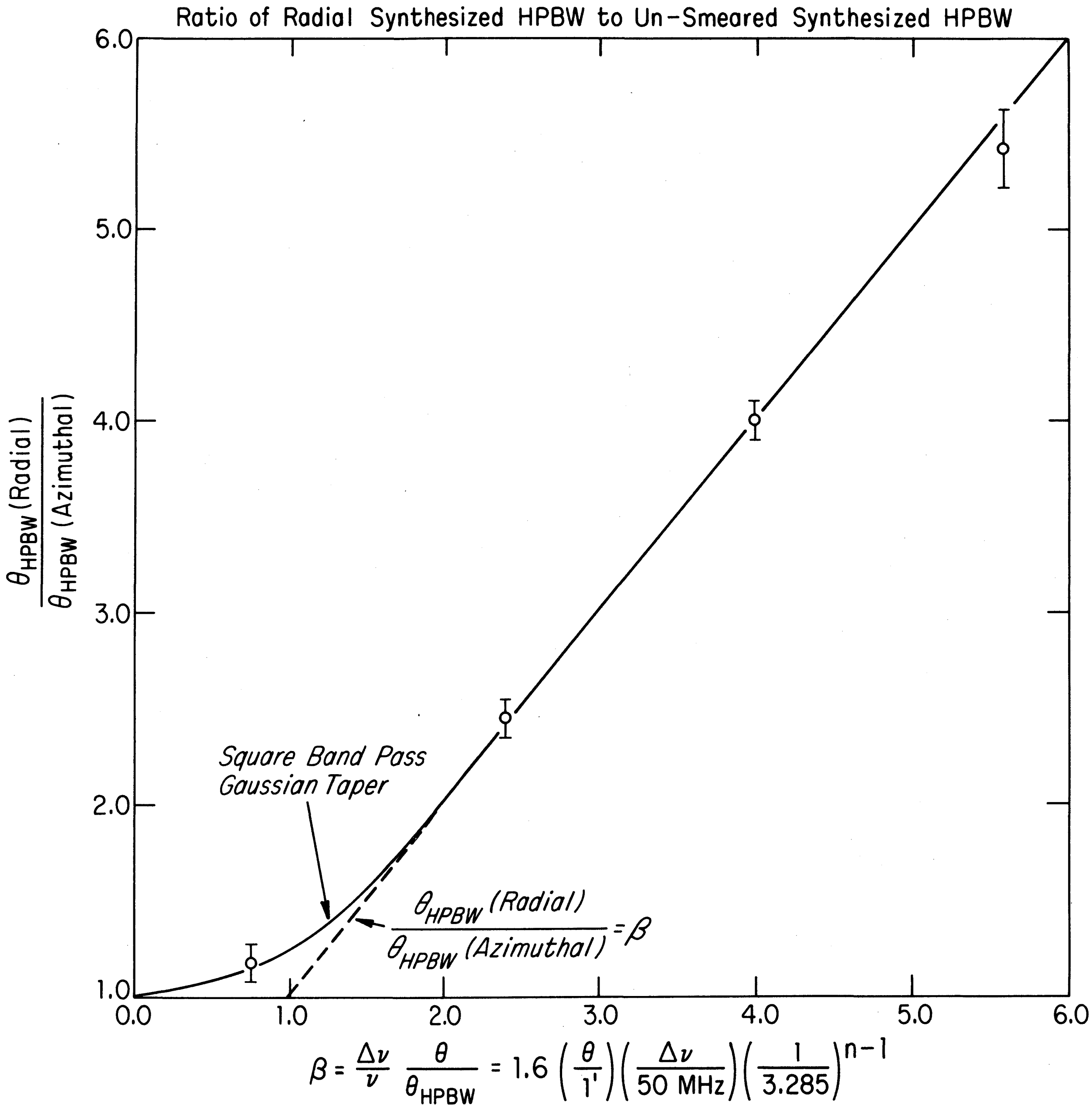


Figure 2-19. Ratio of radial to azimuthal beam width, due to finite BW, plotted as a function of $\beta = \beta(\Theta,\ \Delta\nu,$ configuration).

Chapter 3

THE VLA ELECTRONICS SYSTEM

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April 1982 Edition

ABSTRACT

The VLA electronics system is discussed both in general and at the level of detail appropriate to an astronomer who wishes to understand the major components that affect the radio signals obtained during observations.

The user who wishes to obtain more technical information about the VLA electronics system should read VLA Technical Report Number 29, "An Introduction to the VLA Electronics System", or other technical reports describing individual modules of the VLA electronics system.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. INTRODUCTION

The VLA electronics system was conceptually designed by S. Weinreb in 1972-1973 and was further developed by members of the NRAO/VLA Electronics division. The objective was to provide a continuum and spectral line system operating on 27 antennas in four frequency ranges: 1.34 to 1.73 GHz, 4.5 to 5.0 GHz, 14.4 to 15.4 GHz, and 22 to 24 GHz. These frequency ranges or bands are designated by either the approximate central wavelength for each band; 20, 6, 2, and 1.3 cm, respectively, or by the letters L, C, U (for K_u), and K.

Three principal functions are performed in the VLA electronics system: (1) production and delivery of correlator visibility data every 312 ms for the four polarizations and four frequency bands from all N(N-1)/2 pairs of N antennas while operating in continuum mode, with a variable number of frequency channels within a band when operating in one of the spectral line modes; (2) control of antenna and electronics parameters; and (3) monitoring of information about the health and status of N antennas, their electronics, and the control building electronics.

A simplified schematic diagram of the VLA electronics system and its relationship to other systems is shown in Figure 3-1. At the antenna, the rotatable subreflector focuses radiation reflected from the antenna surface onto one of four feeds located on the feed ring at the Cassegrain focus. Control information sent from computers in the control building determines which of the four positions of the rotatable, asymmetric subreflector will be used to obtain the desired feed and frequency band. Radio frequency (RF) signals from each feed are sent via waveguide to the antenna vertex room where they are fed into low noise front ends. The parameters of these front ends, and other parameters of the four bands, are given in Table 3-1.

The RF signals from the front ends are converted to intermediate frequencies (IF) 1325, 1425, 1575, and 1675 MHz in the antenna IF system. The four IF frequencies are derived from duplicate dual orthogonal polarizations designated A and B for the one polarization and C and D for the other polarization.

The antenna monitor and control system, commanded by instructions from the control building, both controls the antenna and its electronics and monitors its health and status. Antenna control and feed selection are achieved by commands sent to the antenna control unit (ACU) in the pedestal room of each antenna. The antenna monitor and control system controls and

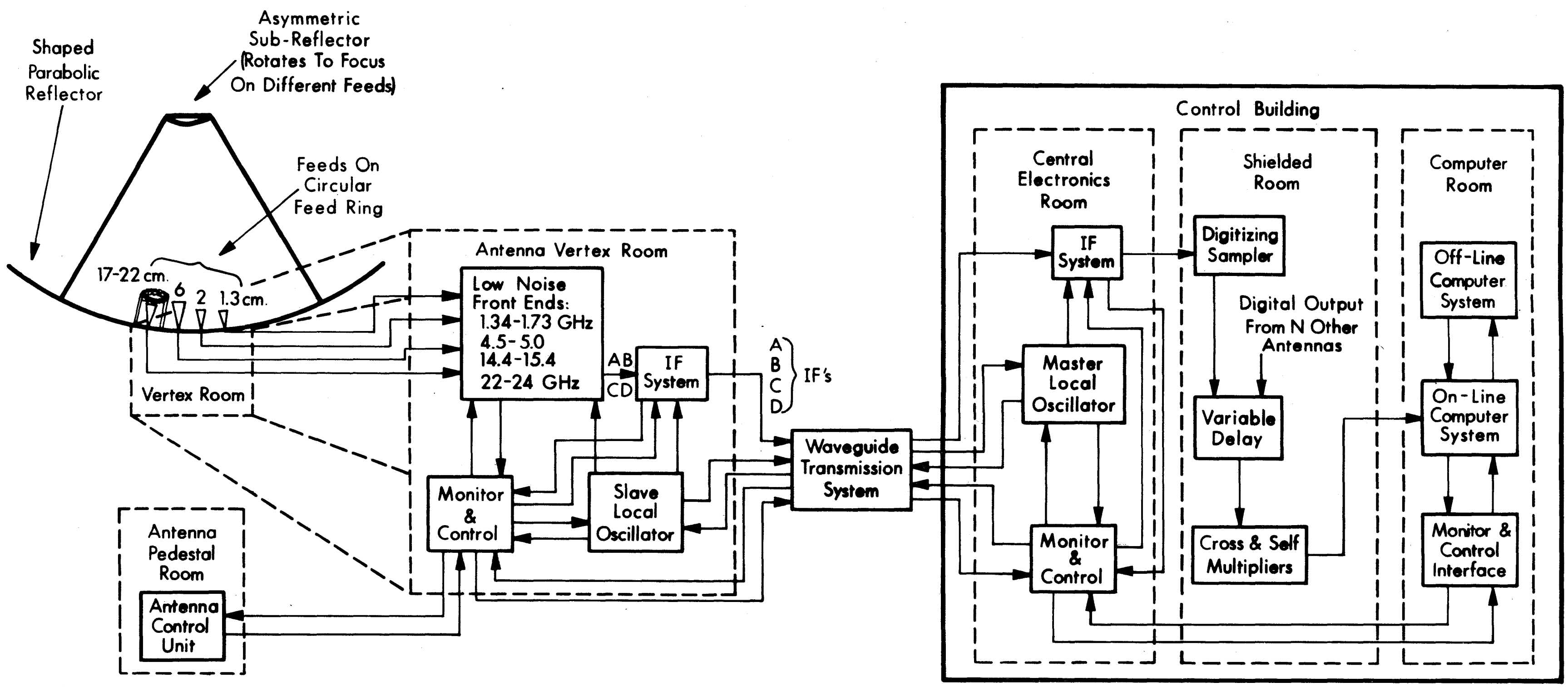

Figure 3-1. A simplified schematic diagram showing the major components of the VLA electronics system, and their location and relation to other systems.

monitors three major electronic systems at the antenna: (1) the duplicated front ends and associated support equipment; (2) the antenna IF system; and (3) the slave local oscillator (LO) system that provides timing and frequency signals needed at many places in the front ends and in the IF system. The slave LO system at each antenna operates under closed loop control based on timing (LO) signals received from and sent to the master local oscillator system in the control building.

Control data sent from the control building to each antenna and data sent from each antenna by the IF, slave LO, and monitor and control systems to the control building are carried by a single 60 mm circular waveguide line along each arm of the array. Data are communicated through the

Table 3-1

Parameters of the Four VLA Frequency Bands

VLA Bands	Wavelength	Radio Astronomy Band	System Temperature (T_{sys})*	Antenna Efficiency (e_a)
1.34- 1.73GHz	17.0 -22 cm	1.400- 1.427GHz	60 K	50 %
4.5 - 5.0	6.0 - 6.7	4.99 - 5.00	50	65
14.4 -15.4	1.95- 2.08	15.35 -15.40	300	54
22.0 -24.0	1.25- 1.36	23.6 -24.0	360	46

*Average values for the antennas

waveguide transmission system with a basic 52 ms cycle. During this 52 ms cycle there is 1 ms when control and timing data are being sent from the control building to the antennas and 51 ms when monitor data, LO information, and data from the A, B, C, and D IF output signals are being sent from each antenna to the control building. The input and output data for all the antennas on one arm propagate in the waveguide in the so-called TE_{01} mode. The 1 to 2 GHz band from each of the arm's antennas modulates a waveguide frequency, $\nu_{carrier}$, that is different for each antenna, ranging from 26.410 GHz to 50.410 GHz. The carrier frequencies are the same in each arm.

In the VLA control building there are three rooms containing the major parts of the control building systems: the central electronics room, the shielded room, and the computer room, as shown in Figure 3-1. The control room where the array operators control and monitor the entire VLA system is not shown because such control and monitoring is achieved solely through CRT terminal interaction with the on-line computer in the shielded room and the computer room. All control commands for antennas or electronics are sent from the on-line computer system through a monitor and control interface to the control building monitor and control system. This system deals with all control information for antennas, antenna electronics, and control building electronics. It also receives all monitor data about the health and status of antennas, antenna electronics, and control building electronics and passes it on in digital form to the on-line computer system. The monitor and control interface in Figure 3-1 is called the serial line controller and the entire monitor and control system is also called the digital communications system (DCS).

The IF signals from each of the four channels, A, B, C, and D, (duplicate dual polarizations) for each of the N antennas, are demultiplexed from the waveguide system and sent to the control building IF system while the timing (LO) information from each antenna is sent on to the master local oscillator system. The local oscillator at each antenna is phase locked to 5 MHz (coarse lock) and 600 MHz (fine lock) signals from the master local oscillator in the control building. Timing signals from each locked LO are returned to the control building and compared with the master oscillator. This round trip phase difference is measured and used to make a correction to the phase for each antenna-IF.

After passing through the control building IF system, the four channels of data from each antenna are sent on to the shielded room. Four channels of data from each of N antennas are sampled and digitized before undergoing variable amounts of delay putting the data from each antenna onto a common time system. Consequently, all signals due to a source at the reference position in the sky arrive at all multipliers at exactly the same time. After delay compensation, 4N digital signals are cross-correlated and self-multiplied to obtain 4N(N-1) cross-correlated outputs (AA, CC, AC, CA, BB, DD, BD, DB for each of N(N-1)/2 pairs) and 4N self-correlator outputs. These are sent to the on-line computer system where each cross-multiplier output is divided by the geometric mean of the outputs of the appropriate self-multipliers (e.g. $A_{jk}/(A_j^2 A_k^2)^{\frac{1}{2}}$) producing normalized visibilities. For a 10 second period (196 waveguide cycles) data are vector averaged to form the complex visibility sent to the MODCOMP named CORA. The system thus produces duplicate measurements of visibilities for four correlator polarization for N(N-1)/2 antenna pairs in the on-line computer system. Some corrections and calibrations are applied on-line before the data pass on to the off-line computer system for additional editing, correction, and calibration.

Figures 3-2 through 3-4 show three of the major locations of VLA electronics hardware. Figure 3-2 shows the inside of the antenna vertex room as seen from the entrance door. The A rack (right side of picture and the B rack (left side of picture) are shown suspended from the ceiling of the vertex room attached to the underside of the shaped, parabolic antenna surface. At the top of the picture are waveguides carrying signals from the Cassegrain feeds to the cooled front ends in Rack A. Rack A also contains most of the antenna IF system. Rack B contains the antenna slave oscillator system, the IF combiner/divider, monitor and control system modules, and the modem interface to the waveguide communications system.

Figure 3-3 shows sections of the central electronics room in the control building. The racks in the bottom picture contain the master local oscillator system, the monitor and control interface (serial line controller), and the phased array output racks for VLBI observations. In the center of the room, shown in the top picture, are three rows of D Racks. Each D Rack receives/sends signals for a particular antenna from/to the waveguide communications system; it contains an IF combiner/divider, monitor and control modules, the electronics room IF system, modems, and LO modules that communicate with the master LO system. The IF signals from the D Racks for all N antennas are sent to the shielded room where the racks and computer (SPECTRE) shown in Figure 3-4 carry out sampling, delay, and multiplication before the correlator outputs for N(N-1)/2 pairs are sent every 10 s to the correlator data handling computers in the computer room.

Now that we have gone through a greatly simplified description of the VLA electronics system, let us go through the system again at a greater level of conceptual detail.

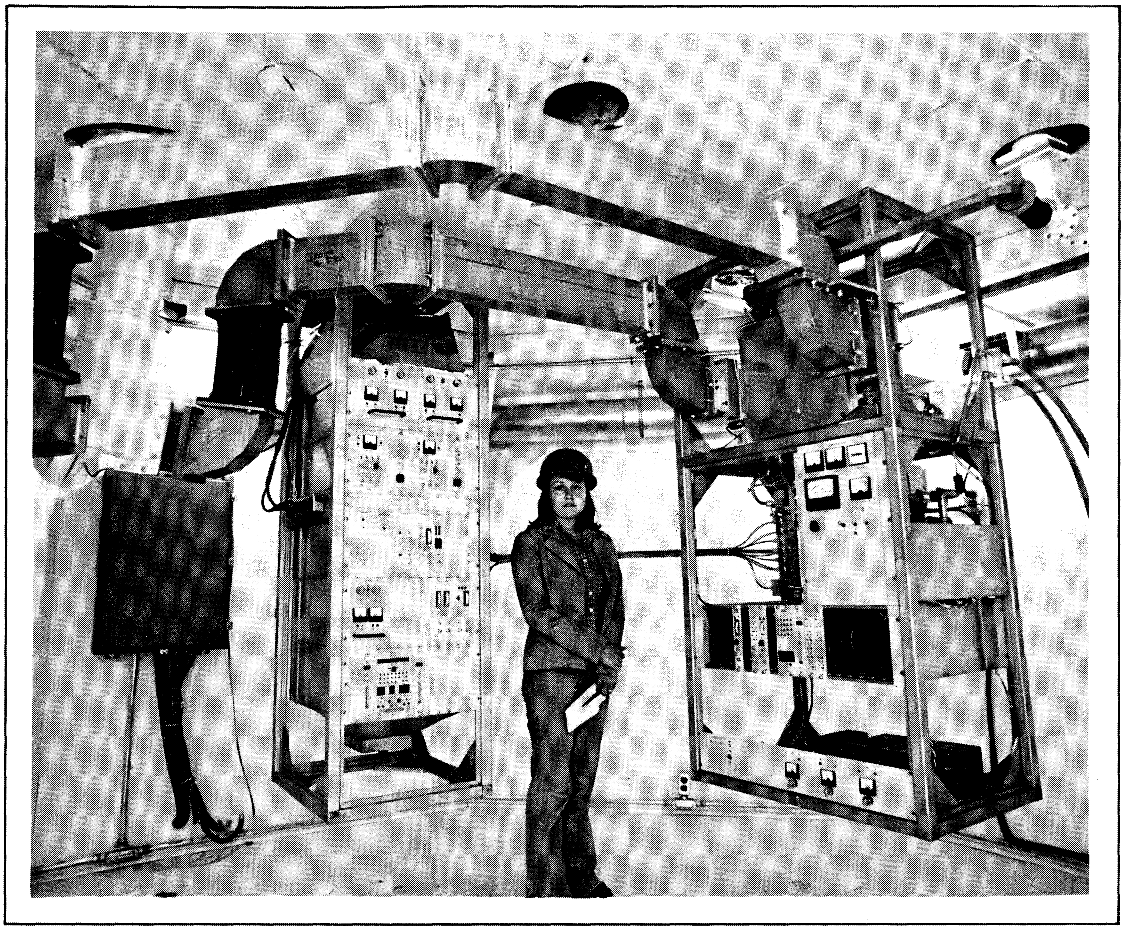

Figure 3-2. A photograph of the inside of a VLA vertex room located under the Cassegrain focus of the parabolic antenna surface.

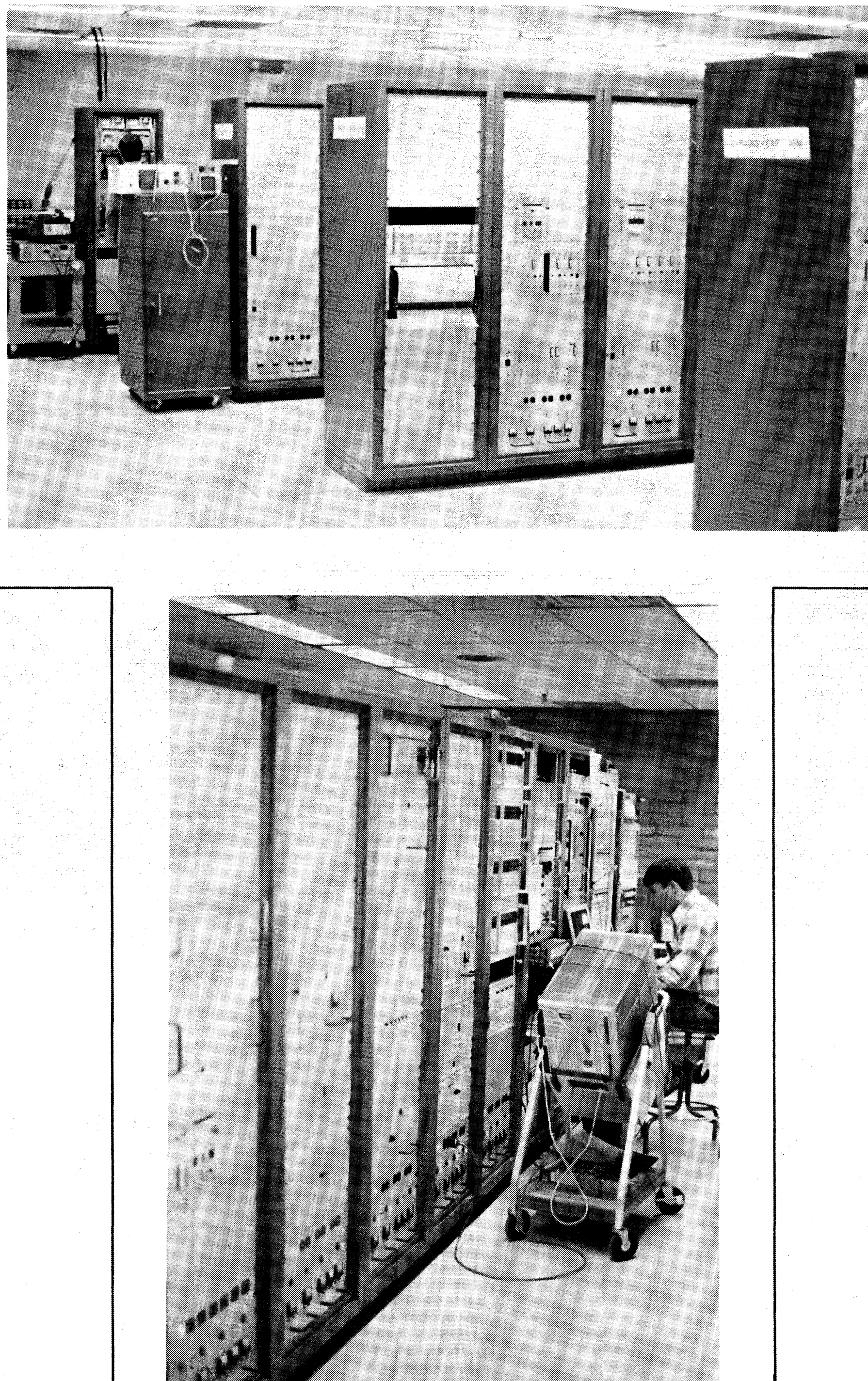

Figure 3-3. Two photographs of the central electronics room. The top picture shows the D-racks for each arm and the bottom photograph shows the row of racks containing the Master LO system, the Monitor and Control Interface, and the phased array output racks.

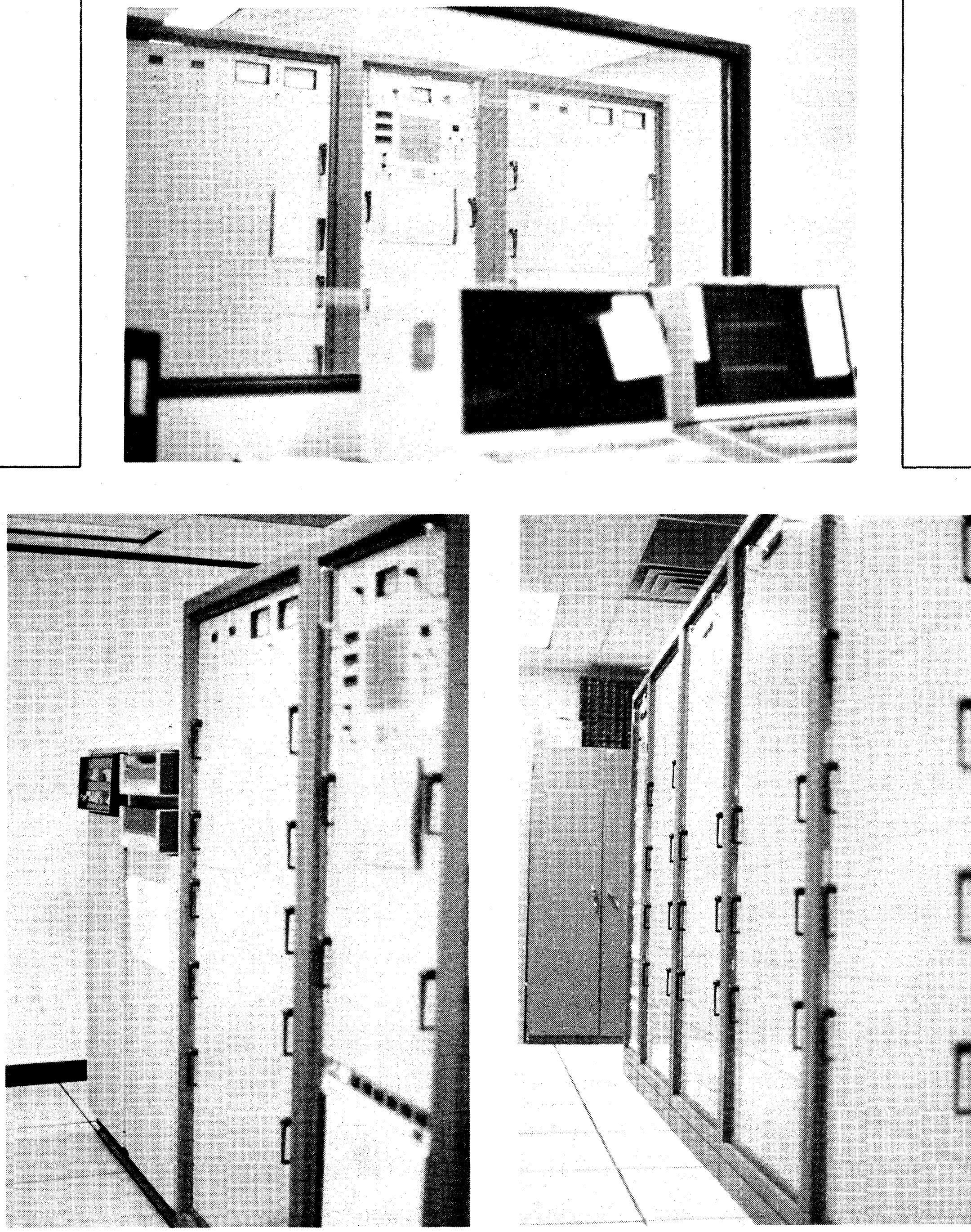

Figure 3-4. Three photographs of the hardware in the shielded room. The top picture is an external view of the sub-room containing sampler/delay hardware and SPECTRE, the first of the on-line data handling computers. The lower left picture shows SPECTRE and the lower right picture shows one bank of delay/-sampler/correlator hardware.

2. A DATAFLOW DESCRIPTION OF THE VLA ELECTRONICS SYSTEM

The VLA electronics system is very complex. In this section we will attempt to discuss the aspects of the system that perform critical tasks by discussing the flow of data or signals in and out of various components. It will be a dominantly conceptual discussion in which components may or may not correspond to actual hardware modules.

Figure 3-5, the multi-page foldout, is a block diagram of the VLA electronics system, with conceptual components ordered and connected in terms of the flow of various signals. The diagram is dominantly concerned with the processing of the signals received from an observed source as the signals proceed from the antenna feeds through the system until the raw visibility measurements, V''_{jkp}, where j and k are antenna numbers and p indicates correlator polarization, (AA or BB = RR or XX, CC or DD = LL or YY, AC or BD = RL or XY, and CA or DB = LR or YX), reside in the on-line computer system in the form of complex numbers for a 10 second integration time. Monitor data output is included where necessay for important corrections and calibration. Timing or LO data are indicated as input to critical components, but the hardware modules that do this are not shown.

Let us now follow the details of Figure 3-5 by starting at the left edge of the diagram with the radiation from the asymmetric subreflector arriving at one of the four feeds. All feeds are dual orthogonally polarized feeds. The 20 cm feed providing signals for the 1.34-1.73GHz frequency range is a dielectric lens surrounded by waveguide elements illuminating a horn. The lens retards wavefronts while the waveguide elements accelerate wavefronts so arrival at the horn is uniform. The 6 cm feed for the 4.5-5.0 GHz range is a corrugated horn. Both the 2 cm feeds for the 14.4-15.4 GHz range and the 1.3 cm feeds for the 22-24 GHz range are multi-mode horns. After each feed, the RF signal passes through a polarization transducer (polarizer) which separates orthogonal polarizations; either circularly polarized signals (R and L) or linearly polarized signals (X and Y) depending upon which type of polarization transducer is mounted at the time. The polarization transducers are changed from one type to another by physically replacing one type with another. The standard mode of operation is with the polarization transducers that give orthogonal circularly polarized signals. The R- or X- polarization is sent via waveguide to the AB front end while the L- or Y- polarization is sent to the CD front end. Before reaching the front ends a calibration signal from

Figure 3-5. Schematic diagram of a conceptual representation of the VLA electronics system.

a stable noise source is added to each RF signal. This CAL signal is switched at a 9.6 Hz rate. When synchronously detected much further down the line in the signal path, this CAL signal provides a means of gain calibration for a major part of the system since the CAL signal is amplified in the same proportion as the input RF sign needing calibration. The injected CAL signal has a known strength which normally contributes roughly 6% to the RF noise in the signal at the point of injection.

The combined RF and CAL signals then proceed to one of the duplicate front ends inside a cryogenically cooled Dewar maintained at a nominal temperature of 18° K. The R- or X- polarized signals go to the so-called AB front end and the L- or X- polarized signals go to the so-called CD front end. The AB and CD systems are nominal duplicates of each other. The VLA front ends are based upon a parametric amplifier followed by a GaAs field effect transistor (FET) amplifier designed for 4.5-5.0 GHz RF signals. With the appropriate position of the coaxial switch, the signals from the 6 cm feeds are fed directly into this paramp/FET amplifier. A final stage of RF amplification is provided by a second FET amplifier outside the Dewar.

The RF signals originating from the 20 cm, 2 cm, or 1.3 cm feeds undergo a frequency conversion before being fed into the 4.5-5.0 GHz paramp. Signals in the 1.34-1.73 GHz range pass through a parametric upconverter that multiplies a 3.2 GHz LO signal with the input RF signal to produce a 4.54-5.93 GHz signal which is fed into the 6 cm paramp with the appropriate position of the coaxial switch. Signals in the 14.4-15.4 GHz band undergo lower sideband mixing with a tunable 17-20 GHz LO signal and the resulting signal at 4.5-5.0 GHz is fed into the 6 cm paramp with the appropriate position of the coaxial switch. The 22-24 GHz RF signals in the 1.3 cm band undergo upper sideband mixing with the tunable 17-20 GHz LO signal and the resulting signal at 4.5-5.0 GHz is fed into the 6 cm paramp when the coaxial switch is in the correct position. Because of its function, the coaxial switch in each AB and CD front end is also called the "band-select" switch.

After the signals leave the 6 cm GaAs FET amplifier, subsequent frequency conversions and amplifications are independent of the original RF observing frequency. The RF outputs from the nominally identical AB and CD systems shown in Figure 3-5 are (1) attenuated during solar observations, (2) amplified by the second FET mentioned above, (3) passed through an RF attenuator, and (4) fed into a transfer switch. Depending upon the setting of the transfer switch, the AB and CD signal can be diverted to either A and

B channels or C and D channels of the antenna IF system. The transfer switch is helpful for the diagnosis of equipment problems in which it is useful to know if the problem is before or after the transfer switch. Normally, signals from the AB front end go into the A and B IF channels while signals from the CD front end go into the C and D IF channels.

After the transfer switch, a splitter divides each RF signal into nominally identical channels denoted A and B for R- or X-polarization and C and D for L- or Y- polarization.

After the splitters, the A, B, C, and D RF signals are then mixed with a phase shifted LO signal in the 2-4 GHz range to obtain 1025 MHz IF signals. The phase shift applied to the LO signal before mixing applies the equivalent of fine delay adjustment, as discussed in Chapter 2, together with any other real time phase corrections that are desirable at this point. The phase shifter gets a signal in the 2-4 GHz range from the slave LO system, a fringe generator provides the phase shift necessary to keep the signal on a positive maximum of the raw fringe pattern as discussed in Chapter 2, and control information from the on-line computer system provides information about any additional phase shift (ϕ_j^{corr} for the j-th antenna) as discussed in the same section of Chapter 2.

All RF channels are converted to the same IF frequency of 1025 MHz, and passed through filters that limit the IF to bandwidths of 50, 25, or 12.5 MHz. A 300, 400, 550, or 650 MHz LO signal is fed into the frequency offset module which then changes the filtered IF signal at 1025 MHz to IF frequencies of 1325/BW, 1425/BW, 1575/BW, and 1675/BW MHz for channels A, B, C, and D, respectively, before being fed into an automatic level control (ALC) loop. The n/BW notation is used here and later to denote central frequency and bandwidth of an IF signal.

The ALC loop maintains a constant IF level on the signal sent to the combiner. The loop is gated so that it does not respond to the noise source periodically turned on at the receiver input. An inset plot in the lower central part of Figure 3-5 shows the wide band CAL signal being measured by the square-law and synchronous detectors. The square law detector measures the gated total power (GTP) level corresponding to the IF total power. The synchronous detector measures the total power amplitude of the CAL signal that was injected at the receiver input with a 26 ms periodicity (9.6 Hz rate). This detector output provides a measure of the gain and noise temperature up to this point in the system. The gain of the system between the point of noise injection between the front end and the point of measurement in the ALC loop is given by

$$\text{Gain} = \text{constant} \times \text{GTP/CAL} \qquad (3\text{-}1)$$

where the constant in Equation 3-1 reflects the strength of the injected noise signal and any gain normalization factor one might choose for each frequency band. The GTP and CAL values measured for the A, B C, and D channels are sent as part of the monitor data to the on-line computer system where they are used for gain calibration, as a function of time, using Equation 3-1.

After the ALC loop, the IF signals at a relatively constant power level are fed into a combiner/divider. This component functions as a signal combiner for data sent from the antenna. The combiner puts together, into the 1-2 GHz range, all IF, monitor, and timing (LO) information for transmission down the waveguide to the control building. The same component functions as an IF divider, taking control and timing (LO) information sent from the control building and dividing it into two parts; one portion contains the control commands which are then sent on to the antenna monitor and control system, and the other portion contains the timing (LO) information sent by the master LO system to the antenna slave LO system responsible for generating all of the previously mentioned LO signals. The combiner/divider sends/receives data to/from a modem which sends/receives data to/from the waveguide transmission system. Data are sent through the waveguide to the control building for 51 ms out of every 52 ms. Control and timing data are sent to the antennas for the other 1 ms in the 52 ms cycle. Insets in the middle Figure 3-5 show the frequency spectrum of the data in the send (upper center of Figure 3-5) and receive (lower center of Figure 3-5) cycles. Each antenna of each arm has a waveguide channel with a carrier frequeny ($\nu_{carrier}$) listed in the lower central portion of Figure 3-5. The send/receive spectrum covers frequencies from (1.0 GHz + $\nu_{carrier}$) to (2.0 GHz + $\nu_{carrier}$).

As shown in the lower central inset in Figure 3-5, control data are sent to antennas in the form of sidebands at the frequency (1.8 GHz + $\nu_{carrier}$). Timing (LO) information is sent in the form of a (1.2 GHz + $\nu_{carrier}$) signal, a (1.8 GHz + $\nu_{carrier}$) signal, and 5 MHz sidebands of the (1.2 GHz + $\nu_{carrier}$) signal. Basic 600 MHz (1800-1200 MHz) and 5 MHz signals are derived from these signals to control the slave LO system. The upper central inset in Figure 3-5, showing the spectrum of data sent down the waveguide from the antennas to the control building, is somewhat more complicated. During the send cycle for each antenna, the timing information used at the antennas is sent back to the control building in the form of (1.2 GHz + $\nu_{carrier}$), (1.8 GHz + $\nu_{carrier}$), and 5 MHz sidebands on the (1.2 GHz + $\nu_{carrier}$) signal. When these signals reach the master LO system in the central electronics room, the 600 MHz phase is compared with the one sent to the antennas, and a round trip phase (ϕ_{RT}) correction is derived and added to the monitor data for use in phase corrections in the on-line and off-line computer systems. The monitor data from each antenna are sent as sidebands on the (1.8 GHz + $\nu_{carrier}$) signal. Finally, the IF data for the A, B, C, and D channels are sent in 50 MHz passbands centered at (1325 MHz + $\nu_{carrier}$), (1425 MH + $\nu_{carrier}$), (1575 MHz + $\nu_{carrier}$), and (1675 MHz + $\nu_{carrier}$), respectively.

A modem in the central electronics room of the control building takes/sends signals from/to the waveguide and, after splitting/combining signals for the different antennas, sends/takes signals to/from another divider/combiner component. As a combiner during the antenna receive cycle, the control data from the on-line computer and timing (LO) data from the master LO system are combined into the basic spectrum of 1200 MHz and 1800 MHz with sidebands. As a divider during the antenna send cycle, the monitor data are split off and sent to the on-line computer named MONTY, the timing (LO) data are split off and sent to the 600 MHz phase comparator. The data for IFs A, B, C, and D are split off into channels with IF frequencies of 1325/BW, 1425/BW, 1575/BW, and 1675/BW, respectively, where BW is the IF bandwidth selected in the antenna IF system. The AB and CD IF signals are then mixed with 1200 and 1800 MHz, respectively, LO frequencies and the results are mixed with tunable 100-150 MHz (A and B) or 200-250 MHz (C and D) LO signals (fluke synthesizers). The resulting lower IF frequencies are between 0.2 and 50 MHz (called baseband). These baseband signals are then passed through final filtering parameters as listed in Table 3-2.

The 0.2-50 MHz IF signals for each channel are fed through a voltage controlled amplifier that adjusts the IF power to ideal levels for the samplers through an ALC loop coupled to the sampler for that IF signal. These are 3-level 2-bit samplers that incidentally, as a part of their clocking mechanism, insert fine delay adjustments in the signal paths in increments of 625 ps. The outputs from the samplers are converted to digital form before being sent into the modules that apply the bulk of the delay compensation needed for each antenna. The amounts of fine delay adjustment in the samplers and gross delay compensation (in 10 ns increments) applied to the IF's for each antenna are determined from commands from the on-line computer system (BOSS). The large coarse delays, plus the fine delays applied inside the samplers, constitute the total antenna delay compensation discussed in Chapter 2. This and the phase shifting done in the IF system constitute the major phase and time compensations discussed in the same section. A second (narrow band) CAL measurement is made beteen the V.C. amplifier and the 2-bit sampler as part of the gain calibration system.

3. LOCAL OSCILLATOR SYSTEM

The local oscillator system is a complex network which produces phase stable signals at many points in the electronics system, for frequency conversion to IF and final IF (baseband) frequencies. At the antenna the LO signals are phase locked to a master oscillator in the control building. The LO system is also used to reduce the fringes to zero frequency. This is accomplished by adjusting the phase of the (2-4 GHz) LO signal sent to the mixer accomplishing (4.5-5 GHz) to 1025 MHz frequency conversion.

Figure 3-6 is a diagram showing the major LO mixings which the user is most likely to encounter. The LO components are connected to the master oscillator by other modules which are not shown. Each LO block contains a technical term (F2, F3, L6, or Fluke synthesizer) for the component, and the indicated LO frequencies (First LO, 2-4 GHz LO (synthesizer frequency), and fluke synthesizer frequency) are used to determine the location of the observing band. Within this band, other parameters can be used to limit the final baseband IF to a particular frequency, primarily for spectral line observations. Values of these frequencies, for a particlular sky frequency, can be determined by running the DEC-10 programs LOSER and DOPSET. Further information on these programs can be found in Chapter 12.

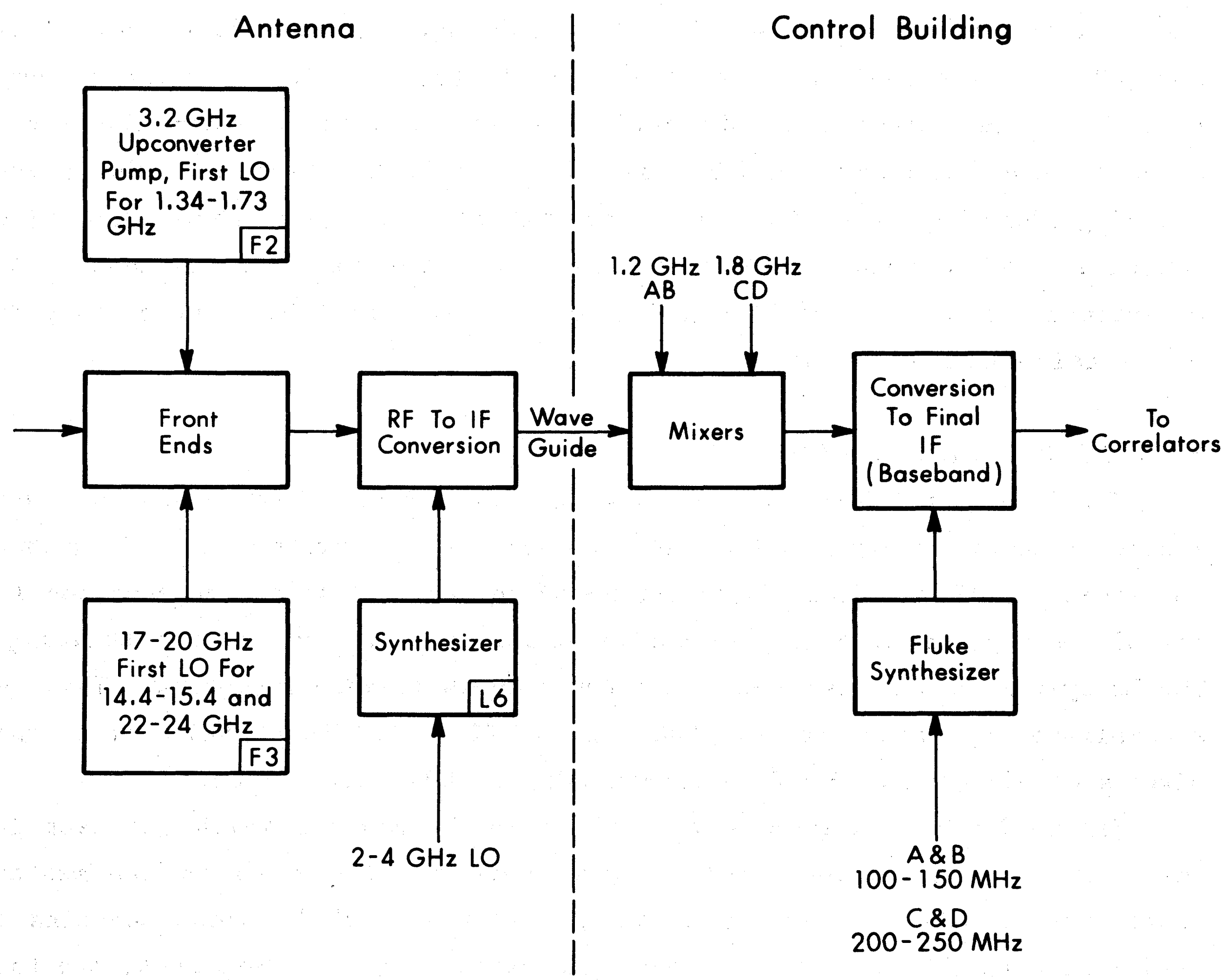

Figure 3-6. A simplified block diagram of the local oscillator system, and its relation to the electronics system. The First LO (-3.2, 19.6, and 17.6 GHz for standard 20cm, 2cm, and 1.3cm), 2-4 GHz LO (2710-4010 MHz), and the fluke synthesizer settings are assigned in control files to set the observing frequency band.

4. CORRELATION SYSTEM

The correlation system is a complex network capable of operating in many modes. In this description we will restrict our discussion to the continuum mode and one spectral line mode. The continuum mode is the most straightforward mode so it will be discussed first. From each antenna sine and cosine signals are formed for each of the baseband channels (A, B, C, D). These eight signals are passed through the delays and on to the multipliers. Sixteen products are formed between all possible pairs of four A and C signals from one antenna and from A and C signals from a second antenna. A similar sixteen products are formed among the B and D channels. Thus in total we have at one instant (92.16 ms)

4	*	4	*	2	*	N(N-1)/2 = 16N(N-1)
Sine & cosine components for A and C		polarizations (A and C products)		Duplicate BD products		Antenna pairs

cross-correlator products. For 27 antennas there are 11232 products or real numbers describing 5616 complex gains.

An integrator system following the multipliers collects the 92.16 ms samples and integrates them for periods from 52.083 ms to 10 seconds in steps of 52.083 ms. Further operations can be performed by synchronous Modcomp computers (SPECTRE and CORA/B) and an array processor. The array processor normalizes each cross-correlation product by the geometric mean of the corresponding self-correlation products, and passes the data at the level of ten second integration times to both magnetic tape and the off-line computer system. Data accumulated for 12 hours adds up to 24.3×10^6 complex visibility measurements which can be reduced to 3×10^6 complex numbers before computing a map in a single Stokes parameter.

The continuum mode operates for bandwidths ranging from 50 MHz to 6.25 MHz. For narrower bandwidths the continuum mode should not be used because the quadrature networks which produce the sine and cosine components do not operate properly.

We will next discuss one of the line modes of the correlator system. In line mode the correlator system is re-configured to provide products for many lags between signals from the two antennas. With the fixed number of multipliers, the number of IF signals correlated must decrease as the number of line frequency channels increases. Table 3-2 tabulates the number of

Table 3-2

IF Bandwidths and Spectral-Line Channel Bandwidths for Various Observing Modes.

Nominal IF Bandwidth	IF passband#	Sampling Frequency	No. of Channels* 1§	2§	4§	Channel Bandwidth
50 MHz	0.19-50 MHz	100 MHz	16	8	4	3.125 MHz
25 MHz	0.19-25 MHz	50 MHz	32	16	8	781 kHz
12.5 MHz	0.19-12.5 MHz	25 MHz	64	32	16	195 kHz
6.25 MHz	0.19-6.25 MHz	12.5 MHz	128	64	32	48.8 kHz
3.125 MHz	0.19-3.125 MHz	6.25 MHz	256	128	64	12.2 kHz
1.563 MHz	0.19-1.563 MHz	3.125 MHz	256	128	64	6.1 kHz
781 kHz	190-781 kHz	3.125 MHz	256	128	64	3.05 kHz
391 kHz	190-781 kHz	3.125 MHz	256	128	64	1.53 kHz
195 kHz	195-391 kHz	1.563 MHz	256	128	64	763 Hz
97 kHz	195-391 kHz	781 kHz	256	128	64	381 Hz

* The numbers given indicate the number of channels processed within the nominal bandwidth. The number of usable channels is slightly less because of band edge effects.

\# The filters are low-pass and the low-frequency limit is determined by the amplifiers except for the 195-391 kHz band which uses a bandpass filter.

§ Number of IFs.

frequency channels versus IF bandwidths for the four modes; 1) one IF band, 2) two IF bands, 3) four IF bands, and 4) polarization mode.

The number of frequency channels increases with decreasing IF bandwidth by using the process called recirculation. A narrower bandwidth permits one to sample at a lower sampling rate and, with the multipliers always operating at their maximum rate of 100 MHz, additional time slots become available. In this extra time a constant delay is added onto the sequence of stepped lags and the data is again read out of storage into the multipliers. Thus, with no additional multipliers, the number of channels can be increased up to 512, with an IF bandwidth of 97 kHz.

The allocation of the correlators for the line mode with one IF band is as follows. Suppose that 16 delay steps are used in one baseline. These delay steps will be added first into one IF path and then into the other for a total of 32 leads with lags. If 27 antennas are used with one polarization per channel we have:

32 *	1 *	351 =	11232	.
delay steps	IF	baselines	correlations	

The maximum number of correlators is always 11232. For other modes of operation the correlators will be allocated differently, but the total will still be 11,232.

In the spectral line mode the Fourier transform of the visibility is taken with respect to the lead and lag time. The transformation and visibility normalization are performed by the synchronous computer, SPECTRE, and an array processor located in the shielded room. Upon completion of these operations the visibilities, as a function of frequency, are passed onto the computer CORA which relays them to the off-line system.

5. TECHNICAL DESCRIPTIONS OF VLA ELECTRONICS

The VLA Technical Reports provide more detailed descriptions of the VLA electronics system and its component modules. Technical Report Number 29, "An Introduction to the VLA Electronics System", provides a more hardware-oriented description of the entire VLA electronics system. Technical Report Number 39, "Correlator System Observer's Manual", discusses details of the correlator system. This report is a basic reference for possible modes of spectral line observing. Other technical reports document individual modules of the system. The reader who wishes to obtain more information about the VLA ELectronics System is referred to this series of Technical Reports.

Chapter 4

ARRAY CONTROL AND DATA ACQUISITION

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April 1983 Edition

ABSTRACT

Operational aspects of the VLA system for array control and data acquisition are discussed. Since the VLA is controlled by an on-line computer system, using information in a number of array control files stored on disk, we discuss the contents of these files in detail. Most of the time the VLA observer will be concerned only with preparing and modifying the source list file, a procedure which is discussed in detail in Chapter 5; however, one should aware of the contents of the other files, since some observing programs will require modification of information in these files.

*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. INTRODUCTION

The control of the array and the data acquisition process are intimately related because each depends on the other, and because they are coordinated tasks of the on-line computer system. Let us briefly mention the major components of the on-line computer system so we can survey the overall problem of array control and data acquisition.

The on-line computer system has six major parts: the first part is a single MODCOMP minicomputer called BOSS, which generally manages the observing, based on information in a set of system control files, and controls the operation of the other on-line computers; the second part is another MODCOMP minicomputer called MONTY, which handles the monitor data coming back from the antennas and electronics and sends out the control data or commands (from BOSS) which control the antennas and electronics; the third part is a MODCOMP called EUNICE which handles all the unit recording devices (i.e. card reader, terminals, and line printer) and all message routing between devices and computers; the fourth part is a MODCOMP called SPECTRE, which manages the correlator system; the fifth part is a Floating Point Systems array processor (controlled by SPECTRE), which calculates visibilities, and for line data converts from cross-correlation function to cross-spectral function; and the sixth part consists of two MODCOMP minicomputers called CORA and CORBIN, which handle the correlator data sent from the correlator system every 10 seconds. The off-line computer system plays a secondary role in the operation of the array by providing array operators and observers with supplementary information about the data produced by the array.

The direct control of the array is accomplished by the on-line computer system. The programs that exercise this control mostly derive their parameters from system control files resident on the MODCOMP disks. The nature and contents of these control files are discussed in Section 2. The portions of these control files of greatest concern to the observer are the source list files specifying each source to be observed with its reference position, frequency, bandwidth, pointing parameters, and various timing and astrometric parameters.

The array operators work in the control room, shown in Figure 4-1, located between the central electronics room and the computer room. They are surrounded by computer terminals and line printers that are the means of communication with the on-line and off-line computer systems. Photographs

Figure 4-1. A photograph of the array control room, with an array operator sitting amongst on-line and off-line communication terminals. The computer room is seen through the windows to the rear. Some of the on-line computer system MODCOMPS are visible just beyond the windows, and portions of the off-line computer system are seen in the background.

Figure 4-2. Two photographs of the MODCOMP minicomputers of the on-line computer system. The top picture shows SPECTRE and some communications terminals. The bottom picture shows the remaining on-line MODCOMP minicomputers in the main computer room.

of the on-line computer system are shown in Figure 4-2. Using the on-line terminals connected to the MODCOMP computers, the operator can request a range of data displays describing the status of any part of the antenna and electronics systems, or correlator, pointing, etc. data. The design of the system is based on the principle that the vast majority of the components of the antennas and electronics will operate in a satisfactory manner under computer control, so the operators need investigate only occasional problems, usually brought to their attention by terminal and line printer output from a data checker program, CHK, that has been instructed about the ranges of correct operation of equipment parameters. The monitor data, which are measurements of about 300 parameters of a single antenna system with its electronics, are the basis for these judgements. The same data allow an on-line program to assign flags which are judgements of data quality for each piece of correlator data.

Figure 4-3 is a schematic diagram illustrating the major features of the array control and data acquisition system. In the upper right portion of Figure 4-3, the terminals and line printer used by the operator to monitor and control the array are shown. Also shown are schematic connections to the on-line and off-line computer systems. Operator commands are shown as sent from terminal to BOSS while data displays can come from almost all computers. MONTY is shown in the critical role of receiving data from all systems and sending all control commands. Control commands are sent to the monitor and control interface, also called the serial line controller, which distributes commands to all antennas, the master LO system, and other electronics. BOSS sends delay control commands to MONTY, which passes them on to the sampler and delay systems preceding the correlators in the shielded room. The left side of Figure 4-3 shows the major data paths to and from the waveguide transmission system together with the appropriate data paths between systems in the cental electronics room and the shielded room. We see that the monitor data returns from all antennas to MONTY via the monitor and control interface. LO signals are exchanged between the master LO system and the D racks for each antenna system, which distribute and receive timing information during the send and receive cycles of the waveguide transmission system. We also see that, after the IF data obtained from each antenna is processed a D rack, its antenna-IF (total power) data are sent to the shielded room where the samplers and delay multiplier system produce cross- and self-correlator

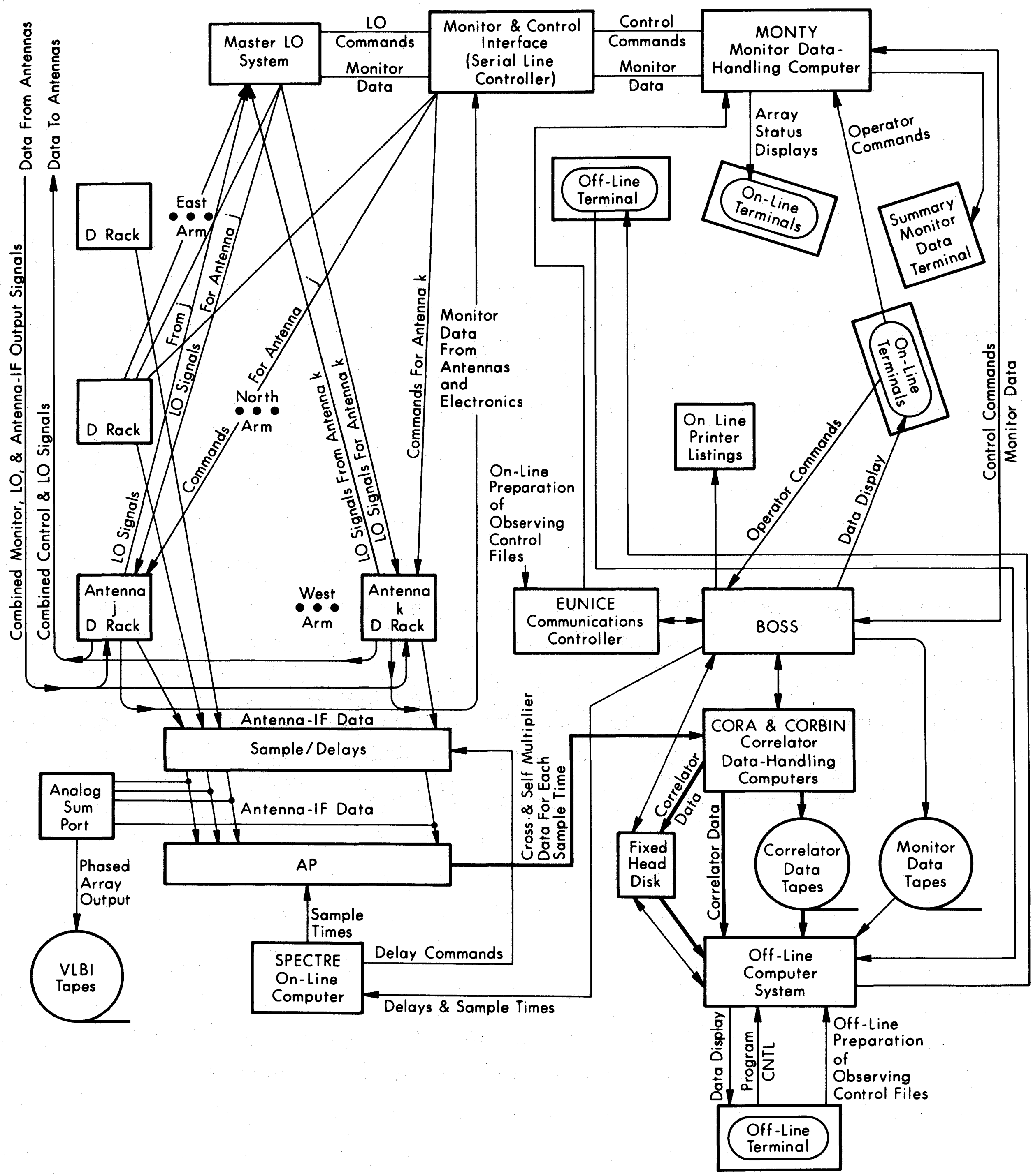

Figure 4-3. A schematic diagram illustrating the major features of the array control and data acquisition system, including the on- and off-line computer systems.

output for each antenna-IF pair once every six waveguide transmission cycles, which is every 312.5 ms. This large volume of correlator data is sent first to the array processor (AP) and then to the correlator handling computers (every 10 seconds), normalizing the cross-correlator outputs by the self-correlator outputs in the process of producing vector averaged real and imaginary parts of the correlator visibilities. Every ten seconds these correlator data are set to magnetic tape and the off-line computer system by the on-line computers. Monitor data are accumalated on MODCOMP disks by a monitor data logging program that selects monitor data points, for varying time itervals, for periodic logging and later transfer to a monitor data tape.

Because correlator data can be stored in the off-line computer system in nearly real time, observers can monitor the output of the array with avariable time lag. An operator's computer terminal can monitor the real-time 10-second data for any antenna pair. When the system is operating well the observer can, if it is desirable, calibrate and make maps in the off-line computer system within hours after the data are taken. Most observers wait until all data on a source are available before mapping, although they sometimes monitor on-line displays of visibility amplitude and phase for calibrators and program sources. Flagging or calibration are usually not done, however, until all data are written into the data base in the off-line computer system.

The control of source observations is philosophically oriented toward specifying the phase reference position and equipment parameters for continuous segments of Local Sidereal Time (LST). We will use the word "scan" to describe each of these contiguous blocks of observing time and the associated data. The array operates on a scan by scan basis controlled by scan parameter specifications supplied by the observers in a source list control file. The resultant data in the off-line system are then organised according to sequential scans and this is what the user deals with in off-line data processing.

2. SYSTEM CONTROL FILES

A. An Overview of Array Control Files

A series of files containing control information are stored on disk in the on-line computer system. The creation and modification of these files by operators or observers is the most direct and common method of controlling the functioning of the array. However, commands can be sent to any antenna by the operator, temporarily superceding control file commands. The operator can also control the sequencing of observation specified in a source list file, skipping to an object late in the list, extending the time on the current source, or skipping back to a an object earlier in the list.

Because of their importance let us discuss the major on-line control files. The following is a list of these files, with a brief description of their contents:

a. ARRAY control file - This file contains information applicable to the whole array (mainly time parameters).

b. SUBn control files - These files (for n = 1, 2, or 3 subarrays) contain names of source list files for each subarray, parameters of LO and receiver settings that determine frequencies of operation, and names of the (IF and ROT) files with parameters for IFs and subreflectors.

c. ANTENNAS control file - This file contains information about the subarray number, station location, and other miscellaneous parameters for each antenna.

d. BASELINE control file - this file contains that positions of the antenna stations, delay constants, and the axis intersection defect parameter for each antenna.

e. POINTING control file - this file contains the parameters used to make azimuth and elevation dependent pointing corrections.

f. IF control files - These files contain (one for each observing band) gain calibration and antenna efficiency parameters for each antenna.

g. ROT or SUBR control files - These files contain (one for each observing band) subreflector rotation and front end parameters

h. Source list files - These files contain sequential lists of source request cards with:

(1) Source Name
(2) Source Qualifier
(3) LST stop time or duration of scan
(4) Right ascension and declination
(5) Epoch of position
(6) Observing band for scan
(7) Observing mode
(8) Calibrator code if a calibrator
(9) Gain code
(10) Bandwidth selection
(11) Feature velocity (for spectral line observations)

plus optional cards for each scan for comments, LO parameters, antenna wrap control, moving source parameters, etc.

Most of these control files are modified only by the array operator or other VLA staff members; the main files created and modified by the observer are the source list files.

For those observers interested in producing their own versions of the systems files in the on-line computer system, we include a column-by-column description of each "card" in the following sections of this chapter. The simplest procedure for producing special system files is to copy the system file, alter it, and catalog the altered file under a new name. The SEDIT text editor on the MODCOMPS is used to do this. CAUTION: Never catalog a file without the telescope operator's permission.

B. Source List Files

The observer has predominant control over the major parameters of the observing process by preparing the source list files. The determination of which source list files control observing in the n-th subarray is accomplished when array operators put the source file name in the first card image of the SUBn file. This is done when the array operator learns from the observer the name of the appropriate source list files.

The source list file describes what sources are to be observed at what time, with specified positions, frequency bands, observing mode, calibrator type, gain code, bandwidth code, and feature velocity for spectral line observations. Special programs called OBSERV, which will be described in Chapter 5, are the ordinary means by which the observer prepares source list files. However, for completeness, let us now describe the different types of card images in source list files and their formats. Most users will not need to know the details described in the rest of this chapter.

The first card in any source list file must contain observer identification information. Columns 1-2 contain /. indicating an identification card. Columns 3-8 contain the observer's last name truncated to the first six characters, ending in Column 8. Columns 9-13 contain the user's DEC-10 user number, ending in Column 13.

Following the identification card there are any number of source cards. The source card specifies the parameters of observation during specified time interval. This time interval can be specified either in terms of Local Sidereal Time (LST) durations or stop times (LST). There is a one-to-one correspondence between the "scan" discussed elsewhere and the data gathered while the subarray is on source for a particular source card.

On each source card the observer must specify a source name in Columns 1-8, ending in Column 8. Sources are further described by a numerical source qualifier, which is an integer number in Columns 9-13 ending in Column 13. The significance of this number is entirely up to the observer. Leaving this blank results in the source having a numerical qualifier of zero. A blank in column 14 means time is specified in terms of LST stop time, and a dollar sign ($) means time is specified in terms of a duration. Durations begin at the completion of the previous operation. No allowance is made for antenna slewing or setup times. Columns 15-22 contain the LST stop time or duration, with HOURS, MINUTES, and SECONDS specified in I2 format in Columns 15-16, 18-19, and 21-22, respectively. Columns 24-36 contain the right ascension of the reference position to be tracked, with HOURS, MINUTES, and SECONDS specified in formats I2, I2, and F8.4 in Columns 24-25, 27-28, and 29-36 respectively. Column 38 contains a plus (+) or a blank for positive declinations and a minus (-) for negative declinations. Columns 39-50 contain the numerical specification of declination, with DEGREES, ARCMINUTES, and ARCSECONDS specified in formats I2, I2, and F7.3 in Columns 39-40, 42-43, and 45-50, respectively. A blank in Column 51 means the position is for a standard equinox of 1950.0, a D means it is an apparent position of date, a C means the position is for a standard equinox of 2000.0, and a Y means the position is for an equinox of the year specified in columns 52-55, which otherwise are left blank. Columns 56-57 specify the frequency band for the observations for the AB and CD channel paramps, with LL for 18-22 cm, CC for 6 cm, UU for 2cm, and KK for 1.3 cm under standard conditions of operation. Three other frequency bands are coded into the system: (1) HH is an L-band frequency which was chosen to minimize interference with 12 and 25 MHz bandwidths, and 21 and 18 are the two letter codes for frequencies in the hydrogen and OH bands. If alias cards are used in the SUBn file, then the band designation specified there should be used. Columns 59-60 contain an observing mode parameter, with blanks meaning normal interferometer continuum mode, Px meaning single dish pointing mode for IF x = A, B, C or D, Ix meaning interferometer pointing mode for IF x = A, B, C, or D, TF meaning a mode for the testing of the front ends, D for delay center determination mode, VA for phased-array mode, and VX for a phased-array mode (weak source) where phase updates are applied from a previous (strong source) observation in VA mode. Column 61 is blank if the source is not a calibrator, but with an A or B it is a high quality, unresolved flux and position calibrator; with a C it is reasonably good, unresolved phase calibrator; and with a T it is a point source with poorly determined flux and position. Column 63 contains a gain code which has values between 0 and 8. Gain codes are chosen depending on the the strength of the source such that, calling GC the gain code the flux of the source is between $K*2^{GC}$ and $K*2^{CG+1}$ Jy. The value of K varies with observing band, as will be discussed in Chapter 5, however GC ranges from a minimum of 3 to a maximum of 8. Columns 65-68 contain the bandwidth codes, wwww, for the A, B, C, and D IFs, so that the bandwidth = $50/2^{w}$ MHz. Below 6.25 MHz the continuum mode should not be used because the quadrature networks do not operate at narrower bandwidths, and one must use the line mode. Columns 69-80 contain the feature velocity for spectral line observations.

When there is a series of source cards, with specified durations or different LST stop times, the on-line computers initiate a change to the parameters of the next source card every time a duration is exhausted or an LST stop time is reached. The time it takes for the antennas to move to the next source position, and the subreflector rotation time, use up from tens of seconds to roughly a minute of time during the first part of each scan.

Each source card can be followed by optional cards, which are of six different types: (1) a comment card; (2) a repeat source list card; (3) an antenna wrap option card; (4) a proper motion option card, used for the Sun, planets, comets, etc.; (5) a local oscillator option card; and (6) a spectral line LO card used for spectral line observations.

The optional comment card can be used to associate observer's comments with specific source cards. Columns 1-3 must contain //* to identify the comment card. Column 4 must be left blank. Observer's comments can then be typed in any of Columns 5-80.

The optional repeat source list card (REW) allows the observer to instruct the system to repeat observing with the current source list until further notice, or to repeat a list involving LST stop times covering a full 24-hour period. The repeat source list card has /REW in Columns 1-4 and follows all other source cards.

More detailed control of repetitive observations is possible with the BAC card. On this card /BAC is placed in columns 1-4 and columns 7-13 contain a (right adjusted) integer which specifies the number of source cards to "back up". The default is n = 1 corresponding to a jump to the previous source card. One can specify n < 0, in which case observing control will skip forward -n "cards" in the source list file.

The optional antenna control card (AN) allows the observer to force motion to a new elevation and azimuth, mainly to control cable wrap problems. Columns 1-4 must contain //AN identifying an antenna control card. Columns 5-60 contain elevation, and azimuth specifications for individual antennas. Each antenna is allocated two columns (one for elevation "plunge" and one for azimuth "wrap"). Odd column numbers after //AN contain a U, D, or blank for elevation specification. U means use elevations greater than 90° (over the top) if possible, D means do not go over the top, and blank means don't care. An example will best illustrate the use of these letters:

```
//ANU U D U D U
```

This means go over the top on antennas 1, 2, 4, and 6; do not go over the top on antennas 3 and 5; and don't care on all the rest. The second column of each pair (azimuth specification, blank in the above card) contains either an R for clockwise wrap (if azimuths differing by more than 360° are possible), an L for counterclockwise wrap, or a blank for don't care.

The above procedure is used when it is desirable to control the wrap on individual antennas, which is usually not the case. To control entire arms of the entire array at once, additional columns on the antenna wrap card are used. To control an array arm, or the entire array, place an identification parameter in Column 71. Use a W, E, or N for specific arms or an A for the entire array. In Column 72 place a U,D, or blank for elevation specification, and in Column 73 put an L, R, or blank for the azimuth control.

The optional proper motion card (PM) is used for observations where the source position changes significantly during a scan. Columns 1-4 must contain //PM to identify the type of card image. Columns 11-20 contain the rate of change of source right ascension in seconds of time per day in a format of F10.0. Columns 21-30 contain the rate of change of source declination in seconds of arc per day in a format of F10.0. Columns 32-39 contain the IAT time corresponding to the position specified on the source card, with HOURS, MINUTES, and SECONDS in I2 format in Columns 32-33, 35-36, and 38-39, respectively. The date is assumed to be the IAT date of observation. Finally, Columns 41-50 contain the equatorial horizontal parallax in seconds of arc in F10.3 format. The observer should be cautioned that the epoch of the position parameters is still active. In the published ephemeris (where these data can be found), the positions of the Sun and major planets are in coordinates of date while, for asteroids, positions are in 1950 coordinates.

The optional local oscillator card (LO) allows source by source control of LO frequencies and synthesizer settings. Columns 1-4 must contain //LO for identification purposes. Columns 5-6 contain the bias digits for upconverters and mixers for AB and CD channels, using the same code as the LO and receiver setting specification card images in the SUBn files. The SUBn files are discussed later in this chapter. Columns 5-80 contain the same information in the same format as the LO and receiver setting specification cards in the SUBn files. Indeed, one can think of this optional card image as allowing the observer to change from a "standard" set of LO frequencies and synthesizer settings, defined by the system or by the user, to a new set each scan. If no LO card image follows a particular source card image, the default parameters are used.

Finally, the optional spectral line card (LI) allows source-by-source control of spectral line parameters for spectral line observations. Columns 1-4 must contain //LI. The remaining parameters on the card are identical to those on the external LO frequency card used in the SUBn files, and, indeed, modify these parameters on a source- by-source basis.

The following is a sample section of a source list file. The cards are for observations of the Sun so examples of the observation request card, the LO control card, and the moving source card are given:

```
 ./HJELLM  11
3C84       1$ 0 08 00  3 16 29.566   41 19 51.92     CC     4 0000
3C84       0$ 0 08 00  3 16 29.566   41 19 51.92     CC     4 0000
//LO                                                      SUNCIF    OFFCROT
SUN        0$ 0 15 00  7 39 49.6824  21 27 31.720D   CC     7 2222
//PM        226.678  -561.152  0  0  0      8.6600
//LO                                                      SUNCIF    OFFCROT
3C84       0$ 0 08 00  3 16 29.566   41 19 51.92     CC     4 0000
//LO                                                      SUNCIF    OFFCROT
```

In this example of a source list file, the first scan (where the source qualifier is 1) is a calibrator observation, with the normal situation of solar attenuators turned off. The subsequent card images are for observations with the solar attenuators switched on by appropriate entries in the non-standard IF and ROT files named SUNCIF and OFFCROT. One then alternates a calibrator observation with a solar observation. Since the Sun undergoes large proper motions, it is necessary to use the moving source (PM) card.

It should be emphasized that, most of the time, only the source request card is used in the source list file, and LO, LI, and PM cards are not present.

C. Remaining System Control Files

In this section we give the details for the seldom used process of producing card images for each system file that an observer may want to create. You should discuss such changes with a staff scientist and/or array operators before attempting to produce these files.

a. The ARRAY File

The array file contains three lines of information, which can be thought of as 80 column card images, corresponding to three major classes of control information.

The first card image contains time information: dUT1/dIAT is placed in Columns 1-15 in units of seconds per day; Columns 16-30 contain the modified Julian date at which dUT1/dIAT projects to UT1 = UTC; and Columns 31-45 contain the value of IAT - UTC.

The second card image in the ARRAY control file contains the coordinates of the pole: in Columns 1-15 and 16-30 the values of X and Y in seconds of arc, respectively, relative to the convential international origin are supplied; in Columns 31-45 and 46-60 the rates of change dX/dt and dY/dt, respectively, are (optionally) given in units of seconds of arc per day; and in Columns 61-75 the modified Julian day epoch for X and Y are (optionally) supplied. The information on the first two card images is taken directly from the U. S. Naval Observatory Time Service Announcements Series 7. All parameters use an F format.

The third card image in the ARRAY file contains miscellaneous control function information which will be used to indicate who can control various one-of-a-kind devices. Columns 1-4 specify the controlling subarray for the four quadrants of the correlator system- only this subarray can change its mode; Columns 6-9 specify the controlling subarray for each of the final synthesizers for the four (ABCD) IFs; Column 11 is blank when the de-icers are off and has a T when they are turned on; and Column 12 is blank if refraction corrections are to be based on measurements of the weather station, but contains a T if estimated values of refraction, based on a seasonal and diurnal model, are to be used.

b. Subarray Files SUBn = SUB1, SUB2, SUB3

Since the VLA can function in up to three subarrays, there must be a subarray file for each subarray in operation. The antennas that are to function in each subarray are specified in the ANTENNAS control file.

The first card image in a SUBn file gives the names of the source list files that will control the observing in that subarray. This looks something like FILE1bFILE2bFILE3bFILE4 (where b indicates a required space), which prescribes that the observing in this subarray should first be controlled by the source list in FILE1. When this source list is completed, control changes to FILE2, then to FILE3, and FILE4 in sequence. When a source list file has been completed, each letter in its name is replaced by a "\", e.g., FILE1 is replaced with \\\\\.

The remaining card images in a SUBn file are optional combinations of three types:

(1) Alias card - optional means of specifying nonstandard band designations.

(2) LO and receiver setting card (LO) - optional specification of LO frequencies, synthesiser settings, and the names of fields with alternative IF parameters, front end parameters, and subreflector rotation parameters.

(3) External LO frequencies card (LI) - optional card associated with the spectral line system for specification of special parameters for this mode of operation.

Alias cards cannot precede the first card with source list file names. On an alias card, Columns 1-2 specify the desired nonstandard band notation, replacing the standard LL, CC, UU, KK, UC, or CU. Columns 3-4 contain the letters AL (for alias), and Columns 5-6 contain the standard band codes being replaced and for which an LO card will be supplied. Examples of alias card images are: 18ALLL 21ALLL which might be used when the observer wishes to use both 18 and 21 cm wavelengths; the cards inform the computer that both are at L band.

The LO and receiver setting card is always present for the standard band and frequency setting, and additional ones are used for every new band designation made on an alias card. In SUBn files columns 1-2 contain the AB and CD band designations according to standard on-line usage (L, C, U, K), or as changed by an alias card; however, in source list files columns 1-2 of the LO card contain //, and the band designation is determined by the previous source list card. Columns 3-4 always contain the letters LO. Columns 5-6 contain bias digit codes for upconverters and mixers for AB and CD sides, according to a code whereby 0 means center frequency of entire band, 1 means center frequency of bottom third of band, 2 means center frequency of middle third of band, and 3 means center frequency of top third of band. Columns 7-13 and 14-20 contain the AB and CD, respectively, first LO (front end) frequencies in GHz and F7.1 format. Columns 21-25, 26-30, 31-35, and 36-40 contain the A, B, C, and D, respectively, (2-4 GHz LO) synthesizer frequencies. The B synthesizer frequency is 300 MHz higher than the A synthesizer frequency and the D synthesizer frequency is 550 MHz higher than the C synthesizer. These LO frequencies are determined by the expression

$$f(2\text{-}4\ \text{GHz LO}) = 2400 + 50n \pm 10\ ,$$

where n is an integer such that f lies within the range 2710 to 4010 MHz. The synthesizers being set are the L6 modules shown in Figure 3.6.

Continuing with the LO and receiver setting card, Columns 41-50 and 51-60 are the fluke synthesizer settings in F10.1 format, with ranges of 100-150 MHz and 200-250 MHz, for the AB and CD channels, respectively. Columns 61-70 contain the left-adjusted name of the file containing IF gain calibration parameters, the so-called IF files. Columns 71-80 contain the left-adjusted name of the file containing front end and subreflector parameters, the so-called ROT files with subreflector rotation parameters.

The SUBn files should always contain LO and frequency card images for the standard band combinations. The following is a minimum SUBn file, without alias cards, followed by explanations of each LO card entry:

As seen in the above example, standard system IF files are named SYSCIF, SYSLIF, SYSUIF, and SYSKIF for the C, L, U, and K bands, respectively, and the standard system ROT files are named SYSCROT, SYSLROT, SYSUROT, and SYSKROT. Observers who use nonstandard IF and ROT files must supply different designations. Any modification of files beginning with the letters SYS, or of the ANTENNAS, ARRAY, or SUBn files, should be done only with the advice and consent of the array operator.

```
FILE1 FILE2 FILE3 FILE4
CCLO                    3560 3860 3310 3860  100.0   200.0  SYSCIF   SYSCROT
LLLO00 -3.2    -3.2     3340 3640 3090 3640  100.0   200.0  SYSLIF   SYSLROT
UULO    19.6   19.6     3290 3590 3040 3590  100.0   200.0  SYSUIF   SYSUROT
KKLO    17.6   17.6     3560 3860 3310 3860  100.0   200.0  SYSKIF   SYSKROT
____   _____  _____    ____ ____ ____ ____  ______  ______  ______   _______
Band    AB     CD        A    B    C    D     AB      CD     "IF"     "ROT"
       First  First          2-4 GHz LO      Fluke   Fluke   File     File
        LO     LO     synthesizer settings   Synth.  Synth.
  ___
 Bias Digits
```

An additional LO frequency card (LI), to be used in the spectral line system to further specify frequencies within the band determined by the LO card, is optionally supplied, with one card for each band. Formats are as follows. In SUBn files columns 1-2 contain the AB and CD band designations; however, in source list files the LI cards have // in columns 1-2, and the band is determined by the previous source list card. Columns 3-4 must contain the characters LI, indicating it is a spectral line card. Columns 6-9 contain the default IF bandwidth codes, if not specified on the source cards (0-9 for each of four IFs). Column 11 contains an L if it is a line observation card and a C if it is a continuum card. Column 12 indicates which velocity system is to be used, with T for topocentric, H for heliocentric, L for the local standard of rest, and a blank if an LO setting from an LO card is to be used. Column 13 gives the units of the velocity of the feature to be centered in the band, with V or blank for km/sec and F for kHz. Column 14 contains a Y if the fluke synthesizers are to be up-dated, and a blank if they are not. Columns 15-17 contain the correlator mode code. Columns 18-19 specify the averaging time, where a blank, 0, or 1 means 10 seconds, and a larger integer (n) means 10n seconds. Columns 21-23 contain the beginning channel number. Columns 24-26 contain the LOG (base2) of the number of channels. Certain standard line frequencies can be specified by putting a line transition code into columns 27-30 (i.e. H, H2O, H2CO, 1612, 1665, 1667, 1720), in which case columns 31-46 must remain blank; alternatively, columns 27-30 may be left blank and one can specify a spectral line rest frequency (in MHz) in columns 31-46. Finally, columns 47-63 and 64-80 contain the AB and CD external LO frequencies (in MHz).

DEC-10 programs called DOPSET and LOSER can be used to calculate the frequencies for the LO and LI cards, as discussed in Chapter 12.

c. ANTENNAS File

The ANTENNAS file supplies miscellaneous information about each antenna. Columns 1-5 contain the physical ID number of an antenna in I5 format, ending in Column 5. Columns 6-10 contain the DCS (digital communication system) address, in octal, ending in Column 10. Columns 11-15 contain the station ID in (A2,I1) format ending in Column 15 as, for example, CW5. Columns 16-20 contain delay line number in I5 format. Column 40 contains a T if elevations greater than 90 degrees are forbidden, and is blank if they are allowed. Column 44 contains a minus sign (-) if the antenna is to be ignored because it is nonoperational. Column 45 has the number of the subarray to which the antenna is assigned. In column 51, a T means the round trip phase correction is to be turned off. A T in column 55 means that phase switching for this antenna is to be switched off at both the antenna and in the delay/muliplier hardware. A T in column 56 means that data should not be collected from this antenna (spectral line only). This file is modified only by VLA staff. The following is an example of a card image in the ANTENNAS file, corresponding to antenna #1 located on station W8:

```
    1    1  AW1           T    1    T    T
```

d. BASELINE file

The BASELINE file contains the antenna station positions, a delay constant, and the axis intersection defect parameter. On each card image, Columns 1-2 contain the antenna's physical ID number ending in Column 2. Columns 3-15, 16-30, and 31-45 contain, respectively, L_x, L_y, and L_z for the station positions in nanoseconds with an F15.4 format. Columns 46-60 contain a delay constant in nanoseconds with an F15.4 format. Columns 61-70 contain the axis intersection defect parameter ("K" term) in units of nanoseconds with F10.4 format. This file is modified only by VLA staff.

The following is an example of a card image in the BASELINE file:

```
 1   509.530    -1338.480       -745.203      -1545.0
```

e. POINTING file

The pointing file contains the pointing parameters for the Azimuth (AZ) and Elevation (h) dependent pointing formula for each antenna. This card image is in free format with the following information in order: the antenna physical ID number; the arm reference angle in degrees; the azimuth tilt E-W component, A1; the azimuth tilt N-S component, A2; the coefficient of a COS(AZ) term, A3; the coefficient of a SIN(AZ) term, A4; the axis perpindicularity error, A5; the collimation error, A6; the azimuth encoder offset, A7; the elevation tilt E-W component, E1; the elevation tilt N-S component, E2; the coefficient of a COS(h) term, E3; the coefficient of a SIN(h) term, E4; and, the second to the last number, the elevation encoder offset, E5. Thus there are seven azimuth pointing parameters (A1, A2, A3, A4, A5, A6, and A7) and five elevation pointing parameters (E1, E2, E3, E4, and E5). The last parameter on the card is the approximate reading (in turns) of the 600 MHz round trip phase detector; this parameter is used to resolve ambiguities about which lobe of the 600 MHz cycle is correct. The following is an example of a POINTING file card image:

1,-60 +0.14,-1.00,0.,0.,0.,-0.91,+42.02, +0.14,-1.00,0.0,0.0,-0.30,0.25

f. The ROT or SUBR files with Front End and Subreflector Parameters

The front end or subreflector files contain various subreflector and front end parameters. These are usually referred to as ROT files because they contain subreflector rotation parameters. The standard system ROT files are called SYSCLROT, SYSCROT, SYSUROT, and SYSKROT for the four observing bands. The choice of which ROT files are operative for a partcular subarray is made by putting the ROT file name in Columns 71-80, left-adjusted, in the SUBn file for each subarray.

There is one ROT file for each frequency band, and within a ROT file there is one card image for each antenna. Columns 1-5 contain the (physical) antenna ID number ending in Column 5. Columns 6-40 contain subreflector rotation and focus parameters. In Columns 6-10 there is the azimuth collimation error, in arcminutes, in format F5.2. In Columns 11-15 there is the elevation collmation error, in arcminutes, in format F5.2. Columns 16-30 contain the computer command for the subreflector rotation setting in format F15.1. Columns 31-35 contain the F0 focus parameter, a computer command, in F5.1 format starting in Column 31; and Columns 36-40 contain the F1 focus parameter, a computer command, in F5.1 format starting in Column 36. The focus curve is computed from

$$\text{focus} = F0 + F1\ \text{SIN}(h)$$

where h is the elevation.

Various front end parameters are specified in columns 44-70. If column 44 contains a T, the AB paramp output is switched into the CD IF system and the CD paramp output is switched into the AB IF system; however, if this column is blank, the normal situation of AB into A and B IFs and CD into C and D IFs will occur. A T in column 45 means to use this antenna for a reference for interferometer pointing. The paramps for AB and CD channels can be turned off by placing the letter T in columns 47 and 48, respectively. The 5 GHz attenuator (usually 8 dB) following the AB and CD paramps can be inserted in the signal path by putting the letter T in columns 49 and 50, respectively. The choise of high or low DC gain in the frequency converter detectors for all four IFs is chosen by placing a T or a blank in columns 52-55. The solar calibration noise tube is turned on (for antennas 17 and 18) by placing a T in column 57. For solar observations, a 20 db attenuator, located between the second stage paramp and the FET amplifier, is turned on if a T is in column 58. A T placed in column 63 means the on-line system temperature correction will be applied to the data; a blank means it will not. The standard noise tube can be turned on by a T in column 64 and turned off by a blank. A T in column 65 means the noise tube will switch on and off at a 9.6 Hz rate; a blank means it will not switch. Columns 67-70 should have T's if the frequency converter alternate input switches are to be turned on for ABCD IFs, and should be blank if they are to be turned off. Finally, columns 71-74 contain the front end filter codes for ABCD IFs. A blank or zero for an IF selects the unfiltered, full bandwidth; howver, a 1 selects 25 MHz bandwidth at an IF frequency of 1025 MHz while a 2 selects 12.5 MHz bandwidth at an IF frequency of 1027 MHz. The latter specifications are useful only for P band.

g. IF Files with Gain Calibration Parameters

The IF files contain gain calibration parameters for each antenna. The IF files used to control the observing in the n-th subarray are specified by putting the IF file name in Columns 61-70 of the IF and receiver setting card image in the SUBn file. The standard system parameters are in IF files named SYSCIF, SYSLIF, SYSUIF, and SYSKIF, so when the user changes IF parameter files other names must be used. There will always be a different IF file for each frequency band. There is a single card image in each IF file for each antenna and IF combination. Columns 1-4 contain the physical antenna ID number in format I4, ending in Column 4. Column 5 contains the IF identification character: A, B, C or D. Columns 6-15 contain the IF peculiar delay in nanoseconds in F10.4 format. Columns 16-20 contain the IF peculiar phase (positive for decreasing phase) in degrees in F5.1 format. Columns 21-25 contain the zenith efficiency parameter E0. Columns 26-30 and 31-35 contain the E1 and E2 parameters for surface accuracy deterioration with elevation. Columns 36-40 contain the E3 parameter for atmospheric absorption. The latter four parameters are in format F5.4. The net efficiency is calculated from E = E0 (SIN(h)-1)E1 + (COS(h))E2 - (CSC(h)-1)E3. Columns 41-45 contain the noise tube temperature (in degrees) in format F5.3. A T in Column 50 means that this IF is out of operation and should be ignored, whereas a blank means the IF is in operation. Finally, a T in column 51 means a constant delay of 0.32 μsec should be added to the delay for this IF.

Chapter 5

PREPARATION FOR OBSERVING

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April 1983 Edition

ABSTRACT

We discuss what the observer does to prepare for observing with the VLA. This includes the things that must be done before arriving at the VLA site, the things that are to be done to prepare the observing program, and discussion of many details that might affect observing programs. The most important responsibility of the observer is the planning and preparation of the text file(s) that control the observing process in the on-line computer system.

Because of their role in preparing an observing program, we discuss: a simple subset of the capabilities of the DEC-10 text editor (SOS); various means of supplying source names and positions; and the OBSERV program for preparing observing control files in the DEC-10. Also discussed are the details involved in using non-standard frequencies, and the known sources of interference.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. INTRODUCTION

Considering the complexity of the VLA, the instrument is usually relatively easy to use. Observing procedures are automated to the extent that that once the appropriate control files are generated there is nothing for the observer to do except carry out data reduction. If one uses the VLA in a standard operating configuration, there are few system parameters that the user needs to be concerned with. The most significant parameters are time of observation, observing duration per scan, band (sky frequency), and bandwidth. Solar system objects, especially the sun, require further complications such as moving coordinates. The philosophy of the observing session requires careful thought. Considerations such as u-v plane coverage, signal-to-noise ratio, the total amount of observing time per object, and the location of sun and moon should be evaluated before an observing proposal is submitted. In this chapter we will discuss various items to consider when organizing an observing program, and how to prepare the observing source list.

2. PRELIMINARY PLANNING FOR VLA OBSERVING

A. VLA Staff Aid

Each scheduled observing program is assigned a VLA staff member who should be the first person consulted concerning problems before, during, and after observing. For observers inexperienced with the VLA this staff member should be consulted at least a few weeks before the observing run begins. Current characteristics of the array and the status of software should be discussed so the user can optimize use of the instrument. In addition to the user obtaining current status information, it is important that the staff member be familiar with the planned program so that advice can be optimized.

B. Materials to Bring Along

The user should plan to bring along all information critical to carrying out the observing program. Although some library facilities are available at the VLA site, the user should not count on obtaining critical information at the site. At the very least, the observer should prepare and bring along the following: (1) a list of all sources, with source positions, that might be observed; (2) an assessment of the minimum amount of observing time and u-v coverage needed to attain the goals of the program; (3) an estimate of maximum flux densities of sources, good to at least a factor of two; and (4) a calibration plan matched to the characteristics of program sources. Positions for any epoch may be used; however, epoch 1950.0 positions are treated as "standard". Although it is important to plan in advance, it is best to delay generation of the final observing program until arrival at the VLA site.

C. Arrival at the Site

Observers should come to the VLA site at least one or two days before the observing begins. Since you cannot count on your staff contact being available on weekends, unless special arrangements have been made, and because other staff that you might need to consult with are not around on weekends, this advance time should occur during the week. Observers should also plan to spend about a week after the observing run for editing, calibration, mapping and initial image processing. Experience has shown that, even if the user is planning further data reduction elsewhere after leaving the site, intolerable and impossible demands on VLA staff and facilities can occur when observers attempt to get everything done in only a few days.

D. First Things to Do

Upon arrival at the site, the first priority is to get settled in a room in the Visiting Scientist Quarters and to be sure that the logistics of eating are well in hand. This is to avoid finding yourself after 4:30 pm with room or meal problems and no one to help you straighten them out.

Inexperienced observers should next talk with the VLA staff member assigned to help them out. At this point a re-discussion of the goals of the program should occur, with specific evaluation of the current status of everything needed to accomplish the program. Discussions with recent observers and other VLA staff may also be valuable. Although your VLA staff contact should be your main source of information, outside of documentation, other input is often very helpful.

3. DETAILED PLANNING OF OBSERVATIONS

A. Need for Planning

Many small details need to be considered in the planning of a VLA observing program. The flexibility of the VLA gives the user many options (and defaults) that may effect scientific results.

Observers should finalize, on paper, their observing and calibration plans for at least the first several hours of observing. If possible, it is a good idea to have an observing plan, with alternatives, prepared for the entire observing run. However, if this covers more than 24 hours, it may be wise to delay the most detailed planning of all but the first 24 hours because actual experience while observing tends to lead to modifications of programs. In the detailed plan the sequence of calibration should be established and the times of observation of all sources, whether in LST durations or stop times, should be roughly specified. In many cases this means establishing a specific cycle of observations of an hour or two that is repeated a number of times. Once the cycles or detailed times of observation are planned, the observer should check such things as elevation limits, excessive move times, azimuth limits, and adequacy of integration time and hour angle coverage. The OBSERV program that we will discuss shortly is an aid in both preparing and checking the observing program.

B. Calibration Strategy

It is wise to err on the side of overcalibration, particularly if the quality of the weather is uncertain. At least 10% and sometimes as much as a third of the observing time should be spent on calibrators. For 6 and 20 cm observations, about five minutes out of each half hour should be devoted to phase calibrators. For 2 and 1.3 cm observations, five minutes out of each fifteen or twenty minutes may suffice. Phase calibrators are chosen from either the observer's own knowledge that they are point sources (at the appropriate wavelength) with good positions, or from the observer's perusal of the Calibrator Manual at the VLA. In addition, the flux densities of phase calibrators, all of which tend to be time variable and for which flux density histories are never completely adequate, will need to be determined by bootstrapping from observations of good flux density calibrators. Tables of information about these are also available in the Calibrator Manual. All VLA flux densities are based on 3C286. It is best to include this source at least once for each frequency and bandwidth to be used, if at all possible. If not, secondary flux calibrators are available, including a number of circumpolar sources that can be observed at any time.

If more than one frequency is being used, it is recommended that all observations involve the basic sequence CALIBRATOR - SOURCE - CALIBRATOR for 1.3 and 2 cm and SOURCE-CALIBRATOR or CALIBRATOR-SOURCE for 6 and 20 cm. For high frequency observations it is important to choose a phase calibrator as close to the source as possible to reduce differential atmospheric effects. During bad weather, observations at 2 and 1.3 cm may not be possible.

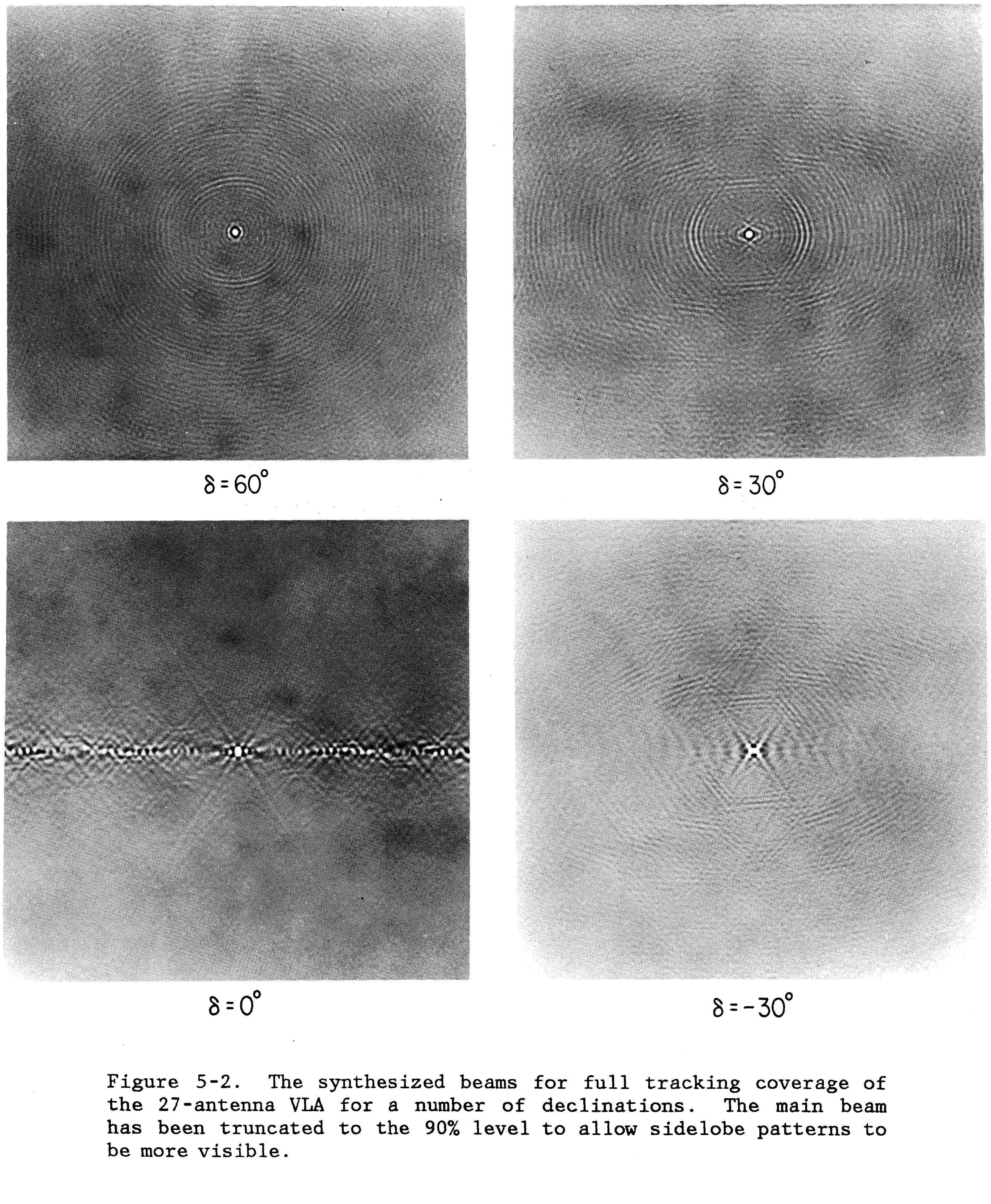

Figure 5-2. The synthesized beams for full tracking coverage of the 27-antenna VLA for a number of declinations. The main beam has been truncated to the 90% level to allow sidelobe patterns to be more visible.

Table 5-1
Maximum and Minimum Beam Sidelobe Levels

Declination (degrees)	Maximum (fraction)	Minimum (fraction)
80	0.07	-0.14
60	0.08	-0.17
40	0.11	-0.25
20	0.16	-0.40
0	0.2	-0.42
-20	0.2	-0.4
-40	0.2	-0.44

Table 5-2
Sidelobe Levels for 30^o Declinaton Buildup Map

H_{start}	H_{stop}	H_{range}	Inner 1/4 Maximum Sidelobe Level	Outer 3/4 Maxumum Sidelobe Level
-6^h	$-5^h\ 45^m$	15^m	27%	12%
-6^h	$-5^h\ 30^m$	30^m	16	4
-6^h	-5^h	1^h	9	4
-6^h	-4^h	2^h	8	3
-6^h	-3^h	3^h	7	2
-6^h	-2^h	4^h	5	2
-6^h	0^h	6^h	3	2
-6^h	$+6^h$	12^h	3%	<1%

E. Sensitivity, Resolution, and Confusion

In addition to the question of the u-v coverage obtained for VLA observing, it is necessary to be aware of the sensitivity, resolution, and confusion limitations of the observations. Table 5-3 summarizes the approximate parameters of these limitations for the standard 27-antenna observing situation. As seen from Table 5-3, one of the principal advantages of the VLA is the sensitivity of its 130 m collecting area. A bandwidth of 50 MHz was assumed for the sensitivity calculations in Table 5-3, so scaling with the square root of the bandwidth should be applied for other cases.

F. Subarray Operation

The VLA can operate antennas in up to three subarrays, with each subarray operating independently and simultaneously. Depending upon the goals of the observing program, it may be desirable to use more than one subarray. For example, if simultaneous frequency coverage is important while sensi-tivity and u-v coverage is no problem, it may be desirable to schedule different frequencies in different subarrays. However, for practical reasons involving the VLA calibration programs, you should never use fewer than three antennas in a subarray and it is strongly recommended that there be at least four, to allow for one possible antenna-IF failure. One achieves subarray operation by having a different source list file for each subarray and having the array operator modify the subarray files (SUBn) to indicate which antennas and which source list files are to be used in each subarray. The user should be warned that, because the number of antenna pairs in a subarray is N(N-1)/2, where N is the number of antennas, one rapidly loses both sensitivity and u-v coverage by reducing N. Under most circumstances, the user will be much better off using only one subarray, but alternating observations of different types.

Table 5-3

Sensitivity, Resolution, and Confusion Limits With 27 Antennas

Frequency	1.34-1.73	4.5-5.0	14.4-15.4	22.0-24.0	GHz
Wavelength	22.4-17.3	6.67-6.00	2.08-1.95	1.36-1.25	cm
Band Designation	20cm L	6cm C	2cm U	1.3cm K	
System Temperature	60	60	120	400	°K
RMS Sensitivity in 10 minutes (50 MHz bandwidth)	0.13	0.10	0.2	1.0	mJy
RMS Sensitivity in 12 hours (50 MHz bandwidth)	0.015	0.012	0.03	0.12	mJy
Untapered Brightness* Temperature (A configuration)	6.9	5.5	34	54	°K
Dynamic Range Without Self Calibration**	100	50	25	10?	
Antenna Beam Size (HPBW)	30'	9'	3.7'	2'	
Brightest Source Expected in Antenna Beam	100	2.3	<0.1	<0.01	mJy

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

$$\Delta T \simeq (1.46\lambda^2/\theta_1\theta_2)\ \Delta S$$

Where θ_1 and θ_2 are the half-power synthesized beamwidths in arcseconds, λ is the wavelength in cm, and ΔS is the rms sensitivity per beam area in mJy.

**Dynamic range is extremely dependent on declination, time of day, season, and frequency of calibration.

G. Final Details of Source Scheduling

Once the basic questions of calibration procedures, subarrays, and integration times for sources and calibrators are settled, more detailed source scheduling can proceed. It is recommended that a written plan of sources and observation times be prepared, either for the entire program or for basic cycles repeated often in the basic program. At the very least, you need to figure out the sidereal times (LST) for the first and last time the array will be on each source. Also, check that the source is above elevation limits using Figures 5-3 or 5-4.

Figure 5-3 is a plot showing the correspondence between Altitude-Azimuth and Hour Angle-Declination. Figure 5-4 shows the hour angle limits as a function of declination for 8°, 10°, and 20° elevation limits. The 10° limit is useful for scheduling if you want maximum hour angle coverage without danger of encountering the 8° instrumental limit. The 20° limit is useful when you want to avoid large air masses.

a. Bandwidth Selection

Selection of the observing bandwidth depends upon a number of considerations. Maximum sensitivity is obtained with 50 MHz bandwidth, although the field of view will be limited, as seen from Table 5-3. However, with observations of small sources this is no problem, and is, in fact, desirable to limit problems with confusion. In almost all cases, detection experiments should be carried out with 50 MHz bandwidth, as should mapping of faint, small extended sources. For larger sources and the larger array configurations, a narrower bandwidth should be used to widen the field of view. Independent of any other consideration, 50 MHz bandwidth is most desirable for 2 and 1.3 cm operation; this provides needed sensitivity and it does not limit the field of view. For observations at 20 cm, where interference may appear in the 50 MHz bandwidth but not in the 25 or 12 MHz bandwidths, it may be desirable to choose a narrower band which is interference free (cf. Section 6 in this Chapter).

b. Move Times

The time required for slewing the antenna from one source to another must be considered when choosing a duration time. You do <u>not</u> get your duration time in addition to the slew time. If you specify a 10 minute duration, and the slew time is 4 minutes, the antennas will be on the source roughly 6 minutes. The OBSERV program can predict move times.

The antenna slew rates are: 20°/minute in elevation and 40°/minute in azimuth. Be sure to include slew times when choosing the observing time for each source. In addition, it takes 30-50 seconds for the system to completely "set-up" after the antennas slew. On-source calibration times can frequently be as short as 2 minutes, so slew and set-up times are important to consider when choosing short durations.

Tracking a source near the zenith can cause difficulties because of the large rate of change in azimuth. Since it is not possible to observe a source within 0.3 degrees of the zenith, sources between declinations 33° 40' and 34°30' should not be scheduled near transit (cf. Fig. 5-3).

The next consideration is the slewing direction. The antennas will always follow the shortest path when moving to the next source. However, if azimuth cable limits will be encountered before reaching the source, or during the tracking duration you have specified, the computer will instruct those antennas to slew in the opposite direction. You have three choices in coping with the antenna cable wrap problem:

(1) Do nothing. You can ignore the situation and let the computer decide. This technique is the least effort but may lead to missing a calibrator scan entirely, or part or all of a scan on a program source.

(2) Schedule carefully. If you find out where the antennas are pointing at the end of the previous program, you may be able to schedule your sources so as to minimize cable unwrapping at an inconvenient time.

The cable wrap limits are listed in Table 5-4 lists information about these antenna wraps and azimuths, where Z is the true azimuth and AZ = Z - 180° is the "antenna azimuth".

Table 5-4
ANTENNA WRAP AND AZIMUTH INFORMATION

Range in Z	Antenna Azimuth (AZ)		
	CCW limit	Center	CW limit
$180^\circ \pm 265^\circ$	95°	360°	625°

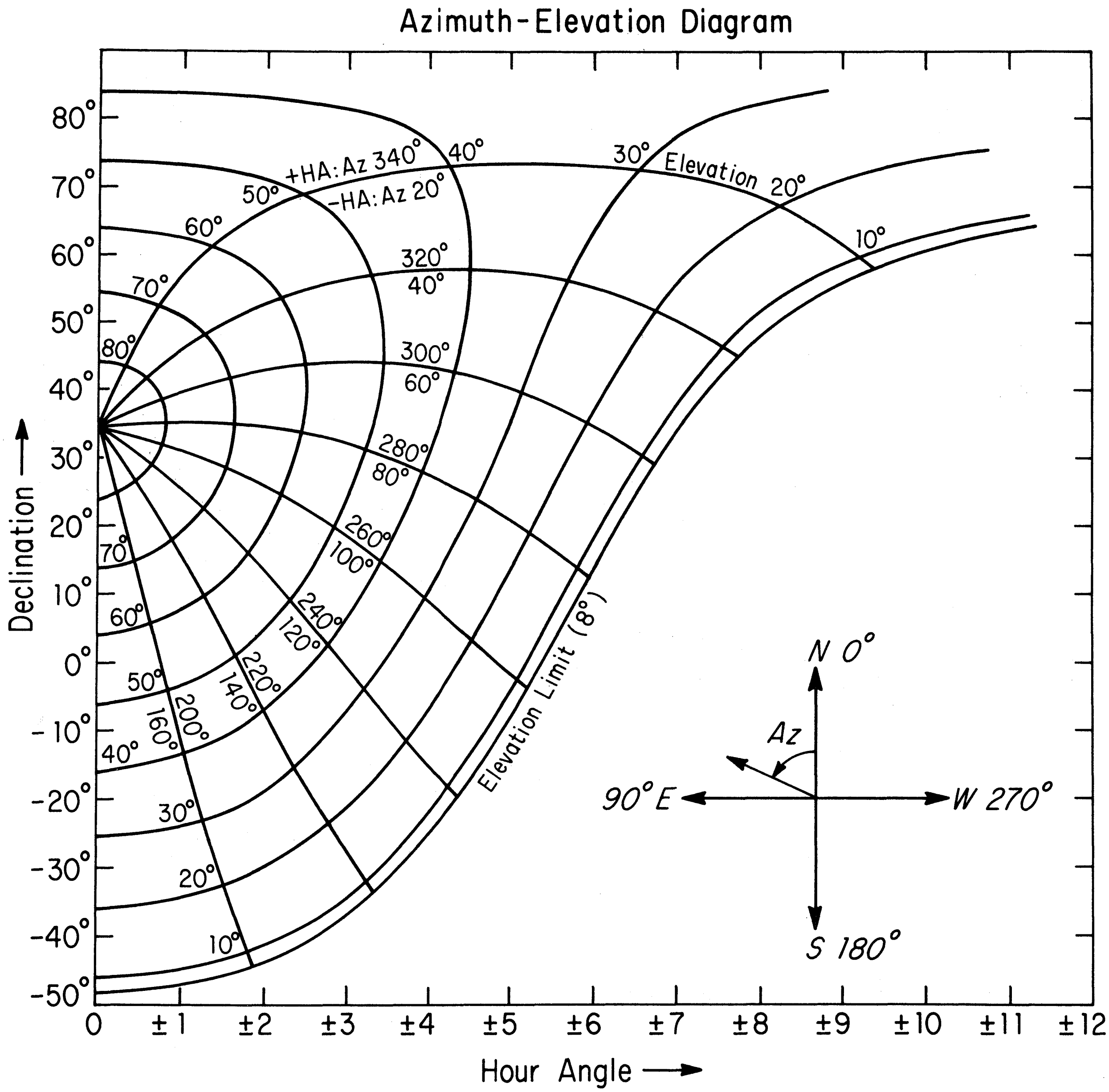

Figure 5-3. Chart for conversion from Alt-Az (Elevation and Azimuth) coordinates to (H,δ) coordinates.

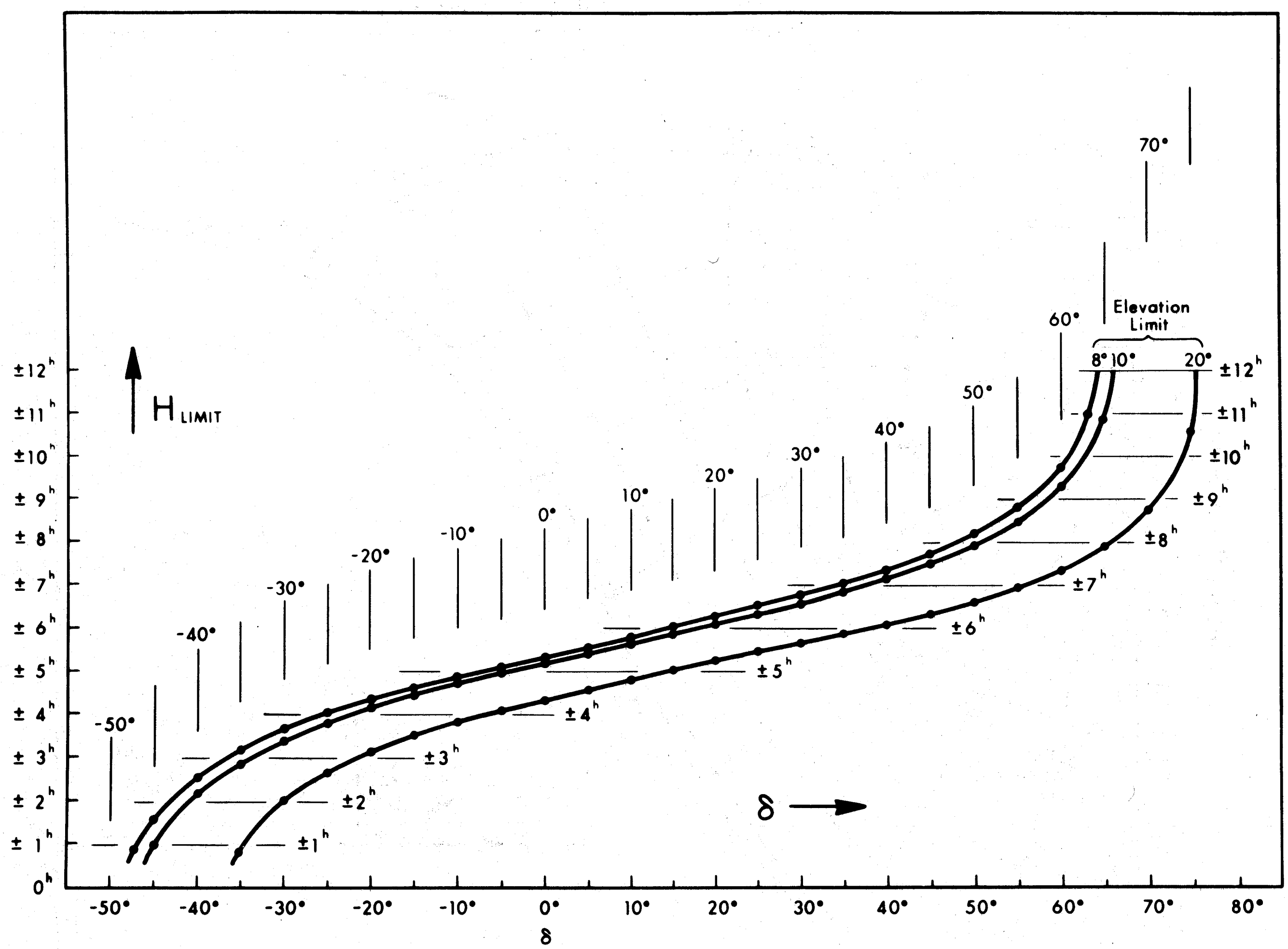

Figure 5-4. Plot of hour angle limits as a function of declination for elevation limits of 8°, 10°, and 20°.

(3) Insert cable wrap cards. You can force the antennas to wind in a particular direction any time you choose. The procedure for adding a cable wrap (AN) card is explained later in this chapter in the section on OBSERV. In addition to controlling the direction of rotation in azimuth, you can allow or disallow the "over-the-top" mode in which the antennas are capable of tipping 35^{o} beyond the zenith. This capability may be enabled unless you inhibit it with a cable wrap (AN) card in the OBSERV program. Allowing over-the-top observing can cause confusion in determining what paths the antennas will take on their next slew, because they will remain over-the-top until a limit is anticipated when slewing, or until you prohibit it with an AN card. The CHKOBS features in a DEC-10 program called OBSERV, will give position information that is very helpful in keeping track of antenna movement. If you anticipate difficulty in using over-the-top geometry, we suggest arranging your schedule to avoid it or to prohibit it with an AN card. If you choose the latter, an AN card must accompany each source card in which you think the computer may choose to move the antennas over the top.

c. Primary Beam Considerations

In some instances the desired field of view may be so wide that the antenna beam attenuates the signal at the edge of the field. One can approach this problem in two ways. Either allow the attenuation and try to correct for it later, or observe the field with multiple antenna positions. If maximum flux accuracy is desired, the second approach is superior. If having all the sources in one map, or minimizing observing time, is important the first approach may be satisfactory. However, one should be aware of the reduction in signal-to-noise ratio. In the extreme case of sources near the first null in the beam, all signal will be lost.

It is sometimes possible to take advantage of the first null in the antenna pattern. If a strong source is in the vicinity of the source of interest, the beam null ($\sim 3.4' \lambda_{cm}$ from the field center) may be placed on the strong source. Except for an unusual case, the peak of the beam need not point exactly at the source of interest.

Figure 5-5 shows the antenna pattern for the four main observing bands. Beyond the plotted curve the beam pattern is too poorly known to allow reasonable measurements of surface brightness.

d. Polarization Calibration

Polarization data are always gathered with the VLA. Normally IF channel A (or B) receives right-hand circular polarization and channel C (or D) receives left-hand circular polarization. Polarization data are calibrated with the DEC-10 program POLCAL after the regular calibration procedures are completed.

POLCAL will solve for the system polarization parameters and the calibrator polarization parameters simultaneously. Thus any calibrator suitable for one's program can also be used for the system polarization calibration. The calibrator should be observed at several hour angles corresponding to a wide range of parallactic angles. (See Figure 5-6 for a plot of parallactic angle vs. hour angle.) Good parallactic angle coverage is the most important requirement for good polarization calibration. If this is not possible, one may be able to borrow calibration parameters. The antenna polarization does not change quickly, so using previously determined parameters may be adequate. The determination of absolute position angle requires at least one observation of a strongly polarized calibrator (like 3C286 or other sources in the Calibrator Manual) with known position angle.

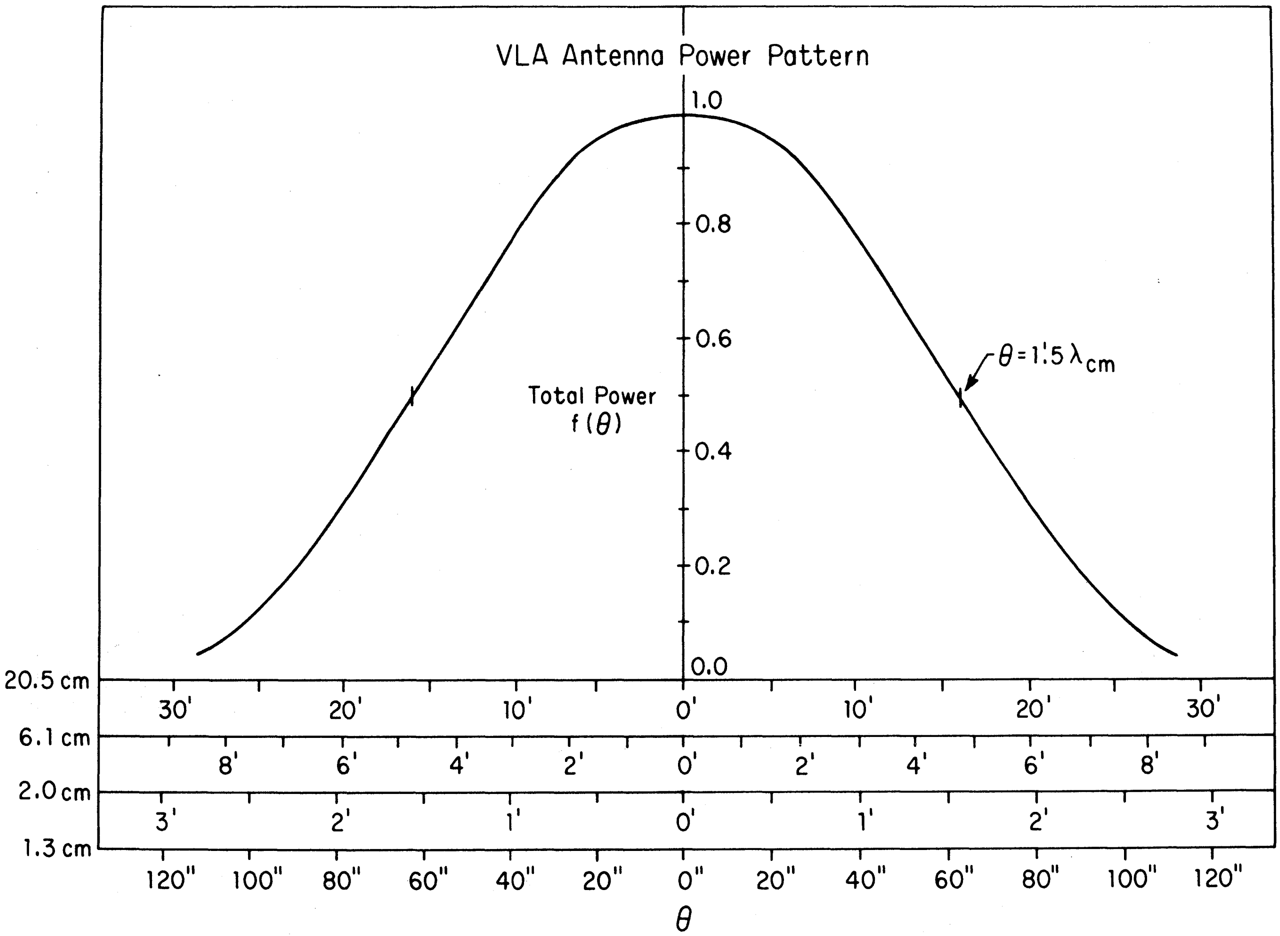

Figure 5-5. Antenna power pattern for all VLA observing bands.

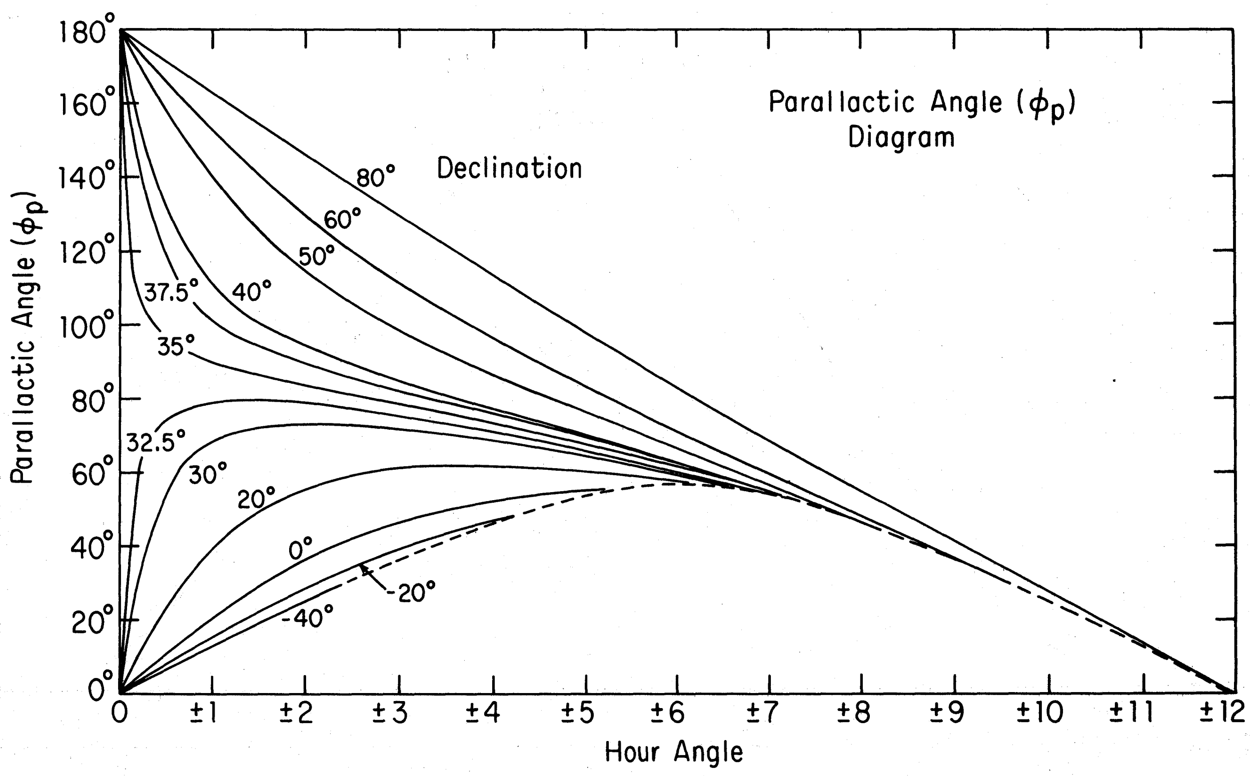

Figure 5-6. A plot of parallactic angle vs. hour angle for various source declinations.

e. Standard vs Non-Standard Frequencies

Selection of standard frequencies for each observing band is recommended unless other considerations are important. The default frequencies are listed in Table 5-5.

Table 5-5
Standard Continuum Observing Frequencies

	BAND				
Bandwidth [MHz]	21cm HH [MHz]	20cm LL [MHz]	6cm CC [MHz]	2cm UU [GHz]	1.3cm KK [GHz]
50.0		1464.90	4885.10	14.9649	22.4851
25.0	1413.00	1452.40	4872.60	14.9774	22.4726
12.5	1406.75	1446.15	4866.35	14.9837	22.4664
6.25		1443.03	4863.23	14.9869	22.4632
3.125		1441.46	4861.66	14.9883	22.4617
1.5625		1440.68	4860.88	14.9891	22.4609
0.78125		1440.29	4860.49	14.9895	22.4605

As this is written, a few VLA antennas have been equipped with an experimental system operating at 300-350 MHz. This system, called P band, is being tested for possible use as a standard VLA low frequency system.

f. Bandwidth Effect on Intensity and Beam

A wide bandwidth, which is usually chosen to improve the sensitivity, can decrease the field-of-view and broaden the synthesized beam. Beam broadening and central intensity loss should be considered when choosing a bandwidth. If a wide field of view is necessary, you must decide what loss can be tolerated at the edge of the field, and choose the appropriate bandwidth. However, as the bandwidth is narrowed, the observation time for a source must be increased to maintain the same sensitivity. In addition to causing a loss of intensity, the bandwidth also widens the radial dimension of the synthesized beam as the distance from the phase center increases. These bandwidth effects are discussed in more detail in Chapter 2 where figures show the quantitative effects of bandwidth on point source intensity and beam shape. Table 5-6 lists a few values of the intensity loss due to finite bandwidth, for all four VLA configurations, as a function of $\beta = (\Delta\nu/\nu)(\Theta/\Theta_{HPBW}) = 1.6(\Theta/1')(\Delta\nu/50MHz)(1/3.285)^{n-1}$ (n = 1, 2, 3, and 4 for the A, B, C, and D configurations), where Θ is the angular displacement from the phase reference position.

Table 5-6

Loss of Peak Intensity Due To Finite Bandwidth*

$\beta=(\Delta\nu/\nu)(\Theta/\Theta_{HPBW})$	I_{beam}/I_o	Θ(BW=50MHz)			
		A	B	C	D
0	1.0	0	0	0	0
0.52	0.95	13"	40"	2'	8'
0.74	0.90	20"	60"	3'	11'
1.0	0.80	25"	80"	4'	15'
2.0	0.50	50"	3'	9'	30'

* No tapering and uniform weighting of computed image.

g. Integration Time and It's Effect on Intensity

Increasing the integration time interval of the correlated signals to too large a value can cause a loss of intensity for map features far away from the phase center. The loss increases as the distance from the phase center increases. In Table 5-7 we list one measure of the effects of averaging time: the averaging times for which intensity loss equals that due to finite bandwidth.

Table 5-7

Averaging Time for Which Integration Time Losses
Equal Bandwidth Losses for $\delta = 90^{o}$

ν[MHz]	Averaging Time(seconds)				
	$\Delta\nu$ = 50MHz	25MHz	12.5MHz	6.25MHz	3.125MHz
1460	415	210	105	55	25
4885	140	70	35	18	9
15000	45	22	10	5	3
23000	30	15	7	3	2

The normal integration time is 10 seconds in the on-line computer system and on the MODCOMP archive tapes. However, under special circumstances one can request a minimum integration time of 3 1/3 seconds. Unlike bandwidth losses, intensity losses due to too large an averaging time (greater than 10 or 3 1/3 seconds) can be removed by re-filling data bases with shorter averaging times.

If one is greatly concerned with losing intensity by integration, a conservative approach should be adhered to. However, since the worst case only occurs during part of the tracking on a particular source, and since increasing integration time reduces disk storage space and reduces off-line computer program execution time, it is well worth choosing the maximum possible integration time.

h. Correlator Saturation and Bandwidth Codes

At various stages in the VLA data processing system the real and imaginary parts of the visibility function are stored as 16 bit integers, with an associated "gain code" that indicates the scaling factor between these integers and the true visibilities. As part of the preparation for observing the user must estimate the flux level and associated gain code for each source to be observed. If a gain code is to high for a weak source, the visibility may not be represented with sufficient accuracy. On the other hand, too low a gain code for a strong source will result in "saturation" where the stored real or imaginary parts of the visibility should exceed 32767, but are truncated in the high order bits, resulting in an unpredictably bad number.

The weakest sources should have a gain code of 3 while the strongest sources should have a gain code of 8. As a rough rule of thumb, if S is the flux density of a source (above 8 Jy at 20 and 6 cm, above 80 Jy at 2 and 1.3 cm), the gain code should be such that $K*2^{GC} <= S <= K*2^{GV+1}$, where K ~ 1 for 20cm and 6 cm, and K ~ 10 for 2 cm and 1.3 cm.

A more correct treatment of the problem is required when sources are so strong that they contribute significantly to the system temperature. It may be possible to arrange for test observations to determine the gain code for which saturation occurs for particular strong sources.

4. PREPARING SOURCE LIST FILES WITH THE DEC-10 OBSERV PROGRAM

A. Supplying Source Information

The DEC-10 OBSERV program requires specification of source names, positions, and (optional) gain codes by the user. Although these can be typed in using the OBSERV program, it is usually more convenient to put this information in text files stored on disk in the DEC-10. The OBSERV program can then search these files for the needed information for a specified source. Source information can be put into disk files in three ways: (1) from punched cards; (2) by using the DEC-10 text editor (SOS); and (3) by using the SUNOBS program to prepare source list cards for features on the surface of the Sun.

a. Supplying source information on punched cards

The observer can supply source information in the form of punched cards. For each source one supplies a card with the following information:

```
NAME  hh mm ss.ssss  ±dd mm ss.sss   X    l c u k
```

where NAME is any string of up to eight characters without imbedded blanks, followed by right ascension with the hours, minutes, and seconds separated by at least one blank, followed by declination with the degrees, arcminutes, and arcseconds separated by at least one blank, followed by an optional calibrator code character (X = C, T, A, etc.), and then gain codes for the

the 20, 6, 2, and 1.3 cm observing bands can be (optionally) specified by the integers (between 3 and 8) l, c, u, and k, respectively. Any number of source cards can be entered, and these cards must be followed by a DEC-10 End-Of-File card. EOF cards may be found next to the card punch in the computer room, which is located opposite the DECWRITER by the DEC-10 tape drives. The EOF card has holes punched out of all 80 columns for the rows corresponding to "&", "-", 0, 1, 6, 7, 8, and 9.

Once you have a source card deck with an EOF card at the end, insert the cards into the card reader (next to the line printer). Then turn on the power to the card reader, and press the RESET button. On the secondary console (DECWRITER) next to the tape drives, type (we will follow the convention that instructions typed by the user are underlined)

o-assign cdr:

o-copy FILNAM.SOU[13,PN]=cdr:

where each command line is terminated by a carriage return, and the cards will be read into a file name FILNAM.SOU in your [13,PN] area. FILNAM is any string with up to six characters, the SOU extension is required for source input cards for OBSERV, and PN is the user or programmer number assigned the first time you arrive at the VLA site. When the cards have been read in, type the following into the secondary console:

o-deass cdr:

after which you can remove the card deck from the card reader and turn off it's power.

c. Supplying source information using the DEC-10 Text Editor (SOS)

The DEC-10 text editor named SOS can be used to write source card information in a text file in preparation for input to OBSERV. Before this can be done, you must log in by typing (at any free DEC-10 terminal)

login 13,PN

where PN is the number mentioned above. The DEC will respond with the prompt PASSWORD. Type in your assigned password, which will not be echoed on the screen. The RETURN key is pressed after each entry. The period on the left edge of the screen is the prompt symbol for operating systems commands, including those which initiate the running of programs.

You are now ready to enter source information into the computer. SOS is a powerful, line oriented text editor. You can learn all of its capabilities, some of which are discussed in Chapter 7, from manuals at the VLA site. For now we will discuss a simple sub-set of its commands.

Think of a name for your file (say GALAXY) and type

sos galaxy.sou

(either lower or upper case will do). The extension SOU is necessary. A prompt for line number 100 will appear on the screen. Then type the source name, right ascension, declination, an optional calibrator code if the source is a calibrator not listed in the Calibrator Manual, and gain codes for L C U and K bands for each source (optional). One or more spaces should be left between each parameter. When a source "card image" is completed, type a RETURN and you will be prompted with another line number.

Continue typing line-by-line, until all sources are entered into the file. You then get out of line input mode by hitting the ESCAPE key (hold down the CNTRL key while pressing the "[" key on some terminals), which we will indicate by ESC. An example of the dialogue creating a source file using SOS is shown below. A description of gain codes and calibrator codes is given in Chapter 4. In the example the calibrator code has been omitted, and the gain codes are all 3 (gain codes 0, 1, and 2 are valid but not recommended even for the weakest sources), for all except the last source.

```
.sos galaxy.sou
INPUT: GALAXY.SOU
00100  IC3943   12 56 11.6   28 22 00.   3 3 3 3
00200  RB203    12 56 21.3   28 07 49.   3 3 3 3
00300  N4860    12 56 39.2   28 23 35.   3 3 3 3
00400   1259+271 12 59 23.4  +27 05 54.3   C   5 5 5 5 ESC
*e
```

After exiting the typing mode of SOS by hitting the ESC key (which is a CNTRL [on the ADDS terminal) you will then see the asterisk "*" prompt for various possible SOS commands. One such command is the letter e, which causes an exit from SOS and a return to monitor level.

If you want to make changes in a source file, you run SOS again and make use of various delete ("d"), replace ("r"), print ("p"), and insert ("i") commands followed by line numbers, or ranges of line numbers in the format n:m where n is a starting line number and m is an (optional) ending line number. The following is an example of a second editing session on GALAXY.SOU:

```
.sos galaxy.sou                                     ;to edit galaxy.sou
EDIT: GALAXY.SOU
*p/1                                                ;to list the file (page 1)
*i300                                                      ;to insert after line 300
00350  SS433 19 09 21.286  4 53 54.07  3 3 3 3
```

```
*r300                                                      ;to replace line 300
00300  NGC4860  12 56 39.2   28 23 35.   3 3 3 3
*p100:400                                                        ;to print 100 to 500
00100  IC3943    12 56 11.6   28 22 00.  3 3 3 3
00200  RB203    12 56 21.3   28 07 49.   3 3 3 3
00300  NGC4860   12 56 39.2   28 23 35.   3 3 3 3
00350  SS433 19 09 21.286  4 53 54.07  3 3 3 3
00400   1259+271 12 59 23.4  +27 05 54.3   C   5 5 5 5

*e                                                                  ; exit from SOS
```

Note that we use a convention in this Introduction whereby comments are added to the right of proper computer dialogue if prefaced with a semi-colon (;).

c. Supplying source information for solar observing

A program called SUNOBS can be used to prepare observing cards for observation of features on the surface of the Sun. This program prepares an observing file for solar observations which can then be accessed by OBSERV, as an OBSERVFILE, for the addition of calibrator and other source cards. The use of SUNOBS is documented in the Observer's Reference Manual. The user supplies solar ephemeris information to SUNOBS, and then can create source cards for specified heliocentric or heliographic coordinates. Each source card is accompanied by an LO card naming the files in which special solar parameters are set and a PM card specifying the proper motion parameters for tracking a feature on the moving and rotating Sun (using a linear proper motion approximation).

B. Running OBSERV in the DEC-10

a. The OBSERV Program

The OBSERV program is executed by typing

```
r OBSERV
```

and once OBSERV responds with an asterisk (*) prompt, you can type OBSERV commands. The following is an example of (1) what you will see after OBSERV indtroduces itself, (2) what you will get if you ask for a display of current OBSERV parameters by typing INPUTS, (3) and a short dialogue setting some of the parameters applicable to the OBSERVFILE to be created:

```
OBSERV [100,4]    Version 0.3    04-FEB-83    15:47
======
I help you prepare observing source lists.
* inputs
```

```
OBSERV INPUTS
====== ======
  (GENERAL) ========
observfile. . . . OBSERV.OBS[13,]
sourcefiles . . . DSK:MCL.HSH
program . . . . . CONTINUUM
  (MISC) ===========
outfile . . . . . TTY:OBSERV
infile. . . . . . DSK:OBSERV.OBS[13,]
  (MAKOBS) =========
id  . . . . . . . <proposal number> <id>
maxlines. . . . . 500
* sour galaxy                  ; add GALAXY.SOU to sourcefiles
* observfile exampl                 ; name source list file
* id ah99 11                   ; add proposal and user ID
* maxl 100                     ; will be < 100 lines
```

Note that in OBSERV, like many other DEC-10 data reduction programs, you need type only the minimum number of first characters in a command name that will uniquely distinguish that command from the others in the program.

The name (with six or less letters) you specify for the OBSERVFILE will name a file (in this case EXAMPL.OBS) with the source list cards for your observing program. The MCL.HSH file, listed as a SOURCEFILE, is the Master Calibrator List (stored on disk in a "hashed" form). After one has specified the SOURCEFILE named GALAXY.SOU, both MCL.HSH and GALAXY.SOU will be used to obtain position, calibrator code (if any), and gain codes (if any) for any source named in the MAKOBS part of OBSERV. Since the calibrator file (MCL.HSH) stored on disk contains all the necessary information about calibrators in the Calibration Manual, the user need not include such calibrators in their own .SOU files. To reduce storage space in the OBSERV program keep MAXLINES to a reasonable minimum. This is the maximum number of lines in your observinglist. If you type INPUTS after the input of the commands shown above, you will now see

```
OBSERV INPUTS
====== ======
  (GENERAL) ========
observfile. . . . EXAMPL.OBS[13,]
sourcefiles . . . DSK:MCL.HSH, GALAXY.SOU[13,]
program . . . . . CONTINUUM
  (MISC) ===========
outfile . . . . . TTY:OBSERV
infile. . . . . . DSK:OBSERV.OBS[13,]
  (MAKOBS) =========
id  . . . . . . . AH99  11
maxlines. . . . . 100
```

Commands at this level are used to set parameters for the rest of the OBSERV "sub-programs". Type HELP while in OBSERV, and, as for any of the other DEC-10 data reduction programs, you will see a listing of all of the current commands, and information about syntax and meaning of each command. Some of the commands are common to all data reduction programs, and the rest, which we will concentrate on here, are commands of OBSERV. The following is an example of the complete HELP file for the top level of OBSERV when this was written:

```
OBSERV COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file
savecommands <file-specification>       Save current inputs in given file
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT,MAKOBS
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT,MAKOBS
setdefaults <kind> | <nothing>          Set INPUTS to original defaults
finish                                  Stop program and leave
observfile <filename.OBS[13,pn]>        Source list file under preparation
sourcefiles <DSK:filename.SOU[p,pn]...> File(s) with source input data
program  CONTINUUM | LINE | VLBI        Type of observing program
go SETDEF                               Assign OBSERVFILE source list defaults
   MAKOBS                               Make OBSERVFILE additions/modifications
   CHKOBS                               Check source list cards in OBSERVFILE
   READ                                 Read INFILE (.SOU) & check for errors
   LIST                                 List .OBS | .SOU file on OUTFILE device
explain <subject> | <empty>             Type more about <subject> or type
  OBSERV                                  special OBSERV information files.
outfile  TTY: | LPT: | <DSK:filename>   Output destination for GO LIST | READ
infile <DSK:filename>                   GO LIST | READ input file (.OBS | .SOU)
id <proposal number> <usernumber>       Source list ID card information
maxlines <integer>                      Max. number of card images (<=500)
```

Once the parameters at the top level of OBSERV are set, there are five things that on can accomplish by typing GO followed by an execution option. Typing GO READ will result in a check of any (.SOU) source input file, named by the INFILE command, to see if entries are proper source information "cards". For example

```
* infile galaxy.sou          ; to name a source information file
* outfi tty:                 ; to type READ output on terminal
* go read                    ; and then check its contents
```

then

```
* outfil lpt:oldfil           ; to specify line printer output
* infile oldfil.obs           ; for OLDFIL.OBS source list file
* go LIST                     ; to get hard copy of OLDFIL.OBS
```

The GO READ and GO LIST commands are intended to allow listing and checking of previously prepared SOURCEFILES and OBSERVFILEs.

The most important things accomplished by the OBSERV program are achieved by running, usually in sequence, GO SETDEF, GO MAKOBS, and GO CHKOBS. SETDEF, MAKOBS, and CHKOBS are "sub-programs" inside OBSERV. The SETDEF sub-program is used to set default parameters for observing source cards, any of which can be re-specified inside MAKOBS. OBSERVEFILE source cards are added (or modified) in the MAKOBS sub-program. Finally, the CHKOBS sub-program is used to analyze the contents of an OBSERVFILE to see if it meets obvious conditions, such as whether format is "bad" or whether the sources are above a specified elevation limit, etc.; the CHKOBS program can be run with CHECKOPTION of SUMMARY or DETAILED to obtain varying levels of information.

Some users can get confused about "where they are" while running OBSERV or any of the sub-programs SETDEF, MAKOBS, or CHKOBS - because all of them have the same (*) prompt symbol. In this case it is recommended that users run OBSERV under control of a program called DANEEL which is discussed in Chapter 7. Once DANEEL has been run, the execution of any program, including OBSERV, can be carried out by typing GO <program name> with the result that thereafter all (*) prompts are preceded by the name of the program or sub-program name currently being run.

b. Setting Source List Defaults with SETDEF in OBSERV

The SETDEF sub-program inside OBSERV is used to set default values of parameters that will be used in MAKOBS - unless re-specified for each source card inside MAKOBS.

```
*go setdef                    ; run SETDEF after running OBSERV

SETDEF [100,4]    Version 0.2    07-FEB-83    09:22
======
I set default parameters for MAKOBS card fields.

*inp source                   ; to see part of SETDEF INPUTS

SETDEF INPUTS (SOURCE)
====== ====== ========
```

```
  (SOURCE) =========
name. . . . . . . .  SPOLE
qualifier . . . .       0
stoptime. . . . .     0:00:00
duration. . . . .     0:15:00
oduration . . . .     0:17:00
cduration . . . .     0:03:00
ra. . . . . . . .    00h00m00.0000s
dec . . . . . . .  -90d00'00.000"
epoch . . . . . .  '      '
bands . . . . . .  CC
mode. . . . . . .  '  '
calcode . . . . .  ' '
gaincode. . . . .  3
widths. . . . . .  '0000'
```

Here and below we will usually specify one of the options SOURCE, AN, PM, LO, or LI in asking for INPUTS or HELP. Without using these options to select a sub-set for the INPUTS and HELP displays of SETDEF, you will get too much information displayed on the screen and the top part will scroll off.

In general you specify a parameter with a command in SETDEF if it is valid for a large number of source cards, and you do not want to re-supply the parameter in MAKOBS for each source card. For example, for a program involving only 20 cm observations at the default frequency, with 25 MHz bandwidth, on can use the dialogue

```
* band 20cm                 ; to set the observing frequency
* width 1111                ; to set the bandwidth, and
* go makobs                 ; and then run MAKOBS
```

The DURATION command in SETDEF is used to specify a duration that will not be re-specified in MAKOBS. CDURATION and ODURATION commands can be used to save time if the calibrators (CDURATION) and/or the program sources (ODURATION) will be observed for the same amount of on-source time per scan. The CDURATION and ODURATION parameters are used in MAKOBS by typing an "o" or a "c" for a DURation, and the program will then use the default values set in SETDEF.

In addition to preparing source cards, one can used SETDEF to: control antenna wraps and over-the-top operation (with optional AN cards for each source card); specify proper motion parameters for sources moving at non-sideral rates (with optional PM cards); specify parameters for non-standard frequencies, receiver control filesk, and/or sub-reflector control files (with optional LO cards); and specify the parameters for spectral line observing (with optional LI cards). At this stage (or after typing SETDEFAULTS inside SETDEF) the inputs for these types of SETDEF commands are in a special form as illustrated by the following dialogue:

```
* inputs an
  (AN) =============
elazoptios  . . . Specify <Antenna> <El-plunge> <Az-wrap>
* inputs pm
  (PM) =============
pmrate. . . . . .  Specify RA and DEC proper motion
pmiat . . . . . .  Specify epoch (IAT) of PMRATE
horizontalparallax Specify equatorial horizontal parallax
* inpu lo
  (LO) =============
biasdigits. . . .  Specify AB, CD bias digits by band
firstlo . . . . .  Specify AB, CD front end LO frequencies by band
synthesizer . . .  Specify A,B,C,D synthesizer frequencies by band
flukesynthesizer.  Specify AC, BD fluke synthesizer frequencies by band
rcvrfile. . . . .  Specify receiver file names by band
subrfile. . . . .  Specify subreflector file names by band
* inp li
  (LI) =============
chanwidths. . . .  Set WIDTHS to '    ' after altering CHANWIDTHS
normalization . .  Specify the normalization option
averagetime . . .  Specify the scan averaging time
beginningchannel.  Specify the beginning channel
numberchannel . .  Specify the number of channels
restfrequency . .  Specify a line transition code
externalfrequency  Specify AC, BD external LO frequencies
```

The above INPUTS for the AN, PM, LO, and LI cards are simply prompts providing some information about each command. If any command in each category is supplied with parameters, then subsequent source cards made in MAKOBS will be accompanied by a card in that category.

The following is the part of the HELP display unique to SETDEF:

```
SETDEF COMMANDS
====== ========
go OBSERV                               Return to OBSERV level
   MAKOBS                               Make OBSERVFILE additions/modifications
   CHKOBS                               Check source list cards in OBSERVFILE
explain <subject> | <empty>             Type more about <subject> or type
  SETDEF                                  special SETDEF information files.
name  <string of 1 to 8 characters>     Name of source
qualifier  <integer>                    Source qualifier (0 to 32767)
stoptime  <hh:mm:ss>                    Default observing scan stop time
duration  <hh:mm:ss>                    Default observing scan duration
oduration  <hh:mm:ss>                   Default source duration
cduration  <hh:mm:ss>                   Default calibrator duration
```

```
ra     < HHhMMmSS.SSSSs >              Default source right ascension.
dec     < DDdMM'AA.AAA" >              Default source declination
epoch   ' ' | D | C | Yyyyy            (RA,DEC) epo.:1950 | DATE | 2000 | yyyy
bands   20cm | 6cm | 2cm | 1.3cm       Observing bands for all IFs
        LL   | CC  | UU  | KK  |
        HH   | VC  | VK  | VL  |
        18   | 21
mode   ' '|IA|IC|PA|PC|D|TF|VA|VX|VS|  Default array observing mode
           1A|1C|2A|2C|4|4A              ' ' is normal interferometer mode
calcode  A | B | C | D | E | F | T     Default calibrator code
gaincode  <3 <= integer <= 9>          Assign smallest 2**GAINCODE > Flux(Jy)
widths    <wwww>                       wwww = ABCD BW codes, BW=50/(2**w) MHz
                                         w = 0-3 (continuum), 0-9 (line)
elazoptions  A|N|S|E|<Ant1 ... Antn>   Antenna Elev-plunge and Az-wrap Options
             U | D | ' '                 Plunge: U=elev > 90d, D=elev < 90d
             L | R | ' '                 Wrap: L=CCW Az slew, R=CW Az slew
pmrate  <dra/dt>s <ddec/dt>"           (RA,DEC) Proper motion rate (per day)
pmiat  <hh:mm:ss>                      IAT of P.M. (for current IAT date)
horizontalparallax  <arcseconds>"      Equatorial Horizontal Parallax of P.M.
biasdigits  <band> <AB> <CD>           Bias tuning digits (0-3)
firstlo  <band> <AB> <CD>              LO frequency for the front end
synthesizer  <band> <A> <B> <C> <D>    2-4 GHz LO synthesizer frequency
flukesynthesizer  <band> <AC> <BD>     Fluke synthesizer frequency
rcvrfile  <band> <filename>            Name of special MODCOMP receiver file
subrfile  <band> <filename>            Name of special MODCOMP subreflector
                                         file
chanwidths  <wwww>                     wwww = ABCD Line Channel width codes
                                         Chan. width = 50/(2**w) MHz, w = 0-9
normalization  '   ' | B | AUT | L     Normalization option.
                                         B = band pass normalization
                                         AUT = auto-correlation spectra
                                         L = lag spectrum
averagetime  ' ' | <integer>           ' '=0=10, 0 <= integer <= 630
beginningchannel  <integer>            0 <= <integer> <= 511
numberchannel  <integer>               LOG (base 2) of No. of Chan. (= 3 to 8)
restfrequency <transition code>        Specify transition code of line to
   HI   | H2O  | H2CO |                  use its default rest frequency
   1612 | 1665 | 1667 | 1720
externalfrequency  <ACfreq> <BDfreq>   External LO frequencies
```

The average user with a continuum observing program is likely to use only SOURCE cards. The most common use of LO cards for continuum programs is selection of a non-standard frequency in the 20 cm band, particularly when one wishs to study faraday rotation effects by observing at the upper and lower portions of the band. For example, the following specification of parameters in SETDEF will allow subsequent frequencies of 1382.5 MHz or 1635 MHz by specifying 25 MHz bandwidth and 21 or 18 cm bands (for A and C IFs):

```
* width 1111                        ; for bandwidth of 25 MHz
* synth 18    3510 3810 3260 3810
* fluke 18 112.5   212.5
* syn   21    3260 3560 3010 3560
* fluk  21  · 109.9 109.9
```

For further details on the use of AN, PM, LO, and LI cards you should read the section on OBSERV in the Observer's Reference Manual.

c. Making Source List Cards with MAKOBS in OBSERV

The MAKOBS sub-program can be entered from OBSERV, SETDEF, or CHKOBS by typing GO MAKOBS. The default inputs for MAKOBS are:

```
MAKOBS INPUTS
====== ======
  (GENERAL) ========
allcard . . . . . NO
lineincrement . .   10
autosave. . . . .   20
typeoftime. . . . LST DURATIONS
startdate . . . . 52120 at  0:00:00
adformat. . . . . NAM QUA DUR RA DEC EPO BAN MOD CAL GAI WID
chformat. . . . . NAM
  (MISC) ==========
outfile . . . . . LPT:OBSERV
```

where the default value of the modified Local Sidereal Day Number in the STARTDATE command is generated from that for the date the OBSERV program is run. The correct values for each LST observing day can be found from the numbers on the right of the VLA observing schedules. The second parameter in this command is the scheduled LST for the start of observing.

The ALLCARD command is use to say whether all 80 columns on the "card images" being prepared are to be displayed when all or part of the contents of the OBSERVFILE are listed in MAKOBS with the LIST command. Only for programs using long AN, LO, and LI cards is it likely that one will set ALLCARD to YES.

The MAKOBS program is a special purpose line-oriented text editor. The LINEINCREMENT command is used to specify the intervals between "card" numbers. When one ADDs new source cards between existing source cards the LINEINCREMENT command may need to be used to make the new line increment small enought to fit in the desired source cards. The AUTOSAVE command is used to control how often, in terms of number of OBSERVFILE changes, the current OBSERVFILE is "saved" on disk. Reasonably frequent AUTOSAVEs are useful to prevent losing too much work if the computer should go down or an erroneous massive delete occurs.

The TYPEOFTIME command is used to specify that DURations or STOptimes are in terms of LST (Local Sidereal Time) or UT. Normally only users preparing VLBI observing programs will make use of UT in MAKOBS.

The following is the part of the MAKOBS HELP file unique to MAKOBS when this was written:

```
MAKOBS COMMANDS
====== ========
allcard  YES | NO                     LIST > 71 source list card columns?
lineincrement  <integer>              Interval between line numbers
autosave <integer>                    Save OBSERVFILE after n <= 1000 changes
saveobservfile                        Save current OBSERVFILE on disk
nosavexit <option>                    Exit without saving revisions
                                        <option> = OBSERV|SETDEF|CHKOBS
typeoftime  <LST|UT><DURATION|STOPTIME> Type of time for durations/stop times
startdate  <mLSD | yyMONdd> at hh:mm:ss mLSD | UT date (VLBI) at start time
durations                             Change all stop times to durations
stoptimes                             Change all durations to stop times
lsttimes                              Change UT stop times to LST stop times
uttimes                               Change LST stop times to UT stop times
comment  <line> <string>              Put //*<string> card after <line>
                                        <line>=<integer> | ↑ | . | *
adformat  <Id1> <Id2> ... <Idn>       Specify new ADD format from Id list:
                                        NAM QUA STO|DUR RA DEC EPO BAN
                                        MOD CAL GAI WID
                                        and/or AN,PM,LO,LI card identifiers
chformat  <Id>                        Specify identifier for CHANGE command
list    <line> | <line1> <line2> | ALL List <line>, a range of lines, or all
renumber  <integer>                   Renumber list with LINEINCREMENT steps
add  <line> <cardtype>                Add source list cards after <line>
                                        <cardtype>=blank adds by ADFORMAT
                                        <cardtype>=AN|PM|LO|LI from SETDEF
                                        ESCAPE (CTRL-[) gets you out of ADD
replace <line> | <line1> <line2> | ALL ADD in place of one or a range of lines
                                        ESCAPE (CTRL-[) ends REPLACE
change  <line> | <line1> <line2> | ALL Change line(s) CHFORMAT parameter
                                        ESCAPE (CTRL-[) ends CHANGE
delete  <line> | <line1> <line2> | ALL Delete <line> or a range of lines
copy      <line1> <line2> AFTER <line> Copy 1 or more lines after <line>
transfer  <line1> <line2> AFTER <line> Transfer 1 or more lines after <line>
go LIST                               List OBSERVFILE on the OUTFILE device
   OBSERV                             Return to OBSERV (Save OBSERVFILE)
   SETDEF                             Assign OBSERVFILE source list defaults
   CHKOBS                             Check source list cards in OBSERVFILE
explain <subject> | <empty>           Type more about <subject> or type
  MAKOBS                                special MAKOBS information files.
outfile  TTY: | LPT: | <DSK:filename> Output destination for GO LIST
```

VLBI users making use of TYPEOFTIME UT will note that a UT duration is indicated by a # in column 14, whereas a $ appears in this column for the more common LST durations.

After a source list is prepared, it is recommended that it be put in a form where STOptimes rather than DURations are specified. Only VLBI users will regularly convert between LST and UT using the LSTTIMES and UTTIMES commands. For all users the final source list must contain only LST STOptimes or DURations.

There are four types of commands peculiar to MAKOBS:

(1) parameter setting	ALLCARD, LINEINCREMENT, AUTOSAVE, TYPEOFTIME, STARTDATE, ADFORMAT, CHFORMAT
(2) adding to or changing sourde list	REPLACE, CHANGE, DELETE, COPY, TRANSFER, RENUMBER
(3) listing of all or part of souce list	LIST
(4) changing time specifications	DURATIONS, STOPTIMES, LSTTIMES, UTTIMES

In a typical session preparing a source card list the user will verify that the ALLCARD, LINEINCREMENT, AUTOSAVE, and TYPEOFTIME defaults are correct or changed to what is needed. The STARTDATE will be set to the LST data and time found of the observing schedule. The ADFORMAT command is then used to specify the source card parameters that will NOT be taken from the values set in SETDEF. One then starts the process of adding source cards with the ADD command. At the beginning of ADD mode the user is prompted with the list of identifiers to be typed in for each source card. One exits from ADD mode by pressing the ESC key (CNTL [on some terminals). At this point one can use the LIST command to look at all or part of the card images that have been prepared.

Once source cards have been prepared, one can use the ADD command to insert AN, PM, LO, or LI cards.

The "editing" commands in MAKOBS can be used to CHANGE, RENUMBER, REPLACE, DELETE, COPY, or TRANSFER card images. The CHFORMAT command must be used to specify the identifier to be modified before using the CHANGE command.

After the entire source list has been prepared, one usually executes GO CHKOBS to look for the types of errors that a program can check for. One must be sure that the times in the source list are LST stop times (or durations) before finishing and informing the array operators about the file they are to use to control the observing run.

d. Checking a Source List with CHKOBS in OBSERV

The following is a typical result of the inputs set in CHKOBS before checking a previously prepared source list:

```
CHKOBS INPUTS
====== ======
  (GENERAL) ========
observfile. . . . EXAMPL.OBS[13,]
program . . . . . CONTINUUM
startdate . . . . 52120 at  12:00:00
checkoption . . . DETAILED
array . . . . . . C
overthetop. . . . YES
elevationlimit. .  8d
minimumtime . . .  3min
  (MISC) ==========
outfile . . . . . LPT:AH99
```

The STARTDATE specification describes the LST date and time for the beginning of the observing run for the specified OBSERVFILE. The CHECKOPTION command is used to select BRIEF or DETAILED checking information, with the latter predicting actual observing times and azimuth wrap conditions. The ARRAY command is used when checking array dependent things like antenna shadowing. The OVERTHETOP command specifies if the antennas will be allowed to go up to 35^{o} beyond the zenith. The ELEVATIONLIMIT command indicates the minimum acceptable elevation limit (never less than 8^{o}). The MINIMUMTIME command specifies the minimum amount of time you are willing to accept on any source. Finally, by changing the OUTFILE parameter to TTY: one can see the results of a GO CHECK on the terminal, while changing it to LPT:<1-6 char.> will cause the CHECK results to be printed on the line printer. More information is supplied with LPT: output.

The following is the part of the HELP file unique to CHKOBS, showing the syntax and a summary of the meaning of each command:

```
CHKOBS COMMANDS
====== ========
observfile <filename.OBS[13,pn]>       Source list file under preparation
program  CONTINUUM | LINE | VLBI       Type of observing program
startdate  <mLSD at hh:mm:ss>          Local sidereal date at start time
checkoption  SUMMARY | DETAILED        Level of detail of GO CHECK evaluation
array  A | B | C | CD | D              Which VLA configuration?
overthetop  YES | NO                   Enable observing 35d beyond zenith
elevationlimit <EL>                    Lower elevation limit, 8d <= EL <= 89d
minimumtime <time in minutes>          Minimum observing time for all sources
go CHECK                               Send CHECK operation output to OUTFILE
   LIST                                List OBSERVFILE on the OUTFILE device
   OBSERV                              Return to OBSERV level
   SETDEF                              Assign OBSERVFILE source list defaults
   MAKOBS                              Make OBSERVFILE additions/modifications
explain <subject> | <empty>            Type more about <subject> or type
  CHKOBS                                 special CHKOBS information files.
outfile  TTY: | LPT: | <DSK:filename>  Output destination for GO CHECK | LIST
```

e. An Example of Using OBSERV to Prepare a Source List File

Let us carry out a complete example of preparing a source list file involving the observation of one source at two different frequencies. The hypothetical source that we will observe in RB203, and we have already entered its coordinates in GALAXY.SOU using the SOS text editor. Let us assume that we are scheduled to map RB203 at 6 cm and 2 cm between 0900 and 1200 LST on Local Sidereal Date 52120. Since the source is located at 1256+284, we will use the calibrator 1323+321 which is unresolved at 2 and 6 cm according to the Calibrator Manual. The observing run will begin and end with observations of 3C286 so we can bootstrap fluxes and absolute polarization angle information. Then we will adopt a basic cycle of

RB203	6cm	16 minutes
1323+321	6cm	4 minutes
1323+321	2cm	4 minutes
RB203	2cm	16 minutes

taking 40 minutes per cycle, so 4 cycles will take 140 minutes out of the available 160. Ten minutes at the beginning and end doing 3C286 at both bands will take the rest of the three hours of observing time.

Thus we carry out the following dialogue inside OBSERV, assuming that we have previously set WIDTHS to 0000, ODURATION to 0:16, and CDURATION to 0:4 in SETDEF:

```
* go MAKOBS
MAKOBS [100,4]    Version 0.3    15-FEB-83    10:45
======
I do the editing of observing source lists.
Edit: EXAMPL.OBS[13,11]
* start 52120 at 9:
* add 100
 NAM BAN DUR
> 3c286 cc 0 5 0
Searching source lists for 3C286    ; it looks for 3C286 information
> 3c286 uu 0 5 0                ; which is now stored in a file on disk
> rb203 uu 0 16 0               ; we can specify duration hh mm ss, or
Searching source lists for RB203
> 1323+321 uu c                     ; time set by CDURATION in SETDEF, or
Searching source lists for 1323+321
> 1323+321 cc 0 4 0
> rb203 cc o                  ; time set by ODURATION in SETDEF
> ESC                           ; and then exit from ADD mode with ESC
* list
0010    /.AH99     11
0020    //* FILEID: EXAMPL.OBS[13,11]   CONTINUUM 52120 at  9:00:00   LST DURAT
0100    3C286        0$00 05 00 13 28 49.6570 +30 45 58.640     CC    B 3 1111
0110    3C286        0$00 05 00 13 28 49.6570 +30 45 58.640     UU    B 3 1111
0120    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     UU      3 1111
0130    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     UU    C 3 1111
0140    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     CC    C 3 1111
0150    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     CC      3 1111
* copy 120 150 after *              ; to make one more cycle
* copy 120 * after *                ; to make two additional cycles
* list all                          ; to see all so far
0010    /.AH99     11
0020    //* FILEID: EXAMPL.OBS[13,11]   CONTINUUM 52120 at  9:00:00   LST DURAT
0100    3C286        0$00 05 00 13 28 49.6570 +30 45 58.640     CC    B 3 1111
0110    3C286        0$00 05 00 13 28 49.6570 +30 45 58.640     UU    B 3 1111
0120    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     UU      3 1111
0130    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     UU    C 3 1111
0140    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     CC    C 3 1111
0150    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     CC      3 1111
0160    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     UU      3 1111
0170    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     UU    C 3 1111
0180    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     CC    C 3 1111
0190    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     CC      3 1111
0200    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     UU      3 1111
0210    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     UU    C 3 1111
0220    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     CC    C 3 1111
0230    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     CC      3 1111
0240    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     UU      3 1111
0250    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     UU    C 3 1111
0260    1323+321     0$00 04 00 13 23 57.9160 +32 09 43.000     CC    C 3 1111
0270    RB203        0$00 16 00 12 56 21.3000 +28 07 49.000     CC      3 1111

* add 280
 NAME BAN DUR
> 3c286 cc 0 5 0                    ; now add 3c286 scans at end
```

```
> 3c286 uu 0 7 0                       ; a deliberate error in DUR
> ESC                                  ; exit with ESC or CNTL [
* list 270 *                           ; look at last few cards
0270    RB203       0$00 16 00 12 56 21.3000 +28 07 49.000    CC      3 1111
0280    3C286       0$00 05 00 13 28 49.6570 +30 45 58.640    CC    B 3 1111
0290    3C286       0$00 07 00 13 28 49.6570 +30 45 58.640    UU    B 3 1111
* chf dur                              ; set up to fix DUR error
* chan 290                             ; in card number 290
 DUR
0 5 0                                  ; correct to 5 minutes
* stop                                 ; and convert to STOPTIMES
TYPEOFTIME changed to STOPTIMES.
ADFORMAT DURation changed to STOptime.
* list
0010    /.AH99      11
0020    //* FILEID: EXAMPL.OBS[13,11]  CONTINUUM 52120 at  9:00:00   LST STOPT
0100    3C286       0 09 05 00 13 28 49.6570 +30 45 58.640    CC    B 3 1111
0110    3C286       0 09 10 00 13 28 49.6570 +30 45 58.640    UU    B 3 1111
0120    RB203       0 09 26 00 12 56 21.3000 +28 07 49.000    UU      3 1111
0130    1323+321    0 09 30 00 13 23 57.9160 +32 09 43.000    UU    C 3 1111
0140    1323+321    0 09 34 00 13 23 57.9160 +32 09 43.000    CC    C 3 1111
0150    RB203       0 09 50 00 12 56 21.3000 +28 07 49.000    CC      3 1111
0160    RB203       0 10 06 00 12 56 21.3000 +28 07 49.000    UU      3 1111
0170    1323+321    0 10 10 00 13 23 57.9160 +32 09 43.000    UU    C 3 1111
0180    1323+321    0 10 14 00 13 23 57.9160 +32 09 43.000    CC    C 3 1111
0190    RB203       0 10 30 00 12 56 21.3000 +28 07 49.000    CC      3 1111
0200    RB203       0 10 46 00 12 56 21.3000 +28 07 49.000    UU      3 1111
0210    1323+321    0 10 50 00 13 23 57.9160 +32 09 43.000    UU    C 3 1111
0220    1323+321    0 10 54 00 13 23 57.9160 +32 09 43.000    CC    C 3 1111
0230    RB203       0 11 10 00 12 56 21.3000 +28 07 49.000    CC      3 1111
0240    RB203       0 11 26 00 12 56 21.3000 +28 07 49.000    UU      3 1111
0250    1323+321    0 11 30 00 13 23 57.9160 +32 09 43.000    UU    C 3 1111
0260    1323+321    0 11 34 00 13 23 57.9160 +32 09 43.000    CC    C 3 1111
0270    RB203       0 11 50 00 12 56 21.3000 +28 07 49.000    CC      3 1111
0280    3C286       0 11 55 00 13 28 49.6570 +30 45 58.640    CC    B 3 1111
0290    3C286       0 12 00 00 13 28 49.6570 +30 45 58.640    UU    B 3 1111

* go chkobs                       ; it looks right, so let's CHKOBS it
MAKOBS EXECUTION    on    1983MAR31    at    8:00
====== =========
[DSKD:EXAMPL.OBS[13,11]]
CHKOBS [100,4]    Version 0.3    17-FEB-83    15:13
======
I perform checks on your observing source list.
WARNING: The DETAILED check is meaningless unless the array points to an
         azimuth somewhere in the range of 85 to 275 degrees at the
         beginning of your observing run. Initially, the array is
         assumed to be pointing south at an elevation of 40 degrees.
* inp
CHKOBS INPUTS
====== ======
  (GENERAL) ========
observfile. . . . EXAMPL.OBS[13,]
program . . . . . CONTINUUM
```

```
startdate . . . . 52120 at  9:00:00
checkoption . . . DETAILED
array . . . . . . C
overthetop. . . . YES
elevationlimit. .  8d
starminimumtime . . .  3min
  (MISC) ==========
outfile  . . . .  TTY:
* array d
* che summ
* go che
CHKOBS EXECUTION    on    1983MAR31   at   8:01
====== =========
            Name  Qual  Stoptime      RA             Dec        Epoch  B M C G Width
0010     /.AH99      11
0020     //* FILEID: EXAMPL.OBS[13,11]   CONTINUUM 52120 at  9:00:00   LST STOPT
0100     3C286        0 09 05 00 13 28 49.6570 +30 45 58.640 1950 CC   B 3 1111
0110     3C286        0 09 10 00 13 28 49.6570 +30 45 58.640 1950 UU   B 3 1111
0120     RB203        0 09 26 00 12 56 21.3000 +28 07 49.000 1950 UU     3 1111
0130     1323+321     0 09 30 00 13 23 57.9160 +32 09 43.000 1950 UU   C 3 1111
0140     1323+321     0 09 34 00 13 23 57.9160 +32 09 43.000 1950 CC   C 3 1111
0150     RB203        0 09 50 00 12 56 21.3000 +28 07 49.000 1950 CC     3 1111
0160     RB203        0 10 06 00 12 56 21.3000 +28 07 49.000 1950 UU     3 1111
0170     1323+321     0 10 10 00 13 23 57.9160 +32 09 43.000 1950 UU   C 3 1111
0180     1323+321     0 10 14 00 13 23 57.9160 +32 09 43.000 1950 CC   C 3 1111
0190     RB203        0 10 30 00 12 56 21.3000 +28 07 49.000 1950 CC     3 1111
0200     RB203        0 10 46 00 12 56 21.3000 +28 07 49.000 1950 UU     3 1111
0210     1323+321     0 10 50 00 13 23 57.9160 +32 09 43.000 1950 UU   C 3 1111
0220     1323+321     0 10 54 00 13 23 57.9160 +32 09 43.000 1950 CC   C 3 1111
0230     RB203        0 11 00 00 12 56 21.3000 +28 07 49.000 1950 CC     3 1111
0240     RB203        0 11 26 00 12 56 21.3000 +28 07 49.000 1950 UU     3 1111
0250     1323+321     0 11 30 00 13 23 57.9160 +32 09 43.000 1950 UU   C 3 1111
0260     1323+321     0 11 34 00 13 23 57.9160 +32 09 43.000 1950 CC   C 3 1111
0270     RB203        0 11 50 00 12 56 21.3000 +28 07 49.000 1950 CC     3 1111
0280     3C286        0 11 55 00 13 28 49.6570 +30 45 58.640 1950 CC   B 3 1111
0290     3C286        0 12 00 00 13 28 49.6570 +30 45 58.640 1950 UU   B 3 1111
End of checking operation
* out lpt:ah99          ; Now get CHECK SUMMARY on line printer
* go che
CHKOBS EXECUTION    on    1983MAR31   at   8:01
====== =========
* che det
* go che
CHKOBS EXECUTION    on    1983MAR31   at   8:02
====== =========
* finish                  ; Exit OBSERV, we are done
End of SAIL execution
```

Upon retrieving the LPT output from the line printer in the computer room, the SUMMARY listing is (leaving out some columns to allow new material to fit on this page) as follows:

```
CHKOBS INPUTS
====== ======
  (GENERAL) ========
observfile. . . . EXAMPL.OBS[13,]
program . . . . . CONTINUUM
startdate . . . . 52120 at  9:00:00
checkoption . . . SUMMARY
array . . . . . . C
overthetop. . . . YES
elevationlimit. .  8d
minimumtime . . .  3min
  (MISC) ===========
outfile . . . . . LPT:AH99
--------------------------------------------------------------------------------
        Name    ... Width Featurevel Start-HA-Stop Start-Az-Stop Start-El-Stop
0010    /.AH99     11
0020    //* FILEID: EXAMPL.OBS[13,11] CONTINUUM 52120 at 9:00:00 LST STOPTIMES
0100    3C286     ... 1111               -4.5   -4.4     73     74     34    35
0120    RB203     ... 1111               -3.8   -3.5     81     83     41    45
0130    1323+321  ... 1111               -4.0   -3.9     75     75     40    41
   .
   .
   .
 End of checking operation
```

While the DETAILED check written out to the printer gives:

The DETAILED check is meaningful only if the array is pointing to an azimuth between 85 and 275 degrees at the start of your observing run. Initially, the array is assumed to be pointing south at an elevation of 40 degrees.

```
------------------------------------------------------------------------
        Name   ...  Width Featurevel Start-HA-Stop Start-Az-Stop Start-El-Stop
0010    /.AH99      11
0020    //* FILEID: EXAMPL.OBS[13,11]  CONTINUUM 52120 at  9:00:00   LST STOPTIMES
0100    3C286     ... 1111              -4.5   -4.4     73     74     34    35

 Array: 3.4 Move   1.6 Obs          Time  -158 degrees to limit at stop

0110    3C286     ... 1111              -4.4   -4.3     74     74     35    36

 Array:  .7 Move   4.3 Obs                -159 degrees to limit at stop

0120    RB203     ... 1111              -3.8   -3.5     81     83     41    45

 Array: 1.0 Move  15.0 Obs                -167 degrees to limit at stop
   .
   .
   .
 End of checking operation
```

From the above displays one can check on: azimumth, elevation, hour angle, predicted move times, and predicted time on sources. Errors in planning or preparation can often be caught before observing by careful scrutiny of CHKOBS outputs. CHKOBS will also inform you about badly formatted cards, observations longer than an hour, sources below the elevation limit, shadowing, etc.

More details on the use of OBSERV can be found in the Observer's reference Manual.

f. Arranging for Use of Prepared Source Files

Once a source list file, like EXAMPL.OBS[13,11] has been prepared on the DEC-10, the user next informs the array operator on duty that this is the file to be used to control a specific scheduled observing program. There is a form obtainable in the VLA control room where you record this, and other data helpful to the array operators. This includes specification of two of the major parameters for the data base for the observing run: the visibility averaging time and the gain table interval.

In principle the user is then finished until it is time to begin data reduction when the visibility data base for the observing run has be transferred to disk in the users [14,PN] area in the DEC-10. In practice, the user should be available, at least by phone, for consultation with the array operators during the observing process. The user may also wish to watch the progress of the observations using the facilities available in the on-line computer system, or the DEC-10 facilities for listing and plotting data being written into a data base by the (nearly) real-time FILLER program.

g. The MODCOMP OBSERV Program

Under some circumstances, such as when the DEC-10 is down (as for maintenance), it may be necessary to use the MODCOMP OBSERV program to modify of prepare a source list file. Documentation on how to use this program can be found in the Observer's Reference Manual.

5. ACTIVITIES DURING OBSERVING

A. Responsibilities of the Array Operators

The operation of the array, involving antennas, electronics, and on-line computers, is the responsibility of the array operator on duty. The user provides the operator with the names of source list files, together with other information such as which antennas are to operate in which sub-arrays;

however, everything else related to operation of the array is the responsibility of the array operator. In any situation where the array operator may deem it necessary to override the wishes of observers, they have the authority to do so. This will occur only under circumstances where their knowledge of what is necessary for safe and proper operation makes them, in fact, more knowledgeable than the observer.

Because of the complexity of their job, VLA array operators are fairly knowledgeable about the VLA antennas, electronics, and on-line computer hardware and software. They are also knowledgeable about use of the off-line computer system, particularly the use of programs dealing with visibility data. Because of this, as long as it does not conflict with their prime responsibilities for array operation, the array operator can provide some help in these areas.

The array operators can also point the way to individuals who may be sources of information about areas where questions arise. They are always the best single source of information about the status of the antennas and electronics.

Because the operators carry out their responsibilities in an open control room, several things are recommended. First of all, cultivate a polite relationship with them. Except for emergencies, do not interrupt them if they are in the midst of important activities. Do not carry out loud conversations in the control room. Keep them informed about your whereabouts in case they need to consult with you about problems and recommended changes. Provide them with information about source list files and usage of antennas in subarrays well in advance. Always give them an exact copy of the listing of source list files. Finally, listen well to their advice. While it is likely that you know more about the scientific results you want to get out of your data, no one, except perhaps a few other VLA staff members, knows more about how to run the VLA for your benefit than the array operators.

B. Repair of Malfunctioning Equipment

The speed of repair of malfunctioning equipment will depend upon circumstances. Problems causing the entire array to be down will result in call-out of whatever personnel are necessary. Problems that remove an antenna from the array, that can be solved by module substitutions, will be taken care of by the technician on duty; however, since there is no duty technician during the Midnight to 8 shift, a problem occuring during that time will be deferred. Serious problems that cannot be fixed without extensive work are deferred until normal working hours (Mon-Fri., 8:30 to 4:30, except NRAO Holidays) when staff are available. In addition, at any one time there are about three antennas designated as available for minor repair work. Any of these antennas can be taken out of the array when the technicians wish to carry out their work.

C. On-Line Programs and Displays

There are several terminals and a printer in the control room devoted entirely to communication with the on-line computers, and through them, with the antennas and electronics. Some of these continually display messages generated by the on-line data checker program, CHK. Other terminals are used for specific status or data displays, but can be used to send specific commands to antennas and electronics, over-riding previous instructions. One can also generate special status listings on the printer. One of the terminals is mostly used for display of antenna status parameters and the sending of commands. Another tends to be used for modication of control files and skipping around in source lists to change the observing situation. The program listing visibility data on an on-line terminal or printer is called D10.

If you are dubious about the quality of data to expect due to, say, atmospheric problems, it is advisable to use D10 look at the calibrator phases, which should be constant on short time scales, for a long baseline. If phases are are particularly bad, you may want to request the array operator to switch to an alternate observing file which is better suited to current circumstances.

In addition to the basic CHK and D10 programs, there are a number of other on-line programs or services of interest to the observer.

The operator can, on request, manipulate source list files from a console terminal. One can extend the observing time on a given source, skip ahead to other source request cards, or skip back to other source request cards. Typing /SLIst produces a display of the source request card before the current one, the current one, and the next three source request cards. The operator can also change observing modes. Thus, for example, one can switch to pointing mode to check pointing if a problem is suspected.

A program always used during start-up, and available for use at any time when certain problems are suspected, is called STUpid. This program checks delay centers, phase centers, and pointing offsets. It requires about twenty minutes per observing band to carry out these checks.

Another program that can be run in place of the D10 display is a program that takes data from calibrators and displays normalized antenna-IF gains. This provides one of the quickest ways to detect abnormal behavior of specific antenna-IF systems.

D. Real Time Filling of Off-Line Visibility Data Base

Every ten seconds the data gathered by the observing subarrays are written on a fixed head disk. A DEC-10 program called FILLER is always kept running by the array operators while observing is going on. This program takes the data from the fixed head disk and writes it into a visibility data base on the disks of the DEC-10. The user number on the first card of a source list file is used to determine where the data are written. A change of this number results in a change of where the data are written, so that users will always find their data in their own data storage area.

All data except the data for the current and previous scans are immediately accessible to programs in the DEC-10. Because of this, users can monitor the progress of their observation by running programs from terminals connected to the DEC-10. Because this is decoupled from the on-line system, there is no way the user can make mistakes that affect the operation of the array and the gathering of data. The worst case would be to erase some data files in the DEC-10; however, the data is always being recorded on magnetic tape in the on-line system, so all data can be recovered later on. Thus, the user can run DEC-10 programs (principally LISTER) during the observing process to monitor the course of the observations. From this one can learn things that lead to changes in the observing program.

E. Monitoring Calibrators

The monitoring of antenna or correlator gains and phase centers for point source calibrators is the most straightforward way of assessing system performance.

Much of the time the array operator will be able to diagnose faulty equipment through judicious hunting amongst antenna-IF status displays that rely on the monitor data. At other times the user can both contribute to the diagnosis of the problem and prepare for off-line editing of data by more detailed examination of calibrator data in the off-line computer data base produced by FILLER. The LISTER and VISPLT programs provide the primary means for this type of evaluation. As an example, plots of calibrator phases should be stable. Problems with phases are sometimes revealed only when the observer systematically plots calibrator phases for a reference antenna against all other antennas. One can find periods of phase instability due to unlocked LOs, phase jumps, or systematic phase variations from such plots. In addition to sometimes helping understand equipment problems that can be fixed, these are all things the user will need to cope with in the process of off-line editing and data correction.

F. Monitoring Source Results

The evaluation of calibrator behavior will usually inform the user about the fraction of data that is probably good. Often the observer can spend a great deal of time during the observing process evaluating program sources. Examination of calibrators will provide information about system gains and phase centers, and this information can then be used to make first order evaluations of program sources. Scan average amplitudes will reveal source strength and structure information. For point sources, particularly in detection experiments, phase plots will reveal information about the presence and location of sources.

The user who has attained normal proficiency with the off-line data reduction programs will find that, by judicious preparation of batch jobs to carry out editing, correction, and calibration, one can calibrate and map sources while the observing is still going on. This is the best way to evaluate what you are getting from the array, and often the use of the array can be optimized when you know your results to first order while you still have scheduled observing time that you can replan. Because all the data are not available until the observing run is completed, you generally repeat the whole process of editing, correction, calibration, and mapping at a more leisurely pace after the observing run is finished. Some observers choose to wait until this stage before doing any editing, correction, calibration, or mapping. Indeed, for some observing programs this is the only reasonable course. However, the best use of the array will generally be made by those who actively begin, and go as far as they can with, the process of editing, correction, calibration, and mapping while the observing is still going on.

There is a special class of problems that cause spurious signals to be inserted in data, most of the time at such low levels as to be unnoticed in calibrator data. The most obvious of these is interference generated both outside and inside the VLA. Spurious signals are also obtained when one antenna observes part of another antenna causing "shadowing" when very close antennas are pointed in particular directions. These signals are caused by leakage from vertex room equipment. Even nastier, because of unpredictability, are problems with correlator and sampler hardware which result in the addition of spurious signals. These are recognized by source data that makes no sense. Examples are a few correlators showing higher amplitudes than others, with strong tendencies for phases like 90, -90, 135, -45 degrees, etc. Problems have been found where all AA correlators showed 20 mJy more in amplitudes than all CC correlators, and it was certain tha circularly polarized sources were not being observed. Problems of the latter type will not usually be found in calibrator data or antenna-IF status information. For this reason, it is important for the observer to look for things like this himself. In experiments involving detection of weak sources, this is usually found either from evaluation of source amplitudes or from finding inexplicable "noise" behavior in maps.

G. Useful Practices

During and after the observing the observer will find it useful to have copies of important control files that affect the parameters of the observing. At a minimum, the observer should carefully keep copies of the ANTENNAS file and any source list files that control the observing. The ANTENNAS file will be a convenient record of which antennas are on which stations, together with the assumed station positions. The source list files become useful when questions about what you intended to observe, and in what way, arise. In addition, human errors about source positions happen with sufficient frequency that a record of what positions were supplied to the on-line computers is often useful. For observers using subarrays or nonstandard IF and ROT files, it will be useful to archive copies of the files actually used.

6. INTERFERENCE AND THE SELECTION OF NON-STANDARD FREQUENCIES

A. Radio Interference

a. L Band (1340-1730 MHz)

Interference is most likely to be encountered in the 18-22 cm band. Table 5-8 shows a listing of the frequency allocations within the VLA tuning range. Note that there are only four bands, much narrower than the possible VLA observing bands, allocated to radio astronomy on an exclusive basis and there is one band, 1660-1670 MHZ, which is shared. The numbers of unclassified government assignments in the area, including White Sands Missile Range, provide some idea of frequency usage. However, they do not atclude classified assignments and, except at 1350-1400 MHz, there are also non-government assignments. Much of the equipment at White Sands is used only sporadically. Usage can be heavy during special training missions which typically occur for one or two weeks of each year. Only the 1400-1427 MHz band can be depended upon to be free from man-made signals.

b. C Band (4500-5000 MHz)

As Table 5-6 shows, only 10 MHz of this band is allocated to radio astronomy on an exclusive basis. Internationally, the WARC of 1979 extended the radio astronomy allocation down to 4800 MHz on a seconday basis, but this is unlikely to be implemented within the U.S. Experience shows that very little interference is encountered in the top 150 MHz of the band where most VLA observations have been made. Frequency monitoring by G. Bonebrake in 1976 revealed only a weak sporadic signal at 4700 MHz.

c. U Band (14.4-15.4 GHz)

The band 15.35-15.4 GHz is allocated exclusively to radio astronomy and passive services, and at the 1979 WARC radio astronomy was given an international allocation in the band 14.47-14.5 GHz to protect the Formaldehyde line. Very few cases of interference have been experienced at the VLA site in the 14.4-15.4 GHz band.

d. K Band (22-24 GHz)

Within K band 22.21-22.5 GHz is allocated to radio astronomy on a primary basis shared with fixed and mobile communications services, and the band 23.6-24 GHz is allocated exclusively to radio astronomy and passive services. There is very little evidence of any interference in the 22-24 GHz band.

Table 5-8

SIMPLIFIED LISTING OF U.S. FREQUENCY ALLOCATIONS WITHIN VLA BANDS

VLA Band	Allocation Band	Allocated Services[1]	No. of Unclass. Gov. assignments
1340-1720 MHz	1300-1350 MHz	AERONAUTICAL RADIO NAVIGATION	9
1340-1720 MHz	1350-1400 MHz	RADIO LOCATION, fixed, mobile	4
1340-1720 MHz	1400-1427 MHz	RADIO ASTRONOMY	
1340-1720 MHz	1427-1535 MHz	FIXED, MOBILE	104
1340-1720 MHz	1535-1660 MHz	MOBILE SATELLITE, AERO. RADIO NAV.	3
1340-1720 MHz	1660-1670 MHz	RADIO ASTRONOMY, MET. AIDS	1
1340-1720 MHz	1670-1710 MHz	METEOROLOGICAL AIDS, MET. SAT.	5
1340-1720 MHz	1710-1850 MHz	FIXED, MOBILE	55
4500-5000 MHz	4400-4990 MHz	FIXED, MOBILE	42
4500-5000 MHz	4990-5000 MHz	RADIO ASTRONOMY	
14.4-15.4 GHz	14.3-14.5 GHz	RADIO NAV. SAT., FIXED SAT., FIXED, MOBILE	3
14.4-15.4 GHz	14.5-15.35 GHz	FIXED, MOBILE	5
14.4-15.4 GHz	15.35-15.4 GHz	RADIO ASTRONOMY	
22.0-24.0 GHz	22.0-23.6 GHz	FIXED, MOBILE	1
22.0-24.0 GHz	23.6-24.0 GHz	RADIO ASTRONOMY	

[1] Upper case letters indicate a primary allocation, lower case a secondary allocation.

[2] Assignments are taken from a listing which includes all unclassified government allocations within the area between longitudes 106°W and 109°W and between latitudes 32°30'N and 35°30'N. For transmitter power exceeding 100Wwith area is extended to that between 105° and 110°W and 32° and 36°N.

B. Local Oscillator and Map Frequencies

Standard operating frequencies are programmed into the VLA so that observers with no frequency preference, other than for a particular band, can set up their observing program without consideration of the various local oscillator frequencies in the system. These default frequencies are listed in Table 5-5. These frequencies may change from time to time, so if a frequency range is critical the observer should talk to a VLA operator about the default frequencies. The formulation for calculating the sky frequency from the local oscillator frequencies is given below.

The HH band is a special frequency range of L band which was chosen for minimum interference at 25 and 12.5 MHz bandwidth. Do not use the HH band with any other bandwidths because of interference problems.

Bandwidths of 3.13 MHz and smaller should not be used in the continuum mode because the quadrature networks in the correlator system do not work properly. However, the narrow bandwidths can be used for line observing.

The choice of center observing frequency is restricted by the passbands of the receivers and the local oscillator frequencies available. The suggested usable ranges of the receivers are given in Table 5-3.

Within a particular band the local oscillator (LO) frequencies determine the observing frequency. The observing frequency formula is

$$f_0 = f_1 \pm (f_{L6} - f_A + f_D + f_S + f_{BB}). \qquad (5\text{-}1)$$

Each term is determined as follows.

a. f_1 is the frequency of the oscillator which mixes with the incoming signal. The resultant passes into the C band receiver. f_1 values for the four bands are:

Band	Frequency	Comment
L	-3.2 GHz	fixed
C	0 GHz	fixed
U	19.6 GHz	standard
K	17.6 GHz	standard

The F3 module (for U and K bands) may be set to any frequency between 17.0 GHz and 20.0 GHz satisfying the following condition:

$$f_1 = 17.1 + N \times 0.3 \pm 0.1 \text{ GHz}.$$

b. The sideband of the first mixer for each of the four bands is:

Band	Sign	Comment
L	+	fixed
C	+	fixed
U	-	fixed
K	+	fixed

This determines the sign following the f_1 term.

c. The L6 module may be set to any frequency between 2710 MHz and 4010 MHz which satisfies the following condition:

$$f_{L6} = 2400 + N \times 50 \pm 10.1 \text{ MHz.}$$

d. f_A values for the four IF channels are:

IF	Frequency	Comment
A	300 MHz	fixed
B	400 MHz	fixed
C	550 MHz	fixed
D	650 MHz	fixed

e. f_D values for the four IF channels are:

IF	Frequency	Comment
A	1200 MHz	fixed
B	1200 MHz	fixed
C	1800 MHz	fixed
D	1800 MHz	fixed

f. f_s ranges for the four IF channels are:

IF	Frequency Range	Comment
A	100 to 150 MHz	tunable
B	200 to 250 MHz	tunable
C	-250 to -200 MHz	tunable
D	-150 to -100 MHz	tunable

These frequencies are actually generated from four 100 to 150 MHz synthesizers. In order to produce f_S, the synthesizers are set to:

IF	Synthesizer Setting
A	f_S
B	$f_S/2$
C	$-f_S/2$
D	$-f_S$

For example, if f_S in the C IF were -260 MHz, the C synthesizer would be set to 130 MHz. (This is done for you). It will be noticed that, since the synthesizers are tunable in 1 Hz steps, IF channels A and D are tunable in steps of 1 Hz, but B and C in steps of 2 Hz.

For polarization measurements, it is essential that the local oscillators of channels A and C (and B and D) be locked. This is done in the synthesizer phase lock (L17) module, which forces the following relationships:

$f_S(A) - f_S(C) = f_S(B) - f_S(D) = 350$ MHZ .

Thus, if f_S were chosen to be 110 MHz, for the A IF, f_S for the C IF must be -240 MHz. When these values are put into Equation (5-1), calculations for the A and C IFs will give the same observing frequency.

It is possible to override these constraints by setting the L17 module in independent mode.

g. The values of f_{BB} are:

Bandwidth	f_{BB}[MHz]	OBSERV Program	Comment
50 MHz	25	0	fixed
25 MHz	12.5	1	fixed
12.5 MHz	6.25	2	fixed
6.25 MHz	3.13	3	fixed
3.13 MHz	1.56	4	fixed
1.56 MHz	0.78	5	fixed
0.78 MHz	0.39	6	fixed

These bandwidths are not the hardware filter bandwidths, but 1/2 the sampling rate of the correlator system. The 3 dB filter bandwidths will be about 8% narrower. However, these bandwidths are the basis for frequency calculations. The user specifies the bandwidth code n ($0 < n < 7$) in the OBSERV program such that the sampled bandwidth is $50/2^n$ MHz.

B. The LOSER Program

A DEC-10 program called LOSER will calculate the oscillator settings for a particular map frequency and bandwidth. However, if it is given a frequency incompatable with the possible LO settings, it will give no results. At 50 MHz bandwidth the possible center frequencies are given by

$$f_{50} = 50(N + 1/2) \pm 10.1 \text{ MHz} \qquad (5\text{-}2)$$

where N is an integer. A similar condition restricts the center frequency for a 25 MHz bandwidth:

$$f_{25} = 50(N + 1/4) \pm 10.1 \text{ MHz} \qquad (5\text{-}3)$$

No restrictions occur for bandwidth less than 25 MHz.

To run LOSER on any DEC-10 terminal, log in, and type (either lower or upper case) r loser

LOSER will type a few remarks on the terminal, issue a line feed and type an asterisk (*) prompt. Then type INPUTS and LOSER will reply:

```
LOSER INPUTS
===== ======
  (General)
frequency . . . . . 4885.1 MHz
bandwidth . . . . . 50.000 MHz
  (Misc.)
outfile . . . . . . TTY:
```

The quantities in the right-hand column are default values. To initiate execution, type GO. LOSER will list Local Oscillator settings for 4885.100 MHz, with a bandwidth of 50.000 MHz for which the bandwidth code is 0:

```
Local Oscillator settings for  4885.1 MHz, with a bandwidth of 50.000 MHz.
Bandwidth code is 0
//LO   .0      .0 3560 3860 3310 3860  100.0000  200.0000
```

The //LO etc. line is EXACTLY (including format) what goes into the observer's file (created by the OBSERV program).

There are two ways to put the LO information into the OBSERV file.

a. Use the OBSERV program.

Set the frequencies as the defaults to be used during the program, or set the ADFORMAT so that the desired frequencies are inserted with each source. The frequencies in the above "LO card", the symbols used in Equation (5-1), and the variable name used in the OBSERV program are associated together in Table 5-9.

Table 5-9

Relationship Between Terms in Equation (5-1) and Variables in OBSERV

Frequency Term	Value in Example	Symbol in Formula	Variable Name in OBSERV
1	0	f_1	AB firstlo
2	0	f_1	CD firstlo
3	3560	f_{L6}	A synthesizer
4	3860	f_{L6}	B synthesizer
5	3310	f_{L6}	C synthesizer
6	3860	f_{L6}	D synthesizer
7	100.0000	f_S	AC flukesynthesizer
8	200.000	f_S	BD flukesynthesizer

b. Copy the LO Card Made with LOSER

One transfers the //LO etc. line to the observers file made in OBSERV using special features of the SOS text editor. To do this the LOSER output must be written into an disk file. Type OUTFILE DSK:myfreqi inside LOSER and when the FREQUENCY and BANDWIDTH parameters for your observations are correctly set, type GO. The LOSER output will be written into the file MYFREQ.

Run the SOS text editor on your OBSERV file by typing

SOS observefilename.OBS

and SOS will provide an * prompt. Typing p will print a few lines to assure you that your OBSERVFILE is being addressed. Find a line number where you want the LO information inserted (say it is 650) and type

C650=MYFREQ/S

This version of the copy command allows you to look at the LPT file without copying anything. Type p to look at the file. Note the line number with the //LO etc. Say it is 500. Type e to exit the print part of the copy command. SOS responds with

Source lines =

and now you type 500. An * prompt will appear. Type p/1 and you will see the //LO card at line 650 in your OBSERVFILE.

If you want to copy line 500 of MYFREQ elsewhere type (in SOS) C linenumber = myfreq,500

where linenumber is the destination of the copied line. Repeat this process as often as necessary. To exit SOS type e. Delete the MYFREQ file by typing DEL myfreq.*

To generate new LO frequencies corresponding to a different frequency and bandwidth combination, run LOSER and repeat the entire process.

Chapter 6

USEFUL PLOTS AND TABLES

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April 1982 Edition

ABSTRACT

Frequently used plots and tables are collected together in one place in this chapter.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

FIGURES AND TABLES IN CHAPTER 6

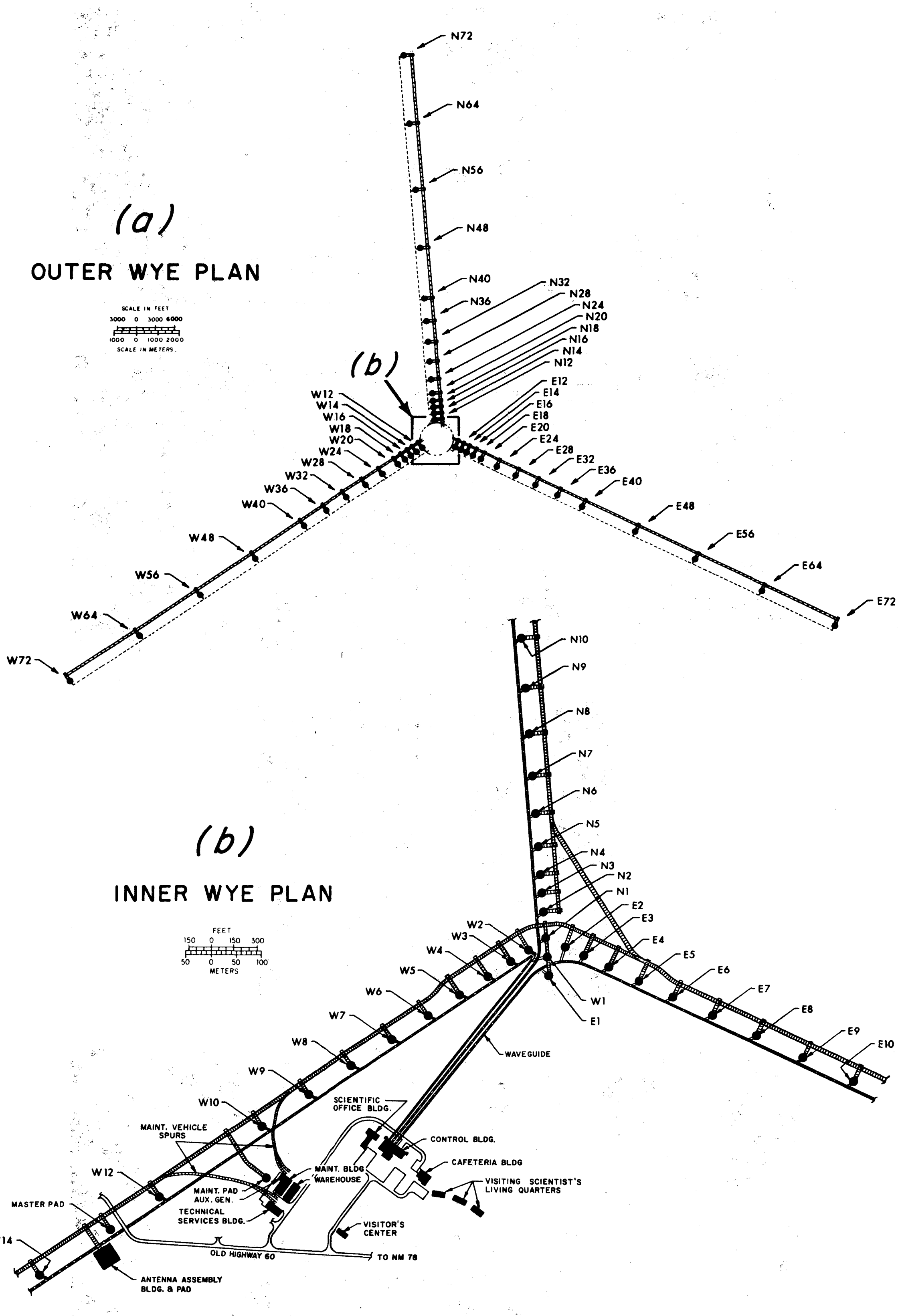

Figure 1-6. Outer (a) and inner (b) VLA wye plans.

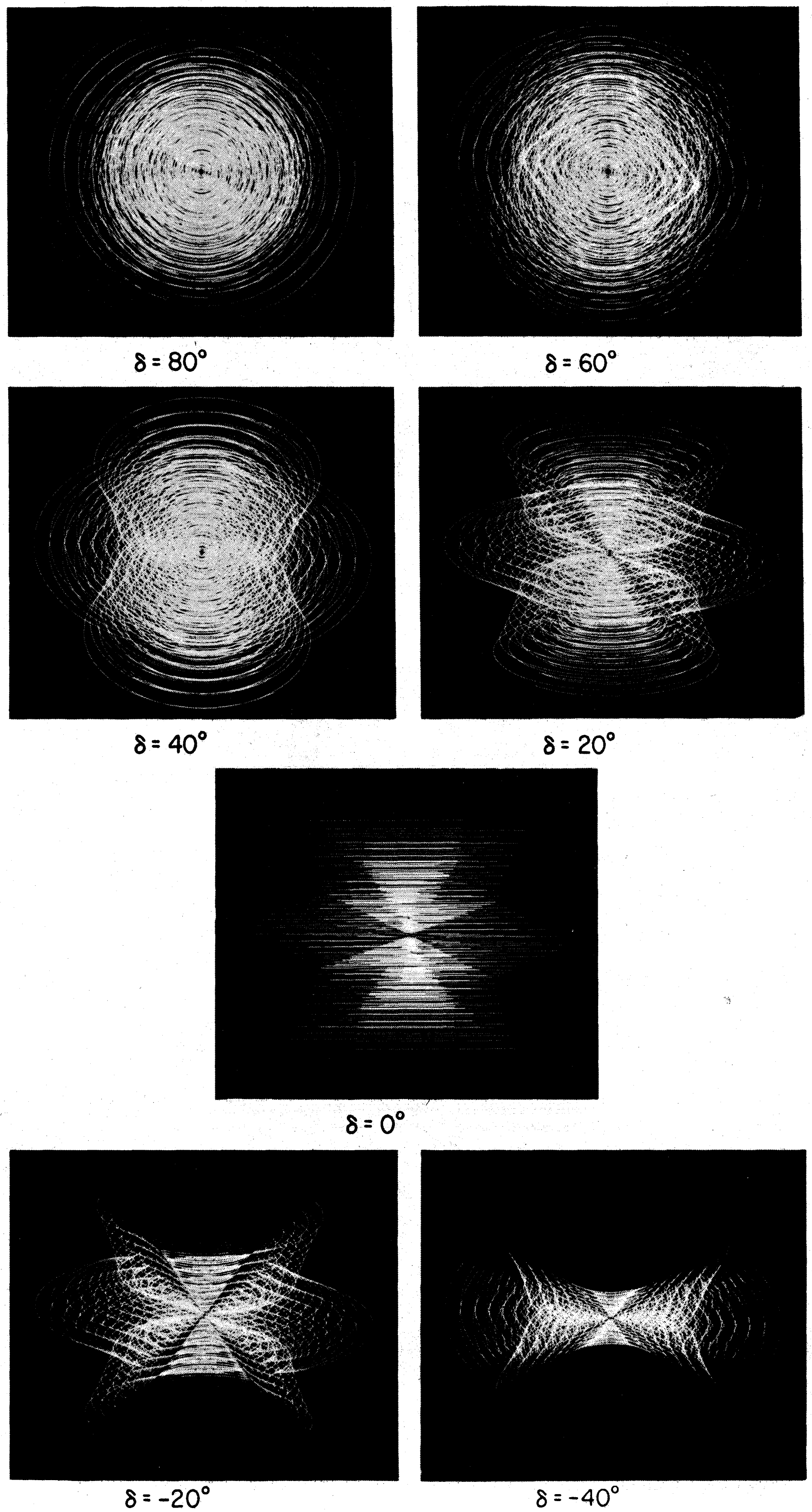

Figure 2-12. Possible u-v plane coverage with the 27-antenna VLA for declinations of 80°, 60°, 40°, 20°, 0°, -20°, and -40°.

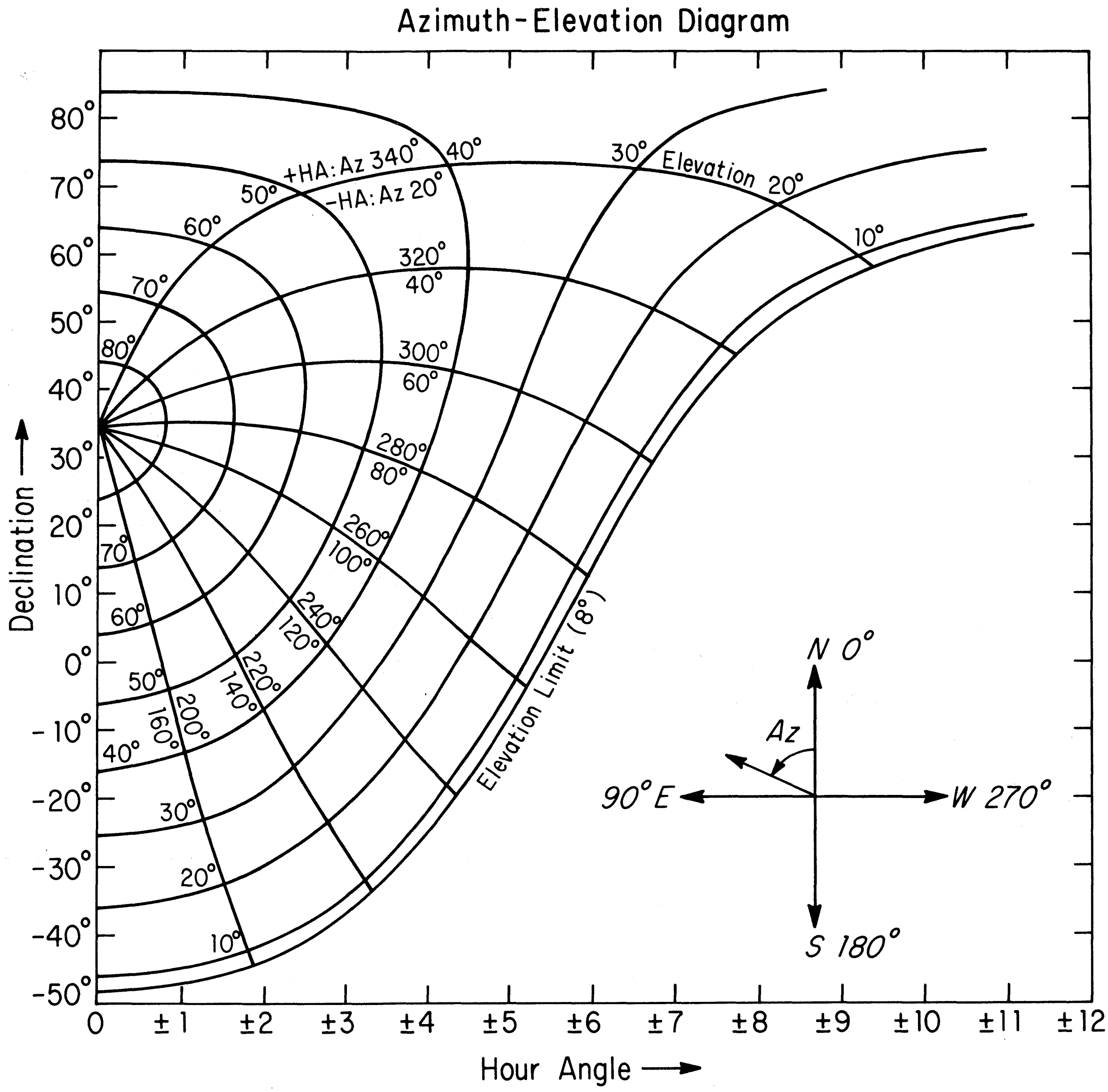

Figure 5-3. Azimuth-elevation diagram for given (HA,DEC).

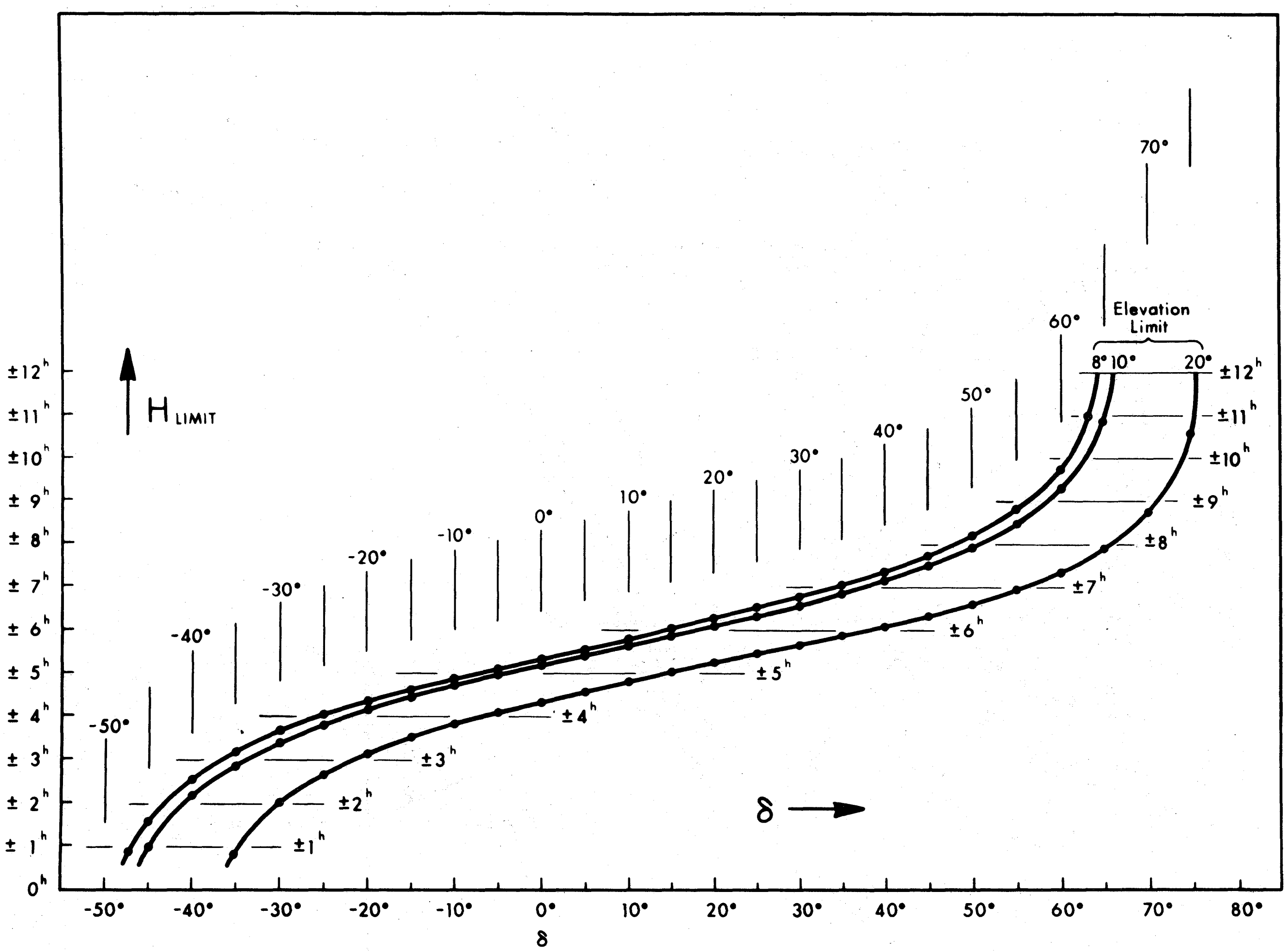

Figure 5-4. Hour angle limits plotted as a function of declination for elevation limits of 8°, 10°, and 20°.

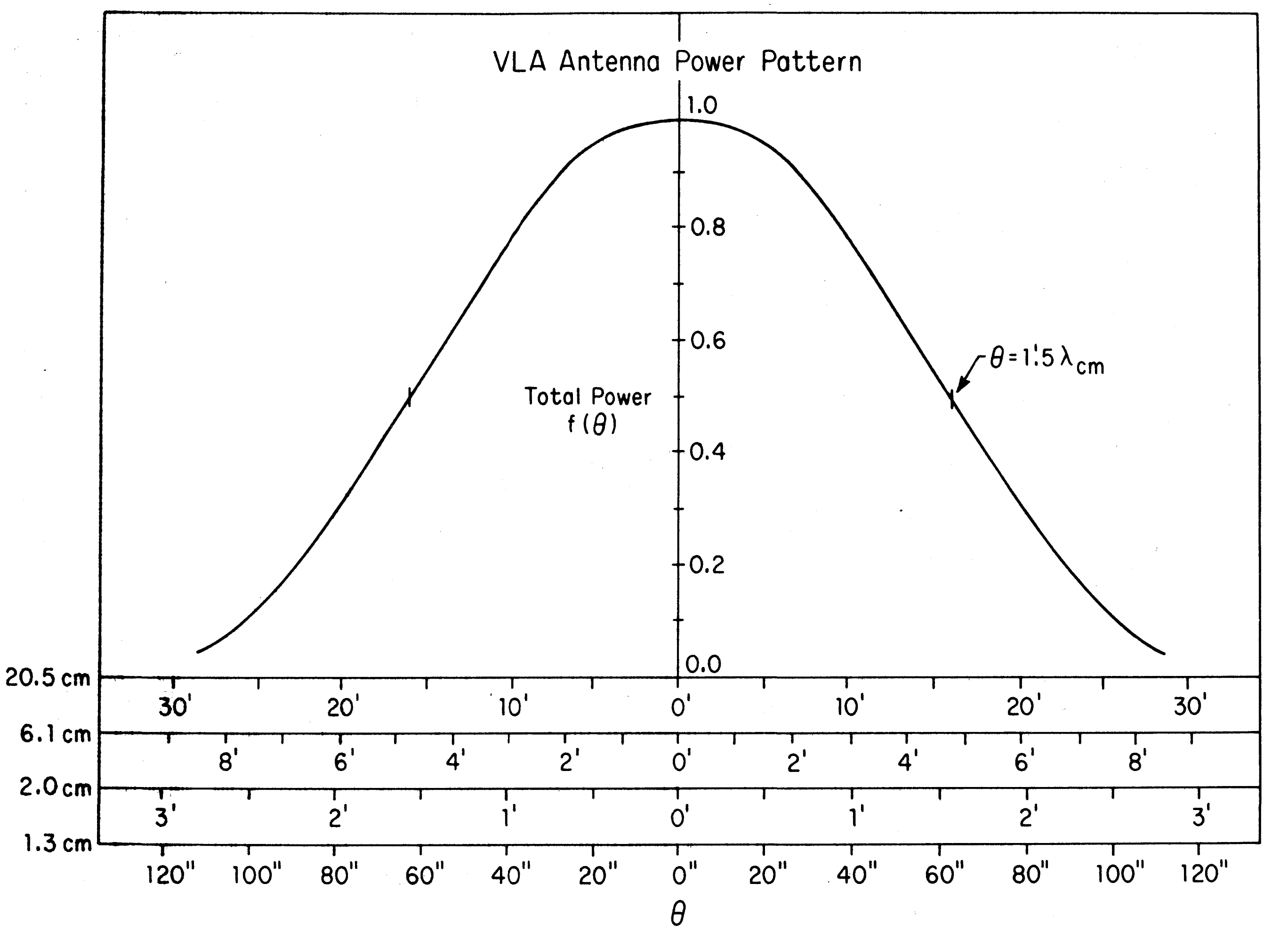

Figure 5-5. Antenna power pattern for all four VLA oberving bands.

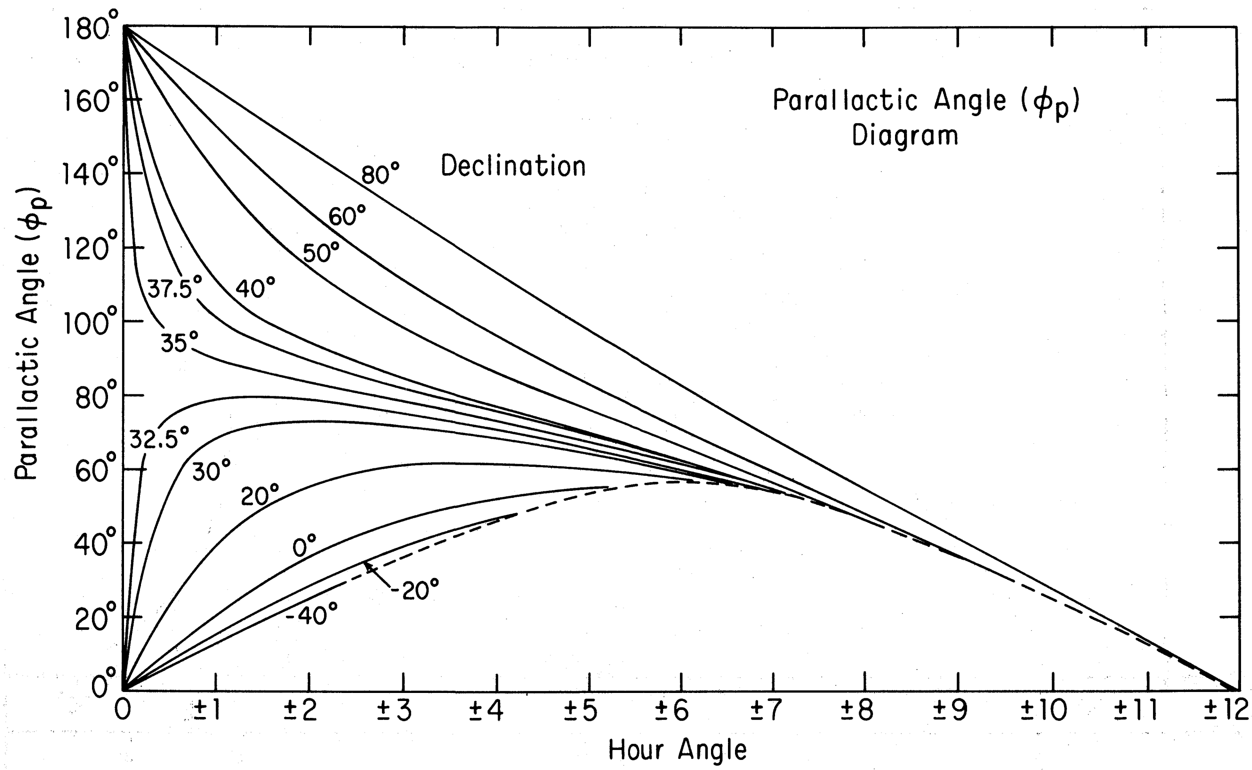

Figure 5-6. Parallactic angle vs. hour angle for various declinations.

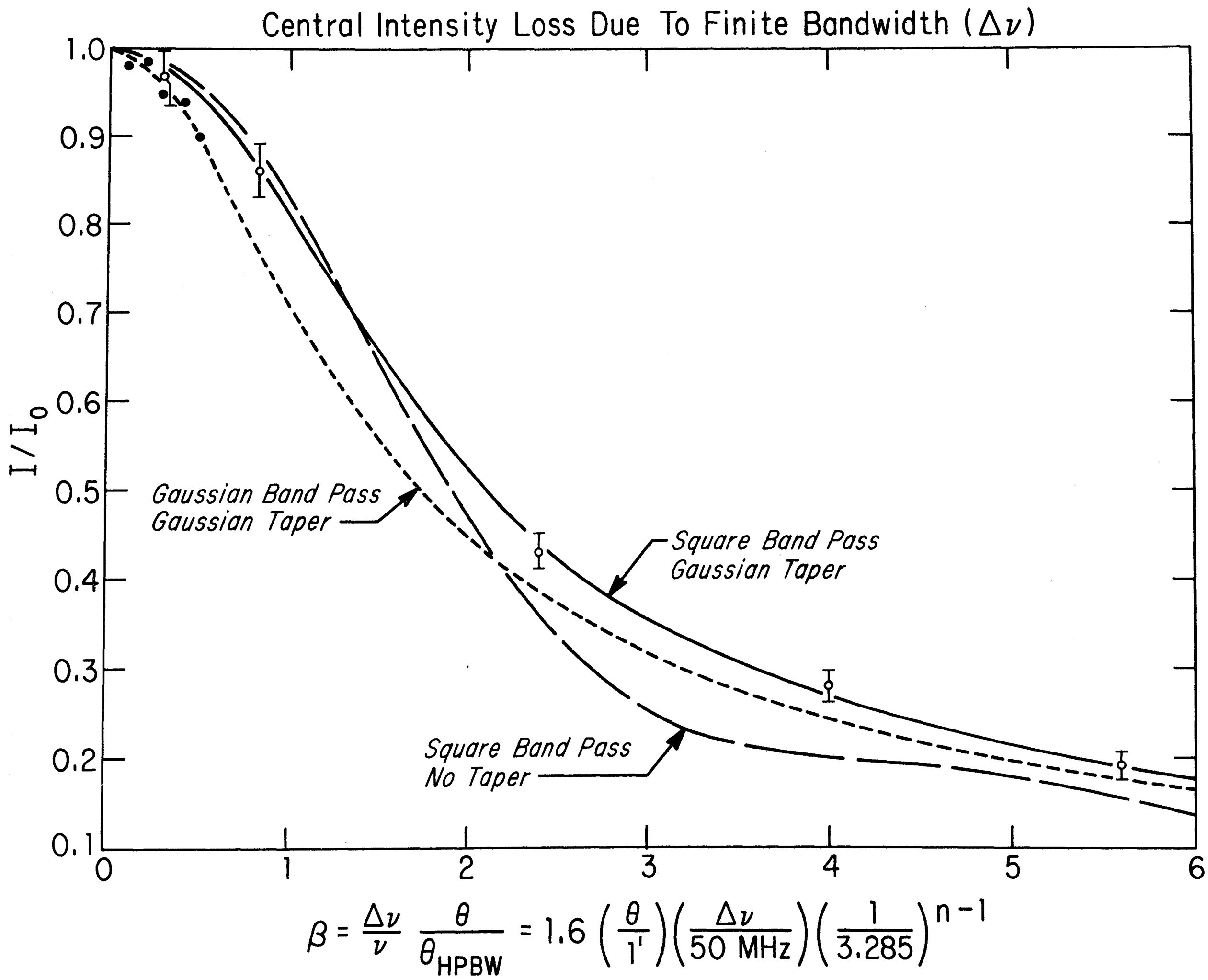

Figure 2-17. Central intensity loss (due to finite bandwidth $\Delta\nu$) plotted as a function of $\beta = \beta(\theta, \Delta\nu, n)$, where θ is angular displacement from the phase center and n = 1, 2, 3, and 4 for the A, B, C, and D configurations.

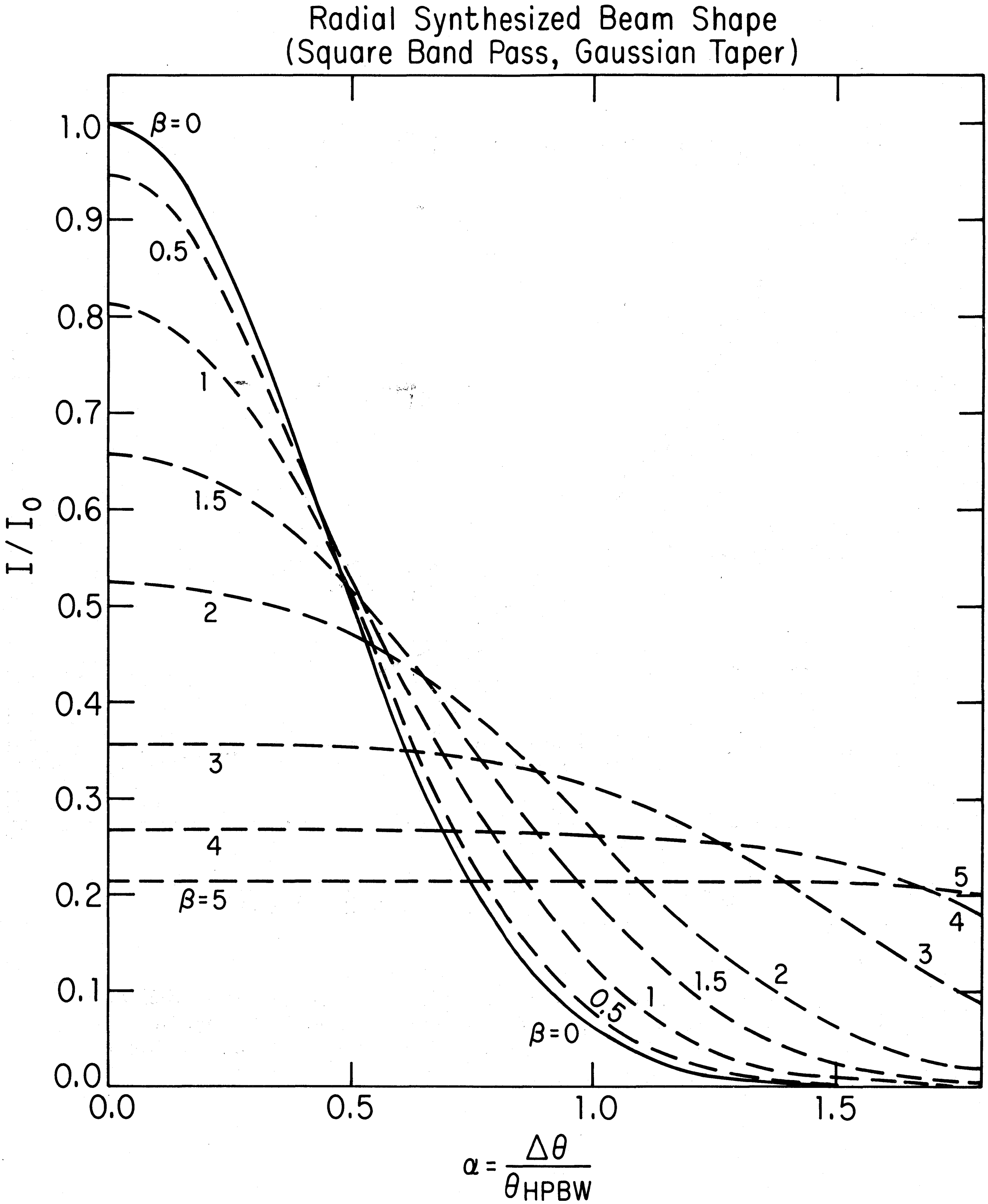

Figure 2-18. Beam shape due to finite bandwidth for a number of values of $\beta = \beta(\theta, \Delta\nu, \text{configuration})$.

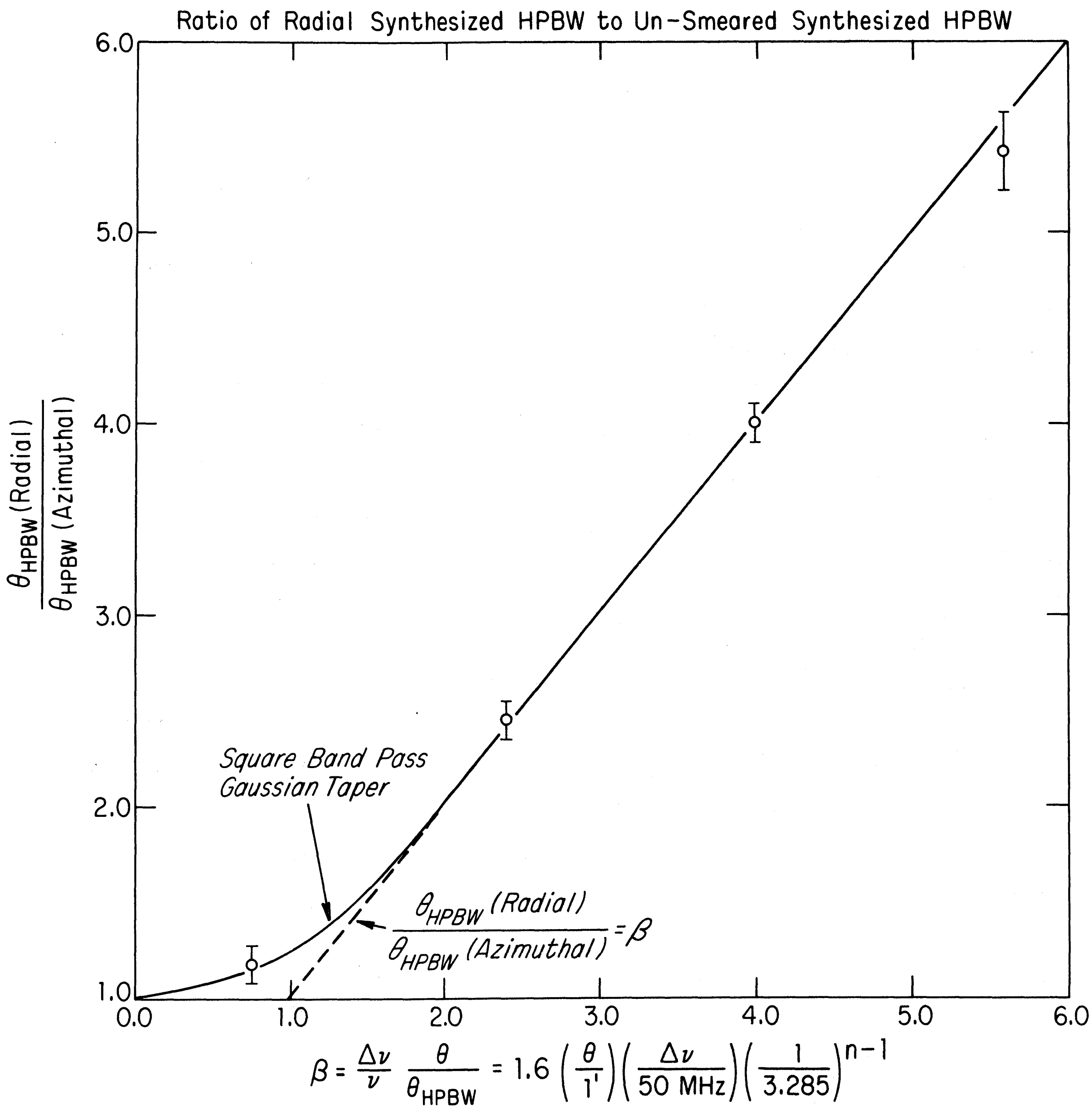

Figure 2-19. Ratio of radial to azimuthal beam width, due to finite BW, plotted as a function of $\beta = \beta(\theta, \Delta\nu, \text{configuration})$.

TABLE 1-1

VLA ANTENNA PARAMETERS

main reflector diameter	25 m (82 feet)
antenna half-power beamwidth	~1'5 λ (λ in cm)
antenna beamwidth between first nulls	~3'6 λ
total geometric aperture	491 square metres
focal length of main reflector	9 m
maximum asymmetric subreflector width	1.83 m
rms surface accuracy for panels	<0.38 mm
rms surface accuracy for panel setting	<0.46 mm
rms surface accuracy for gravity, wind, thermal	<0.36 mm
total rms surface accuracy	<0.70 mm
nonrepeatable pointing errors (for wind <15 mph and <5 degree temperature differences of structure)	<15 arcsec
slew rate, azimuth	40 degrees per minute
slew rate, elevation	20 degrees per minute
drive, servo controlled 5 hp motors	2 per axis
minimum elevation	8 degrees
maximum elevation	125 degrees
minimum zenith angle for tracking	0.5 degrees
azimuth limits relative to track azimuth	±270 degrees
total weight of antenna	419,000 pounds
resonant frequency, torsional	2.2 Hz
resonant frequency, rocking	2.3 Hz
wind speed limits: precision operation	<15 mph
normal operation	<45 mph
survival at stow (snow/ice load 20 lbs per square foot)	<110 mph

TABLE 1-2

VLA OBSERVING BANDS AND ASSOCIATED LINES

VLA Band		Protected Band	Atomic and Molecular Lines
Frequency	Wavelength		
1340-1730 MHz	17-22 cm	1400-1427 MHz	Neutral H (Hydrogen) 1420.4 MHz
			H, He, etc. recombination lines
			$HCONH_2$ (Formamide) 1538- 1542 MHz
			OH 1612, 1665, 1667, 1721 MHz
			HCOOH (Formic Acid) 1639 MHz
4500-5000 MHz	6 cm	4990-5000 MHz	$HCONH_2$ 4617-4620 MHz
			OH 4660, 4751, 4766 MHz
			H_2CO (Formaldehyde) 4830 MHz
			H, He, etc. recombination lines
14.4-15.4 GHz	2 cm	15.35-15.4 GHz	H_2CO 14.489 GHz
22.0-24.0 GHz	1.3 cm	23.6-24.0 GHz	H_2O 22.235 GHz
			NH_3 (Ammonia) 22.834-23.870 GHz

Table 3-1

Parameters of the Four VLA Frequency Bands

VLA Bands	Wavelength	Radio Astronomy Band	System Temperature (T_{sys})*	Antenna Efficiency (ε_a)
1.34- 1.73 GHz	17.0 -22.0 cm	1.400- 1.427 GHz	60°K	50 %
4.5 - 5.0	6.0 - 6.7	4.99 - 5.00	50	65
14.4 - 15.4	1.95-2.08	15.35 -15.40	300	54
22.0 - 24.0	1.25-1.36	23.6 -24.0	360	46

*Average values for the antennas

Table 3-2

IF Bandwidths and Spectral-Line Channel Bandwidths for Various Observing Modes.

Nominal IF Bandwidth	IF passband#	Sampling Frequency	No. of Channels* 1§	2§	4§	Channel Bandwidth
50 MHz	0.19-50 MHz	100 MHz	16	8	4	3.125 MHz
25 MHz	0.19-25 MHz	50 MHz	32	16	8	781 kHz
12.5 MHz	0.19-12.5 MHz	25 MHz	64	32	16	195 kHz
6.25 MHz	0.19-6.25 MHz	12.5 MHz	128	64	32	48.8 kHz
3.125 MHz	0.19-3.125 MHz	6.25 MHz	256	128	64	12.2 kHz
1.563 MHz	0.19-1.563 MHz	3.125 MHz	256	128	64	6.1 kHz
781 kHz	190-781 kHz	3.125 MHz	256	128	64	3.05 kHz
391 kHz	190-781 kHz	3.125 MHz	256	128	64	1.53 kHz
195 kHz	195-391 kHz	1.563 MHz	256	128	64	763 Hz
97 kHz	195-391 kHz	781 kHz	256	128	64	381 Hz

* The numbers given indicate the number of channels processed within the nominal bandwidth. The number of usable channels is slightly less because of band edge effects.

\# The filters are low-pass and the low-frequency limit is determined by the amplifiers except for the 195-391 kHz band which uses a bandpass filter.

§ Number of IFs.

Table 5-5

Default Observing Frequencies for Different Bands and Bandwidths

Bandwidth [MHz]	Observing Band				
	21cm HH [MHz]	20cm LL [MHz]	6cm CC [MHz]	2cm UU [MHz]	1.3cm KK [MHz]
50.0		1464.90	4885.10	14.9649	22.4851
25.0	1413.00	1452.40	4872.60	14.9774	22.4726
12.5	1406.75	1446.15	4866.35	14.9837	22.4664
6.25		1443.03	4863.23	14.9869	22.4632
3.125		1441.46	4861.66	14.9883	22.4617
1.5625		1440.68	4860.88	14.9891	22.4609
0.78125		1440.29	4860.49	14.9895	22.4605

Table 5-1

Maximum and Minimum Beam Sidelobe Levels for Full Tracking with 27 Antennas

Declination (degrees)	Maximum (fraction)	Minimum (fraction)
80	0.07	-0.14
60	0.08	-0.17
40	0.11	-0.25
20	0.16	-0.40
0	0.2	-0.42
-20	0.2	-0.4
-40	0.2	-0.44

Table 5-2

Sidelobe Levels for δ = 30° Source with Varying Integration Time

H_{start}	H_{stop}	H_{range}	Inner 1/4 Maximum Sidelobe Level	Outer 3/4 Maxumum Sidelobe Level
-6^h	$-5^h\ 45^m$	15^m	27%	12%
-6^h	$-5^h\ 30^m$	30^m	16	4
-6^h	-5^h	1^h	9	4
-6^h	-4^h	2^h	8	3
-6^h	-3^h	3^h	7	2
-6^h	-2^h	4^h	5	2
-6^h	0^h	6^h	3	2
-6^h	$+6^h$	12^h	3%	<1%

Table 5-3

Sensitivity, Resolution, and Confusion Limits With 27 Antennas

Frequency	1.34-1.73	4.5-5.0	14.4-15.4	22.0-24.0	GHz
Wavelength	22.4-17.3	6.67-6.00	2.08-1.95	1.36-1.25	cm
Band Designation	L	C	U	K	
System Temperature	60	60	300	400	°K
RMS Sensitivity in 10 minutes (50 MHz bandwidth)	0.13	0.10	0.60	1.0	mJy
RMS Sensitivity in 12 hours (50 MHz bandwidth)	0.015	0.012	0.07	0.12	mJy
Untapered Brightness* Temperature (A configuration)	6.9	5.5	34	54	°K
Dynamic Range Without Self Calibration**	100	50	10-20?	10?	
Antenna Beam Size (HPBW)	30'	9'	3.7'	2'	
Brightest Source Expected in Antenna Beam	100	2.3	<0.1	<0.01	mJy

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

$$\Delta T \simeq (1.46\lambda^2/\theta_1\theta_2)\ \Delta S$$

Where θ_1 and θ_2 are the half-power synthesized beamwidths in arcseconds, λ is the wavelength in cm, and ΔS is the rms sensitivity per beam area in mJy.

**Dynamic range is extremely dependent on declination, time of day, season, and frequency of calibration.

Table 7-1

List of DEC-10 Utility Programs and Monitor Commands

Command	Short Form and Syntax	Purpose
login	log [13,PN]	Log on DEC-10 in your area
	Password	and supply Password when prompted
kjob	k	Log off DEC-10 when finished
directory	dir	List all files/sizes in your [13,PN]
area		
	dir [P,PN]	List all files/sizes in [P,PN] area
	dir/f	Fast list of only file names
	dir/l [P,PN]	Output directory of [P,PN] on printer
delete	del name.ext	Delete name.ext from disk
	del junk.*	Delete all files with name junk
	del *.txt	Delete all files with extension txt
	del ?am?.?xt	Delete files with the letters am and xt in names and extension, but with any char. before & after am, and before xt
type	ty name.ext	Type file named name.ext on terminal
	ty junk.txt[P,PN]	Type junk.txt[P,PN] on terminal
print	pri name.ext	Print name.ext on DEC-10 line printer
	pri	List jobs in current print queue
systat	sy	List all system info. on terminal
	sy f	List available disk space
	sy b	List busy devices like tape drives
	sy s	List what jobs are running (all JOBNUMs)
	sy JOBNUM	List status of job number JOBNUM
	sy .	List status of job on this terminal
who	who	List logged in users by name
queue	que	List jobs in PRINT and SUBMIT queues
help	help	List info. on what HELPs are available
	help SUBJECT	List help info. for particular subject
initia	init	Initialize terminal (get out of problem)
submit	sub batch	Submit batch.ctl for batch execution
	sub batch.job	Submit batch.job to batch queue
	sub	List current batch queue
	sub batjob=/kill	Kill batjob.* in batch queue

Table 7-1 (continued)

Command	Short Form and Syntax	Purpose
do	do batch.job	Execute batch.job on terminal
copy	f2.ext[P1,PN1]pf1.ext[P,PN]	Copy f1.ext[P,PN] into f2.ext[P1,PN1]
rename	new.ext[P,PN]pold.ext[P,PN]	Rename old.ext in [P,PN] to new.ext
r	r XXXXXX	Execute system program named XXXXXX
run	run YYYYYY	Execute program YYYYYY in your area
send	send TTYn:message	Send message to terminal (TTY) number n
set time	set time n	Sets maximum CPU time of n seconds/job
set tty	set tty parameters	Set terminal parameters, see DEC-10 doc.
mount	mount mta:name/reelid:x	Mount tape with reel id. of x
	mount mta:tap/reelid:x/wen	Mount tape setting WENABLE switch to write
unload	unl mta:	Rewind and unload previously mounted tape
deassign	deass mta:	Deassign previously mounted tape (opposite of mount)
continue	cont	Continue execution of program CNTL C'd twice
control c		Interrupt executing program Tow CNTL C's kill executing program
control h		Backspace 1 char., like DEL, RUB, BKSP keys
control o		Suppress current terminal output (a second control o resumes terminal output, some output lost)
control s		Suspend terminal output
control q		Resume terminal output previous CNTL q'd
control r		Re-type current input line
control u		Delete current input line
control w		Delete last word typed
control t		Type status info about current terminal job
control [		ESCAPE key, used in text editor (SOS)

Table 7-2

DEC-10 Text Editor (SOS) Commands

Name	Symbol	Syntax	Purpose of Command
print	P	p	Type current line and next 15 lines
		pn	Type line number n
		p.	Type current line (where pointer is)
		pn:m	Type lines n through m
		pn:m,s	Type lines n through m stripping line #
		p/.	Type all lines on current page
		p↑:*	Type all lines from first to last
help	H	h	Type detailed syntax info. on screen
insert	I	in	Insert lines after line number n
		in,s	Insert lines after n with increment s
number	N	n	Re-number all lines with old increment
		n,s	Re-number all lines with new increment s
delete	D	dn	Delete line n
		dn:m	Delete lines n through m
replace	R	rn	Replace line number n with a new line
		rn:m	Replace lines n through m with new lines
lineprinter	L	l	Print SOS file out on printer after exit
		l,s	Same as above, but without line numbers
exit	E	e	Exit from SOS, back to monitor level, storing file on disk (backed up)
		eq	Exit from SOS, no change in file on disk
		eb	Exit from SOS saving on disk, no back up
		es	Exit from SOS, saving without line no. but backed up on disk
worldsave	W	w	Save text file on disk in current form
transfer	T	tm,n1:n2	Transfer lines n1 thru n2 after line m
copy	C	cm,n1:n2	Copy lines n1 thru n2 after line m
substitute	S	sOLDNEWn:m	Substitute NEW string for OLD string wherever it occurs in lines n thru m ($ = ESCAPE = CONTROL [ )
join	J	jn	Join line n and the next line on line n
extend	X	xn	Start adding text to end of line n
alter	A	an	ALTER mode (inter-line edit)for line n To see ALTER mode syntax type H in SOS

Chapter 7

VLA DATA PROCESSING SYSTEMS

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April 1982 Edition

ABSTRACT

The theory of VLA data processing, and the hardware and software systems available at the VLA to accomplish this processing, are discussed in general terms. This includes the relationship between the on-line and off-line computer systems, and the characteristics of the major off-line hardware and software systems. In this chapter we mainly concentrate on the DEC-10 system. Although the DISPLAY and AIPS systems are mentioned in context, Chapters 10 and 11 deal with them in detail.

This Chapter also covers: logging on and off the DEC-10; the DEC-10 operating system commands that are of interest to VLA users; the DEC-10 text editor (SOS); and the standard commands system used for most of the DEC-10 data reduction programs - including those that communicate with the MAPPER and SORTER/GRIDDER mapping systems.

Chapters 8 and 9 will assume general aquaintance with the contents of this Chapter, and will provide more information on the major DEC-10 programs. Chapter 13, on Data Processing Methods, will concentrate on a more coherent discussion of the philosophy and approach towards VLA data reduction.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. Theory of Off-Line Data Processing

A. General Overview

Let us review the objectives of VLA data processing, and summarize a means of discussing it in terms of equations. The basis of these equations is discussed in detail in Chapter 2, "The Theory of the Instrument".

Off-line data processing has three principal stages:

a. visibility data processing,

b. image computation, and

c. image processing (including display).

In the beginning sections of this chapter we will attempt to summarize the major aspects of all three major stages of processing in mathematical terms. Then we will summarize the major systems used to accomplish this data processing.

B. Visibility Data Processing

Visibility processing begins with the measured visibilities, flags which are judgements of quality generated in the on-line system, and associated information supplied by the on-line system. One generally has data for N antennas, giving up to 8 X N(N-1)/2 measured complex visibilities that we will denote by double-primed quantitities

$$V''_{jkp}(t) = A''_{jkp} \exp[i\phi''_{jkp}(t)] \quad : \qquad (7\text{-}1)$$

the "raw" data obtained from the sampled output in the on-line system after cross-correlation of the delayed IF outputs from the j-th and k-th antennas ($j < k$). The subscript p corresponds to

$p = 1 , 2 , 3 , 4 , 5 , 6 , 7 , 8$

or

p = AA, CC, AC, CA, BB, DD, BD, DB

depending upon which notation is more convenient for the eight correlators that can be obtained from the A, B, C, and D IFs. Note that p will have this meaning whenever associated with a pair of antennas; however, we will also be using variables associated with single antennas, and for these the convention will be

p = 1, 2, 3, 4 = A, B, C, D ;

with circularly polarized signals for which

A or C = L for left circular polarization

or

B or D = R for right circular polarization.

Let us also denote the visibilities produced by the on-line system, after on-line corrections, by single-primed quantities

$$V'_{jkp}(t) = A'_{jkp} \exp [i\phi'_{jkp}(t)] \quad . \qquad (7\text{-}2)$$

The V'_{jkp} data form the starting point of nearly all data processing in the off-line computer systems, whether in the SORTER/GRIDDER mappings system, the DEC-10, or any other computer system that can deal with data produced by the on-line computer system.

Finally, let us denote visibilities that have been subjected to all off-line corrections and calibrations as unprimed quantities

$$V_{jkp}(t) = A_{jkp} \exp [i\phi(t)] \quad . \qquad (7\text{-}3)$$

With this double-primed, single-primed, and un-primed notation for visibilities, amplitudes, phases, etc., we can distinguish between the major stages of processed VLA data.

Flags indicating data quality are generated in association with visibility data in both on-line and off-line systems. Each flag is a boolean quantity with a value of 0 meaning "good" or un-flagged and a value of 1 meaning "bad" or flagged. Following the logic discussed above we can denote on-line flags by f'_{jkp} and the flags in the off-line system by f_{jkp}. Editing of data in the off-line system consists of two distinct stages; (1) flagging of selected data found to be "bad" by setting f_{jkp} to 1; and (2) using the PASSFLAG command to specify whether the programs should select data according to the four combinations UNFLAGGED, MODCOMP, DEC, or BOTH, which correspond to $f'_{jkp}f_{jkp}$ = 00, 10, 01, or 11.

During off-line processing of visibility data, in either the DEC-10 or the SORTER/GRIDDER mapping system, the original V'_{jkp} stored on disk are never modified in any way. The process of correction and calibration is based upon application of a so-called "gain" table which contains antenna-based, complex, correction and calibration factors to be applied to complex visibility data. Programs that process visibility data can be used to deal with visibilities either with or without application of the gain table. As discussed in detail in Chapter 2, there are general equations relating V''_{jkp}, V'_{jkp}, and V_{jkp} data. Let

$$g'_{jR},\ g'_{jL},\ D'_{jR},\ D'_{jL}$$

be the complex "gains" and cross-polarizations used in the on-line system to make the transformation from raw V''_{jkp} data to V'_{jkp} data. The equations accomplishing this are the following:

$$V'_{jkLL} = g'_{jL}g'^{*}_{kL}V''_{jkLL} \tag{7-3}$$

$$V'_{jkRR} = g'_{jR}g'^{*}_{kR}V''_{jkRR} \tag{7-4}$$

$$V'_{jkLR} = (g'_{jR}g'^{*}_{kL}V''_{jkLR} - D'_{jL}V'_{jkRR} - D'^{*}_{kR}V'_{jkLL})\ \exp\ (-2i\phi_p) \tag{7-5}$$

$$V'_{jkRL} = (g'_{jL}g'^{*}_{kR}V''_{jkRL} - D'_{jR}V'_{jkLL} - D'^{*}_{kL}V'_{jkRR})\ \exp\ (+2i\phi_p) \tag{7-6}$$

where ϕ_p is the parallactic angle given by

$$\phi_p = \tan^{-1}[(\cos\ \lambda_{lat}\sin\ H)/(\sin\ \lambda_{lat}\cos\ \delta\ -\ \cos\ \lambda_{lat}\sin\ \delta\ \cos\ H)]\ . \tag{7-7}$$

In Equation 7-7, λ_{lat} is the latitude, H is the hour angle, and δ is the declination. The process of off-line correction and calibration involves additional complex gains and cross-polarizations,

$$g_{jR},\ g_{jL},\ D_{jR},\ D_{jL}\ ,$$

using the equations

$$V_{jkLL} = g_{jL}g^{*}_{kL}V'_{jkLL} \tag{7-8}$$

$$V_{jkRR} = g_{jR}g^{*}_{kR}V'_{jkRR} \tag{7-9}$$

$$V_{jkLR} = (g_{jR}g^{*}_{kL}V'_{jkLR} - D_{jL}V_{jkRR} - D^{*}_{kR}V_{jkLL})\ \exp\ (-2i\phi_p) \tag{7-10}$$

$$V_{jkRL} = (g_{jL}g^{*}_{kR}V'_{jkRL} - D_{jR}V_{jkLL} - D^{*}_{kL}V_{jkRR})\ \exp\ (+2i\phi_p)\ . \tag{7-11}$$

Note that the parallactic angle correction is applied either in Equations 7-6 and 7-7 or 7-10 and 7-11, but not in both.

The on-line system passes the g'_{jp}'s and D'_{jp}'s to the off-line system. One of the possible functions that can then be done in the off-line programs is the undoing of the on-line correction and calibration. Under these conditions the equations of correction and calibration are effectively

$$V_{jkLL} = g_{jL} g^{*}_{kL} V''_{jkLL} \qquad (7\text{-}12)$$

$$V_{jkRR} = g_{jR} g^{*}_{kR} V''_{jkRR} \qquad (7\text{-}13)$$

$$V_{jkLR} = (g_{jR} g^{*}_{kL} V''_{jkLR} - D_{jL} V_{jkRR} - D^{*}_{kR} V_{jkLL}) \exp(-2i\phi_p) \qquad (7\text{-}14)$$

$$V_{jkRL} = (g_{jL} g^{*}_{kR} V''_{jkRL} - D_{jR} V_{jkLL} - D^{*}_{kL} V_{jkRR}) \exp(+2i\phi_p) \quad . \qquad (7\text{-}15)$$

In the DEC-10 (or SORTER/GRIDDER mapping system) the visibilities produced by the on-line system are stored in a data base file which in the DEC-10 is called DBNAME.VIS, although in practice the DBNAME prefix is a name chosen by the user, and these data remain untouched and associated with specific times. Both on-line and off-line correction and calibration factors are stored on disk in a gain table file called DBNAME.GAI with values of

$$g'_{jR}(t_n),\ g'_{jL}(t_n),\ D'_{jR}(t_n),\ D'_{jL}(t_n)$$

and

$$g_{jR}(t_n),\ g_{jL}(t_n),\ D_{jR}(t_n),\ D_{jL}(t_n)$$

where $t_n = t_1, t_2, \ldots,$ with discrete times assigned at the time on-line data is transferred to the off-line computer system, or re-assigned by programs that average visibility data. The time intervals between gain table entries are not related to actual times of obvervation as are, of course, the visibility data. A minimal data base needed for processing consists of three files: a DBNAME.VIS file, a DBNAME.GAI file, and a DBNAME.INX file which contains information about parameters that are global to a contiguous observation with a single set of observing parameters.

Although once visibility data have been calibrated it may be stored (on magnetic tape or disk) in a form where complex visibilites are corrected and calibrated, the user doing processing in the DEC-10 should know of the distinction between the antenna-pair- oriented DBNAME.VIS file without off-line corrections or calibration and the antenna-oriented DBNAME.GAI file with accumulative antenna-based amplitude and phase modification information. Almost all programs in this system that use visibility data have a selectable option to use visibilities with or without the corrections and calibrations in the gain table. The process of correction and calibration of visibility is then empirically described by the methods by which corrections and calibration are determined and entered into the gain table. The upper part of Figure 7-1 schematically indicates this process.

C. Corrections to Visibility Data

The concept of "corrections" as opposed to "calibration" is reserved for amplitude or phase modifications which are describable by algebraic formulae with a relatively small number of parameters to be supplied by the user. Examples are: (1) correction for a known time error; (2) corrections for known errors in the location of antennas; (3) source position offsets; (4) correction for known phase jumps of predictable amounts; etc. All off these corrections are antenna-based and thus are placed into the gain table of a visibility data base. In the DEC-10 this is done by a program called GTBCOR (Gain TaBle CORrection). Before any corrections (or calibrations) are applied the gain table is set (or can be RESET) such that the amplitude and phase parts of all complex gains are 1 and 0, respectively. Subsequent correction and calibration is multiplicative in amplitude and additive in phase.

D. Calibration of Visibility Data

Once the principal corrections that are necessary are applied to the gain table, one can proceed with empirical calibration. This is accomplished based upon data from short observations of amplitude and/or phase calibrators interspersed throughout an observing run. A good phase calibrator is a point source with an accurately known position which is observed at the phase reference position. A good amplitude calibrator is a point source with a flux density (S), at the desired frequency, that is either known ahead of time, or determinable by comparing with observations of a point source of known flux density. For a good amplitude and phase calibrator one knows that after calibration

$$V_{jkp} = S \, , \tag{7-16}$$

that is, the visibility amplitude is equal to the source flux density and the visibility phase is, within error limits, zero. This is strictly true only for the case of p = RR or LL and, as is almost always true, when there

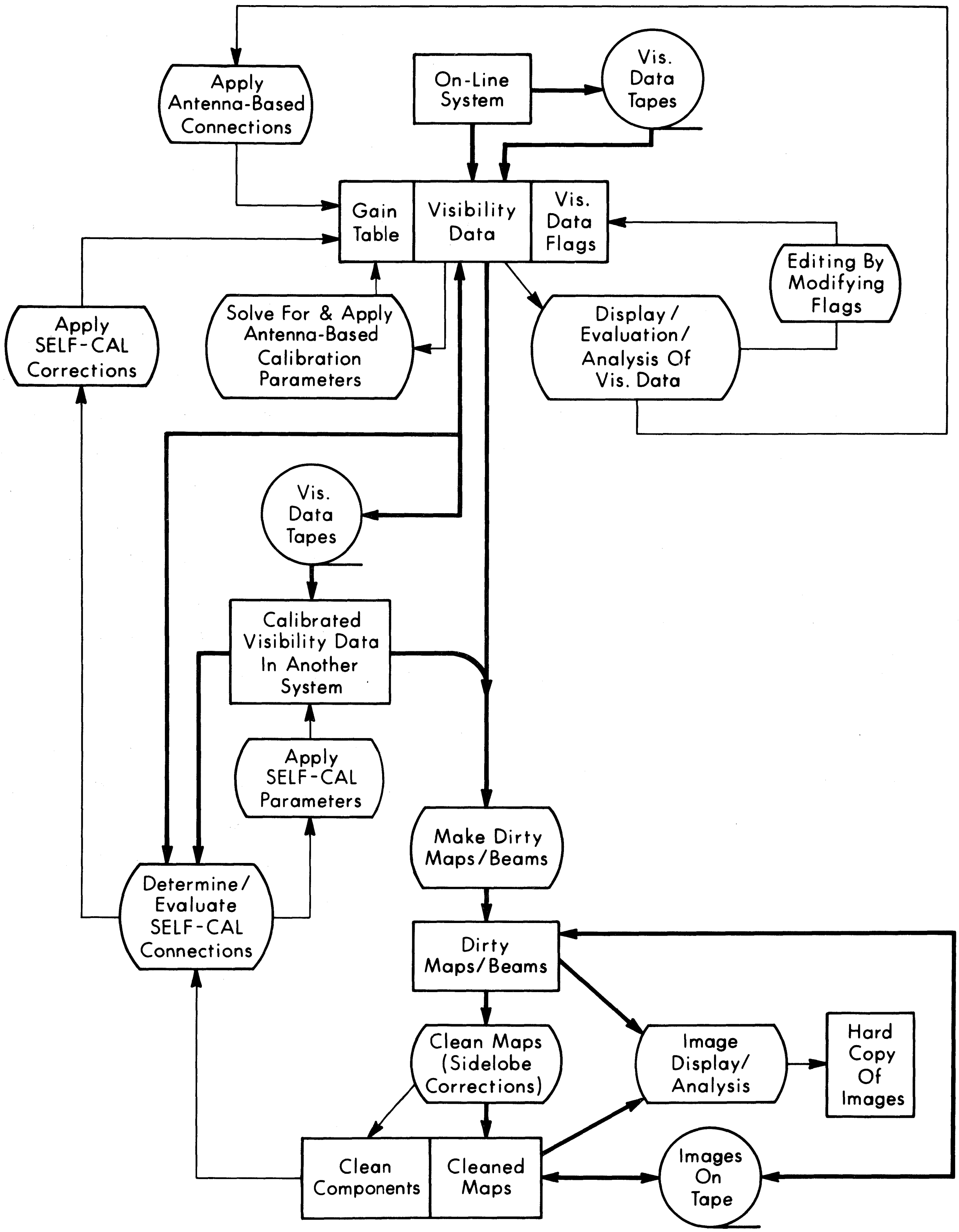

Figure 7-1. A schematic diagram illustrating, in a general way, the major data processing stages for VLA data.

is negligible circular polarization in the calibrator. Let V_{jk}^{corr} be a visibility measurement with only corrections applied, then

$$A_{jkp}^{corr} \exp(i\phi_{jkp}^{corr}) = S\, g_{jp} g_{kp} \exp[i(\phi_{jp} + \phi_{kp})] + \varepsilon_{jkp} \quad . \qquad (7\text{-}17)$$

The DEC-10 program called ANTSOL uses N(N-1)/2 visibility measurements to solve for the N (real) g_{jp}'s and N ϕ_{jp}'s, using a combination of iterative and non-linear least squares methods, and assuming that closure errors (ε_{jkp}) are zero. ANTSOL stores the calibration parameters in a temporary disk file in the DEC-10 called the DBNAME.CAL file. In practice, once the calibration parameters are determined, the closure errors (ε_{jkp}) are a mixture of noise and systematic failures of the assumptions underlying this method of empirical calibration. Closure errors are large, for example, when the "calibrator" is highly resolved. They are also large if the calibrator is too weak and Equation (7-17) is dominated by the noise, or when an antenna-IF has malfunctioned but has not yet had its data flagged as bad. The actual insertion of empirical calibration in the gain table is carried out, not in ANTSOL, but in the DEC-10 program GTBCAL.

E. Making maps or radio images

As discussed in Chapter 2, the process of transforming a set of calibrated visibility data, $V_{obs} = [V_{jkp}(u_{jk}, v_{jk})]$, into a radio image, I(x,y), involves a number of non-unique steps best described as numerical processing. In principal, the visibilities actually processed into a map can be described by

$$V(u,v) = W(u,v)\, T(u,v)\, E(u,v)\, B(u,v)\, S(u,v)\, V_{true}(u,v) \qquad (7\text{-}18)$$

where

V_{true} = true visibility function,
S = sampling function determined by observing circumstances,
B = bandwidth loss function,
E = error function,
W = weighting function, and
T = tapering or grading function.

In practice, the practical necessity of computational speed forces most mapping to be done using the FFT algorithm that requires subsequent steps of convolution and gridding (to a square grid of visibility points in the u,v plane) before carrying out the two-dimensional Fourier transform, that is,

$$V_{grid} = III(u,v)[C(u,v)*[W(u,v)T(u,v)E(u,v)B(u,v)S(u,v)V_{true}(u,v)]] \quad ,(7\text{-}19)$$

where III(u,v) is a sum of the product of two delta functions defining the u,v grid and C(u,v) is the convolution function used to convolve ($W \bullet T \bullet E \bullet B \bullet S \bullet V_{true}$) to the appropriate grid of visibilities. In the ideal world,

$$V_{true}(u,v) = \overline{I_{true}(x,y)} \qquad (7\text{-}20)$$

and one obtains

$$I_{true}(x,y) = \overline{V_{true}(u,v)} \quad , \qquad (7\text{-}21)$$

but in the real world,

$$V_{obs}(u,v) = E(u,v)\ B(u,v)\ S(u,v)\ V_{true}(u,v) \qquad (7\text{-}22)$$

is the basic transformation that is performed by the instrument, and

$$I(x,y) = \overline{III(u,v)\ [C(u,v)*[W(u,v)\ T(u,v)\ V_{obs}(u,v)]]} \qquad (7\text{-}23)$$

is the basic equation describing the data processing necessary to turn a set of observed visibilities into a radio image, which is a two dimensional array of numbers with units of surface brightness (Jy/beam) or brightness temperature (°K).

The observer must choose the values of a large number of parameters inherent in Equations (7-22) and (7-23). The planning and execution of observing involves scheduling, choices of frequency and bandwidth, etc. that constitute choosing some of the parameters of Equation (7-22). The process of flagging bad data, correction, and calibration can be considered as undoing, as far as possible, the effects of the product $S \bullet B \bullet E$ so that the V_{obs} used in mapping are as close to V_{true} as possible.

During the process of image computation the observer chooses the parameters of the functions III, C, W, and T. Understanding both the effects and optimal ranges of these parameters constitutes one of the major jobs of the astronomer during data processing. Without going into the level of detail appropriate to individual programs in different data processing systems, let us discuss the major parameter choices of image computation in a general sense.

a. III(u,v): Gridding Parameters

Let M X M = the size of the image array and dx = dy = cell or grid size in angular units. The angular size of the field to be mapped will then be M•dx X M•dy. The main goal behind the choice of cell size is obtaining the desired number of points per synthesized beam width, which is generally in the range of 2 to 4; it should never be less than 2, lest the sampling theorem (for the u,v plane) be violated with unpredictable consequences. Four points per beam is generally all that is necessary for high quality display of information about point sources. This means that one chooses 2 points per synthesized beam unless "grainy" displays of point sources are undesirable, as in images for publication purposes. Since the synthesized beam width is effected by not only the size of the array of VLA antennas actually used, but also by the parameters of weighting and tapering, the rough rule of thumb discussed in Chapter 2,

$$dx = dy = \lambda_{cm}/L_{km}, \qquad (7\text{-}24)$$

where L_{km} is the maximum antenna separation, can be too small or too large, although it usually results in roughly two points per synthesized beam. Changes in weighting and tapering usually result in a reduced value for the effective L_{km}, and thus an increased cell size.

The choice of M is based upon the size of M•dx relative to the size of the radio source(s) you wish to include in the computed radio image. A dominant radio source with a known angular diameter, Θ_{source}, will usually lead to a simple choice of the smallest $M = 2^n$ greater than Θ_{source}/dx. The best first order choice, for a previously unstudied field, is the smallest $M = 2^n$ that is greater than $\Theta_{ant,HPBW}/dx$, where

$$\Theta_{ant,HPBW} = 1.5' \; \lambda_{cm} \qquad (7\text{-}25)$$

is the half power diameter of the antenna primary beam. Under extreme circumstances involving strong sources on the edges of the antenna beam, it is useful (but otherwise to be avoided) to map out to the antenna first null, i.e. choose the smallest $M = 2^n$ greater than $3.6'\lambda_{cm}$. One chooses large sizes of M only when forced to do so because: (1) the computation time is made longer; (2) disk space for map storage is often limited; and (3) it is more difficult to display and analyze larger images.

b. W(u,v): Weighting Function Parameters

The weighting options implemented in most VLA image-making programs are a simple choice between UNIFORM and so-called NATURAL weighting. With uniform weighting the visibility associated with each grid point is assigned the same weight, irrespective of whether one or hundreds of visibility measurements are effectively represented by a particular grid point; whereas with natural weighting each grid point is assigned a weight proportional to the number of visibility measurements "averaged" together to determine the appropriate visibility. In general, one uses natural weighting only in experiments where one wishes to maximize the signal to noise for detection of weak sources. For mapping of extended sources it is best to choose uniform weighting and use the tapering function to assign relative weights to the inner vs. outer parts of the u-v plane. Natural weighting is formally equivalent to a taper determined by the distribution of measurements in the u-v plane.

c. T(u,v): Tapering or Grading Parameters

The most fundamentally difficult problem in aperture synthesis, because there is no unique answer, is that of choosing the relative weighting of various parts of the u-v plane. The most commonly used tapering function used to change the relative weight of different parts of the u-v plane is the gaussian tapering function,

$$T(u,v) = \pi[\Theta_{taper}/2(\ln 2)^{\frac{1}{2}}]^2 \exp[-(\pi/(\Theta_{taper}2(\ln 2)^{\frac{1}{2}}))^2(u^2 + v^2)] \qquad (7\text{-}26)$$

where Θ_{taper} is the single parameter of the tapering function. If one chooses Θ_{taper} greater than Θ_{HPBW} (L_{taper} less than L_{max}), this corresponds to reducing the aperture being synthesized, with the rough rule of thumb

$$\Theta_{HPBW}(\text{arc sec}) = 2\ \lambda_{cm}/L_{taper}(\text{km}) \quad . \qquad (7\text{-}27)$$

d. C(u,v): Convolution Parameters

The choice of convolution function is basically a prescription of the method by which the visibility measurements near grid points are weighted in the averaging process used to obtain a single complex visibility for each grid point. The simplest, but usually undesirable, convolution function is the so-called "box" convolution in which all visibilities within half a cell of a grid point are simply averaged, without weighting, and if there are no measurements within half a cell of a grid point, a visibility of zero is assigned. Much more effective are functions of the following type: gaussian or exponential times sinc (the best). Each convolution function has a single parameter that describes the range (usually in cells) of data to be used in the weighted averaging process. The main differences between convolution functions are in the degree to which aliased images (from sources outside the area of the computed image) are reduced in intensity in the computed image so they do not interfere with real sources of interest.

F. Cleaning Maps: Sidelobe Correction

The synthesized beam for aperture synthesis maps always contains sidelobes that range from ±1-2% up to larger values when less u-v coverage is obtained. Unless one can properly remove the effects of these sidelobes, sources at the few per cent level would be highly effected by the sidelobes from stronger sources. The process of sidelobe removal is called "cleaning". The clean algorithm (Hogbom, J.A., Astron. Ap. Suppl., 15, 417, 1974) assumes that the real sources in a radio image can be represented by the summed effects of m point sources. This assumption, its limitations, and its mathematical justification are discussed by Schwarz (Astron. Ap., 65, 345, 1978). One begins the cleaning process with a so-called "dirty" map determined from

$$I_{dirty}(x,y) = \overline{III\ [C*(V_{obs}\ W\ T)]} \qquad (7\text{-}28)$$

and a so-called "dirty" beam computed from

$$I_{beam}(x,y) = \overline{III\ [C*(W\ T)]} \quad . \qquad (7\text{-}28)$$

where the same mapping parameters are used in constructing the dirty map and dirty beam images. The cleaning process proceeds in two major stages. In the first stage one subtracts, starting with the map maximum in the area to be cleaned, a series of $I_{beam}(x,y)$ arrays from the dirty map, resulting in a residual map with some point sources removed. This subtraction proceeds, always subtracting point source arrays with positions corresponding to the residual map extrema (positive or negative), and flux values that are some fraction, called the loop gain, of the actual extreme value in the current residual map. Depending upon the complexity of the map one may subract several tens to several thousands of point sources, called "clean components", before the process is stopped because the residual map is reduced to a pure noise map, or according to some other user-controlled criteria. In the second stage of obtaining a clean map, the point sources corresponding to the list of subtracted clean components (I_n, x_n, y_n, n = 1, ..., m) are added back into the last residual map using a point source or beam shape WITHOUT sidelobes - usually a truncated gaussian obtained by a fit to the central part of the dirty beam. The resulting map is the clean map with sidelobe effects removed as well as possible. The dirty map is

$$I_{dirty}(x,y) = \sum_{n=1}^{m} I_n(x_n,y_n) \cdot I_{beam}(x,y) + I_{residual}(x,y) \qquad (7\text{-}29)$$

and the clean map is represented by

$$I_{clean}(x,y) = \sum_{n=1}^{m} I_n(x_n,y_n) \cdot I_{gaussian}(x,y) + I_{residual}(x,y) \ . \qquad (7\text{-}30)$$

Maps with poor signal to noise cannot be successfully cleaned . A good cleaned map will have a residual map with peaks at the noise level. In other cases, the residual map reflects instrumental problems represented by the residual effects of unknown errors described by what we have called the error function E(u,v). Those experienced in aperuture synthesis can often identify obvious patterns in the residual maps that indicate common instrumental or calibration problems (Hamaker, J.P., "Image Formation from Coherence Functions In Astronomy", ed. van Schooneveld, C., pp. 27-53, 1979). Many problems, including some of the phase effects of the earth's atmosphere, can be "calibrated out" using self-calibration techniques.

G. Self-calibration of Source Data

One of the best ways to understand the basic process called self-calibration, as it is used in VLA aperture synthesis, is to consider the "model" of a radio image that is implied in the list of clean components (point sources) obtained while cleaning a map. In cases where one can obtain a "good" model of the radio image from the clean components, one can solve for further amplitude and phase calibration parameters to further improve the dynamic range of VLA radio images. Using this model, one can compute model visibilities for each (u_{jk},v_{jk}) for which one has visibility observations, according to

$$V_{jk}(u_{jk},v_{jk};\mathrm{MODEL}) = \sum_{n=1}^{m} I_n \exp[-2\pi i(u_{jk}x_n + v_{jk}y_n)] \quad , \qquad (7\text{-}30)$$

which, if the model is good enough, is a good approximation to the true visibilities. Clearly one can then calculate the residual error function using

$$E_{jk}(u_{jk},v_{jk}) = V_{jk}(u_{jk},v_{jk};\mathrm{OBS})/V_{jk}(u_{jk},v_{jk};\mathrm{MODEL}) = A_{jk}^{sc} \exp(i\phi_{jk}^{sc}). \quad (7\text{-}31)$$

The self-calibration process available to the VLA user is based upon solving for strictly antenna-based amplitude and phase errors. That is, analogous to the way initial calibration was achieved, one uses the N(N-1)/2 error function measurements from Equation (7-31), and the equation

$$E_{jk}(u_{jk},v_{jk}) = g_j\, \bar{g}_k \exp\,[i(\phi_j + \phi_k)] + \varepsilon_{jk} \qquad (7\text{-}32)$$

to solve for N amplitude and N-1 phase "calibration" errors (the phase for one reference antenna is left alone), assuming closure errors (ε_{jk}) are 0.

Evaluation of self-cal corrections often indicates previously un-diagnosed equipment problems, which are usually solved by flagging data as bad. Similarly, residual closure errors are an indication of problems, and can, for example, be an excellent means for detecting antenna cross-talk or interference. However, the amplitude and phase corrections found during the self-calibration process must be small. Once they are determined, one can apply them to the gain table and a cycle of improvement via self-cal is complete. The process of self-cal via mapping/cleaning/determination of $E_{jk}(u_{jk},v_{jk})$, as illustrated in Figure 7-1, is usually done for two or three iterations, and one of the major signs that it is working correctly is that the magnitude of amplitude corrections approaches unity and the magnitude of phase corrections approaches zero. This self-cal algorithm will not work if the signal to noise of the residual error function is too poor, or if the model is not good enough because the clean components do not represent all the flux of radio sources in the field, particularly when there is a great deal of flux in under-sampled broad structures.

H. Image Display

Beginning with the computation of the first dirty maps and beams, and continuing throughout the cleaning and self-cal process, image display is perhaps the most important aspect of image processing. Contour maps and display of color or black and white images upon TV screens are heavily used to analyze results. The image processing systems have varying degrees of capability in this area.

2. Off-line Data Processing Hardware

A. The DEC-10

The off-line data processing system in the VLA control building is a network of computers organized around a medium-size general purpose computer, a Digital Equipment Corporation DEC-10, and a number of (DEC) PDP-11-based minicomputer systems. The DEC-10 is used both for running data processing programs and for initiating processing in other computer systems in the network. Data transfer amongst components of the network occur via an invisible network communications system called DECNET. In most cases the user will not need to be aware that much of the processing that they initiate is accomplished in other computer systems besides the DEC-10.

Figure 7-2 is a diagram of the relationship between the on-line computer system which is the source of data, the DEC-10, and the other principal components of the network which are PDP-11-based systems called SORTER/GRIDDER, MAPPER, and DISPLAY. Also shown in Figure 7-2 are the various ways in which data passes between systems, including the connections involving magnetic tapes whereby data are transferred to and from other computer systems, including the Astronomical Image Processing System (AIPS)

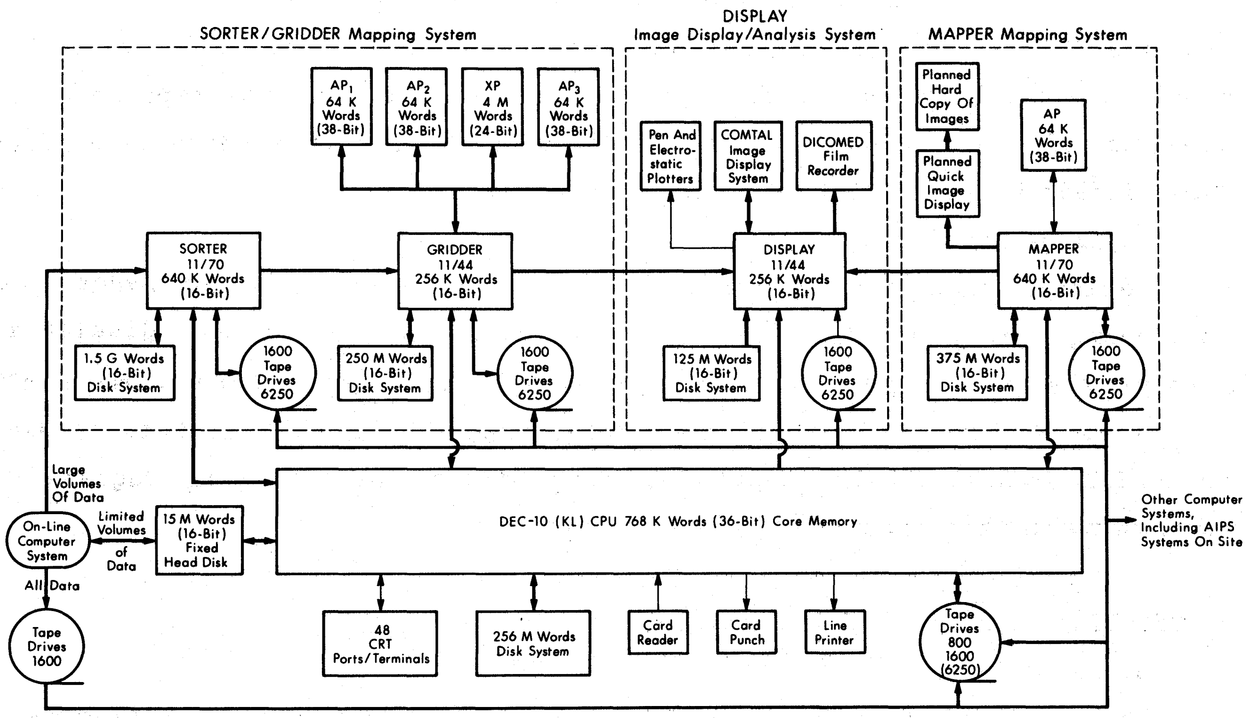

Figure 7-2. A schematic diagram showing the major relationships between the on-line computer system and other computer systems, particularly the DEC-10 and the network components called SORTER/GRIDDER, MAPPER, and DISPLAY.

Figure 7-3. Photographs of some of the hardware of the off-line computer system in the computer room of the VLA control building: (a) DEC-10 tape drives, printer, card reader, and (on right) DISPLAY film recorder; (b) DEC-10 CPU, memory, and disks; and (c) part of SORTER/GRIDDER mapping system.

computers. Figure 7-3 shows pictures of some of the major components of the DEC-10, DISPLAY, and SORTER/GRIDDER hardware.

The DEC-10 is equiped with 768 K words of 36-bit core memory, several tape drives capabable of multiple density operation, several disk systems with 256 M word capacity, CRT terminals for both graphics and text, a 600 lines per minute upper/lower case line printer, and card I/O devices.

Data are passed on by the on-line computer system in one of three ways. All data are written on magnetic tape in the on-line system; therefore it can be read into the DEC-10 using the tape drives. These data can also be processed in other computer systems capable of handling visibility data processing starting with the format written by the MODCOMPS of the on-line system. The principal data path for large volumes of data, particularly spectral line data, is directly from the on-line system through the SORTER/GRIDDER system and then on to magnetic tape; under this system the DEC-10 processes calibrator data written in nearly real time on the fixed head disk, with results passed to the SORTER/GRIDDER system to be applied to the source data before sorting, gridding, mapping, and storage on tape. In addition to calibrator data, limited amounts of source data can be written on a fixed head disk, and programs in the DEC-10 can run in real time transferring these data to DEC-10 disks in appropriate data base formats. Except when most of the source data is routed directly from the on-line system to the SORTER/GRIDDER mapping system, this is the normal data path for all continuum and limited amounts of spectral line data.

The DEC-10 is a time-sharing computer which can run a large number of jobs in either batch or interactive (via terminals) mode. The DEC-10 terminals available to the user are scattered around various rooms and offices in the VLA control building and the Scientific Library/Office building. From the refresh or Tektronix 4012 (or equivalent) terminals connected to the DEC-10 one can: run DEC-10 and network programs interactively; edit text files stored on disk in the DEC-10; prepare DEC-10 batch control files; submit data processing jobs to be run in batch mode; obtain job, system, and file storage information; and communicate with other PDP-11-based systems in the network.

B. The DISPLAY System

The DISPLAY system is a PDP-11-based computer system used for initial image display and analysis. Images can be transferred to (and from)

DISPLAY from other computers in the network linked by DECNET, or by magnetic tape using the FITS (Flexible Image Transport System) format.

The hardware and software in the DISPLAY system are discussed in more detail in Chapter 10. DISPLAY is based upon a PDP11/40 minicomputer (to be up-graded to an 11/44) and a number of display devices. It has a COMTAL image display system consisting of a black and white TV monitor with 256 possible brightness levels and a color monitor with 64 possilble colors. Both monitors are basically TV screens with 256 X 256 picture elements or pixels, a nondestructive cursor, and 1-bit overlay capabilities. The controlling PDP 11 has 256 K words (16-bit) of memory with a 125 M word disk system. In addition to the COMTAL system, with its own memory for image storage and function memory for dynamically changing the mapping of image point values into pixel values, the PDP 11 contains a DEC VT-11 refresh line drawing CRT with 1024 X 1024 resolution, eight brightness levels, and upper/lower case characters. Communication with this system is achieved by a combination of a keyboard and a data tablet, for control of cursors on the VT-11 and COMTAL screens, and for other forms of data input. DISPLAY can make contour maps (and crude gray scale images) on a VERSATEC printer-plotter (shared with the DEC-10). It is also connected to a ZETA pen-plotter used to make contour maps, including ones of publication quality when red ink pens (rather than the standard ball-point) are used.

Finally, the DISPLAY system can record images in black and white or color on a DICOMED film recorder. The standard film format for this system is 35 mm color; however, one can record images in either 35 mm or 4 in. by 5 in. format (including Polaroid) with either color or black and white.

Most of the operation of the DISPLAY system is controlled via a menu-oriented program called IMPS (Interactive Map Processing System). The DISPLAY system hardware and software is described further in Chapter 10 and in the Observers Reference Manual.

C. The MAPPER Map-making System

The component of the network shown in Figure 7-2 called MAPPER is a minicomputer-based system dedicated to making VLA maps, cleaning VLA maps, and carrying out self-calibration on VLA data used for map-making. This system is based upon a PDP 11/70 with 768 K words (16-bit) of memory, a 375 M word disk system, and tape drives. The 11/70 communicates with a Floating Point Systems 120B array processor which is dedicated to making computations for the mapping, cleaning, and self-cal programs running in the 11/70.

Visibility data are supplied to MAPPER by either the DEC-10 or the SORTER/GRIDDER system. Images computed in MAPPER can be transferred to other computers by either the network or magnetic tape using the FITS format.

The mapping, cleaning, and self-cal programs run in the MAPPER system are not directly executed by the user. The user runs programs in the DEC-10 that specify the parameters of mapping, cleaning, and self-cal jobs. These jobs intitiate the transfer of data between systems (when needed) and arrange for batch-like execution in the MAPPER system. The user can obtain information about the status of jobs in MAPPER by running programs in the DEC-10. The user also runs the FITS and other programs used to transfer maps between systems.

D. The SORTER/GRIDDER Map-making System

The SORTER/GRIDDER system, sometimes called the "pipeline", will be predominantly a development system during 1982-83. During this period the user will have some capabilities to do MAPPER-like tasks in this system, and the SORTER/GRIDDER system can be thought of as a more powerful MAPPER system. The communications software for SORTER/GRIDDER will be the same as for MAPPER, hence the user can ignore the differences between the systems.

The SORTER/GRIDDER system will develop unique capabilities in the period 1982-83. It will eventually be able to use calibration data form the DEC-10 to provide calibration for sources in SORTER/GRIDDER. Flagging capabilities for data in this system will be developed. In addition, a powerful image display system will be directly connected to SORTER/GRIDDER to give immediate data display capabilities. As this is being written it is not clear whether this will appear in the system as a more powerful DISPLAY system, or whether there will be another display-oriented system accessing data in the SORTER/GRIDDER system.

E. AIPS (Astronomical Image Processing System)

As discussed in the VLA-oriented Chapter 11, AIPS is a software system for images processing implemented on VAX 11/780 minicomputers at the VLA site, and on both a VAX and a MODCOMP CLASSIC in Charlottesville. All systems are equipped with array processors and 1024 X 1024 B/W or color display systems. When only image computation and processing (including self-calibration) are needed, the VAX-based Astronomical Image Processing Systems (AIPS) at the VLA site (or in Charlottesville) can be used.

3. DEC-10 System Software

A. Logging on and off the DEC-10

Most of the early stages of VLA data reduction are carried out by the user with programs running in the DEC-10 at the VLA site. This includes the initial preparation of VLA observing programs with the OBSERV program, data display programs, editing programs, calibration programs, programs that can carry out mapping, map cleaning, map self-calibration, map display, and programs that transfer data between systems. All of these require that the user be able to use a sub-set of the capabilities of the DEC-10 and its software, both for the software supported by DEC and the software produced and maintained by NRAO.

The DEC-10 is a time sharing system that requires that the user log on a terminal. You must have an assigned user (programmer) number, which we will refer to as PN, and a password, both of which are assigned to users the first time they arrive at the VLA site. One logs into an assigned [13,PN] area to run programs, many of which deal with visibility data bases and map data bases stored in a [14,PN] disk area.

The login process starts with a free DEC-10 terminal. Once the terminal is powered on, hit the RETURN key once or twice. If the display screen responds with periods (.) on the left side of the screen, you are communicating with the DEC-10 operating system and you may be ready to log in. Any other response may mean some user has left the terminal in an odd state, or in the case of no resonse at all, the DEC-10 may be down. Look around for a nearby user who has temporarily left his terminal; once you are sure that you won't be unfairly taking someone elses terminal, hit hold down the CONTROL or CNTL key and then type "c" a couple of times. This should kill any program left running, and may get you the proper period prompts of the operating system. If not, seek help. You log in by typing

login 13,PN

followed by a carriage return (CR or NEW LINE), and if the computer recognizes this, it types

Password:

after which you type your password without any errors, followed by a carriage return (CR) or NEW LINE. An erroneous password will result in a complaint from the computer and a # prompt symbol, indicating that you should type 13,PN (followed by CR), and once again you will be asked for your password. Sometimes the computer will complain about your attempt to log in, requesting that you log off first. This means someone left the terminal while still logged on. After a reasonable attempt to find the miscreant in the neighborhood, type a couple more CNTRL/C's, and then type

k

followed by a CR or NEW LINE, to log the miscreant off.

As just noted, a line of instructions or commands sent to the computer via a terminal is always terminated by a carriage return which corresponds to the CR or NEW LINE key, depending on the terminal. From now on all underlined text, that is part of a computer dialogue, will be assumed to be terminated by a carriage return.

Once the DEC-10 has recoginzed your 13,PN number and password, it will give you some logging on information, plus any notices intended for users of the computer. A program called FERRET runs automatically, though you will not know it until and unless it chides you about certain disk files in your area. After this, the period prompt symbol of the DEC-10 operating system should appear. This always means the computer is ready to accept operating system commands, including those to run programs.

At the end of a session using a terminal, it is essential to log off the terminal and computer, leaving it for another user. This is accomplished, as mentioned above, by typing the operating system command k (for KJOB).

B. THE DEC-10 File System

Many different things that the user will deal with in the DEC-10 are stored in files on disk: data files, batch control files, saved parameter files, temporary files produced by the data reduction programs, visibility and map data base files, etc. All disk files have a name of at least one character, but not more than six characters. Disk files may, and usually do, have an extension of at least one, but not more than three characters. File names and extensions MUST be written together with a period between them if there is any extension at all. All disk files also have a project and a user (programmer) number associated with them, always in the form [P,PN]. Thus a generic file specification is:

name.ext[P,PN]

although the user who has logged into, say, the [13,PN] area can use the option of referring to files in this area without explicitly supplying the

[13,PN] information. However, to refer to files in other areas, such as the [14,PN] area, where your visibility and map data base files are stored, the file specification must always include the [P,PN] area. At the VLA site P = 13 is for areas where users carry out data reduction, P = 14 is where users store visibility and map data base files, P = 11 is where programming development takes place, P = 21 is for areas where a programmer has stored a finished program that has not been officially included in the "system" areas, and other numbers have internal uses.

Files can also have prefixes that always have the format PREFIX:. In the previous paragraphs there was an implied prefix of" DSK:", meaning a generic disk. The prefix LPT: is used in a file specification whenever the file is to be (sometimes automatically) printed out on the line printer. Other prefixes like TEK:, ADDS:, etc. refer to particular terminals (Tektronix and ADDS), while TTY: refers to a generic terminal. Finally, files stored in [14,PN] areas have prefixes like DSKF:, DSKG:, and DSKH:. The array operators put newly created (by observing) visibility data base files in DSKG: areas. With this exception, visitors data base areas are on DSKF:, and VLA staff data base areas are on DSKH:. The prefixes DSKB:, DSKC:, DSKD:, DSKE;, DSKF:, DSKH:, and DSKG: are housekeeping names for storage areas on specific disks or combinations of disks. Normally the user need not pay any attention to the names of the disks on which his [13,PN] and [14,PN] files are stored.

C. Operating System Commands

There are a number of DEC-10 operating system commands that can be executed if the computer is providing you with a period prompt symbol. These commands run data reduction programs, manipulate disk files, provide information about files, or provide information about the status of various jobs, queues, or other parts of the DEC-10 system. The Table 7-1 is a brief summary of the more important ones the user may have some occasion to need.

The use of the TYPE command, or anything that results in listings of material on the terminal which are more than can fit on a screen, requires the user to develop a CNTL/S and CNTL/Q capability. Most users [13,PN] areas will be set up so that when a screen is full, the terminal will beep and pause in the listing of text; to resume the listing the user must type CNTL/Q. If a user wishes to operate the terminal such that output pauses only when the user types a CNTL/S, then type the operating system command
page 0 ; and it will not pause at every full screen.

Table 7-1

List of DEC-10 Utility Programs and Monitor Commands

Command	Short Form and Syntax	Purpose
login	log [13,PN]	Log on DEC-10 in your area
	Password	and supply Password when prompted
kjob	k	Log off DEC-10 when finished
directory	dir	List all files/sizes in your [13,PN]
area		
	dir [P,PN]	List all files/sizes in [P,PN] area
	dir/f	Fast list of only file names
	dir/l [P,PN]	Output directory of [P,PN] on printer
delete	del name.ext	Delete name.ext from disk
	del junk.*	Delete all files with name junk
	del *.txt	Delete all files with extension txt
	del ?am?.?xt	Delete files with the letters am and xt in names and extension, but with any char. before & after am, and before xt
type	ty name.ext	Type file named name.ext on terminal
	ty junk.txt[P,PN]	Type junk.txt[P,PN] on terminal
print	pri name.ext	Print name.ext on DEC-10 line printer
	pri	List jobs in current print queue
systat	sy	List all system info. on terminal
	sy f	List available disk space
	sy b	List busy devices like tape drives
	sy s	List what jobs are running (all JOBNUMs)
	sy JOBNUM	List status of job number JOBNUM
	sy .	List status of job on this terminal
who	who	List logged in users by name
queue	que	List jobs in PRINT and SUBMIT queues
help	help	List info. on what HELPs are available
	help SUBJECT	List help info. for particular subject
initia	init	Initialize terminal (get out of problem)
submit	sub batch	Submit batch.ctl for batch execution
	sub batch.job	Submit batch.job to batch queue
	sub	List current batch queue
	sub batjob=/kill	Kill batjob.* in batch queue

Table 7-1 (continued)

Command	Short Form and Syntax	Purpose
do	do batch.job	Execute batch.job on terminal
copy	f2.ext[P1,PN1]pf1.ext[P,PN]	Copy f1.ext[P,PN] into f2.ext[P1,PN1]
rename	new.ext[P,PN]pold.ext[P,PN]	Rename old.ext in [P,PN] to new.ext
r	r XXXXXX	Execute system program named XXXXXX
run	run YYYYYY	Execute program YYYYYY in your area
send	send TTYn:message	Send message to terminal (TTY) number n
set time	set time n	Sets maximum CPU time of n seconds/job
set tty	set tty parameters	Set terminal parameters, see DEC-10 doc.
mount	mount mta:name/reelid:x	Mount tape with reel id. of x
	mount mta:tap/reelid:x/wen	Mount tape setting WENABLE switch to write
unload	unl mta:	Rewind and unload previously mounted tape
deassign	deass mta:	Deassign previously mounted tape (opposite of mount)
continue	cont	Continue execution of program CNTL C'd twice
control c		Interrupt executing program Tow CNTL C's kill executing program
control h		Backspace 1 char., like DEL, RUB, BKSP keys
control o		Suppress current terminal output (a second control o resumes terminal output, some output lost)
control s		Suspend terminal output
control q		Resume terminal output previous CNTL q'd
control r		Re-type current input line
control u		Delete current input line
control w		Delete last word typed
control t		Type status info about current terminal job
control [		ESCAPE key, used in text editor (SOS)

D. Running Programs on the DEC-10

The general way of running a program that is part of either the DEC or the VLA software system is to type, after the usual period prompt:

r PROGRAMNAME

where PROGRAMNAME is the program name, which is always 6 characters or less. Examples from the VLA data reduction system are

r lister

r FLAGER

R visplt

where either upper or lower case may be used.

In general, the result of typing something like "r pname" is that the program will introduce itself and then give you an a prompt symbol, which is almost always an asterisk (*). At this point the user can type command lines in the syntax appropriate to the particular program. In the case of most VLA data reduction programs, simply typing HELP in response to the program prompt will result in a display of information about the commands available in the program.

If the user runs programs he has compiled and loaded in his own area ([13,PN]), these programs can be run by typing

run PNAME

while logged into the [13,PN] area. The user can run programs located in any other area by typing

run PNAME[P,PN]

where [P,PN] is the disk area for the program.

E. Editing Text Files - the SOS Program

The user must know how to prepare and edit text files in the DEC-10 for two principle reasons: (1) it is one of the best ways to prepare source information cards for use in the OBSERV program which is used to make observing source lists; and (2) text files used as batch control jobs provide an efficient way to carry out many of the VLA data reduction steps.

The text editor is a program called SOS (for Son Of Stopgap, a text editor written by the Stanford Artificial Intelligence Laboratory) which is supported by DEC for DEC-10's. There are many ways to run SOS, e.g.

r sos

or

sos

will result in the computer prompting you with

File:
if you have not been previously editing a file during the same LOGIN session, in which case you then type the NAME.EXT for the file you wish to create. If you were previously editing a file named OLDFIL.EXT,
Edit: oldfil.ext
*
will appear on the screen. In the first case (creating a new file), after you supply the name of the new file, SOS immediately puts you in "typing" or "line writing" mode with line numbers as "prompt" symbols. Whenever SOS provides line numbers rather than asterisks as prompt symbols, you can type in lines of text just like on a typewriter. When in typing mode, hitting a CR or NEW LINE key results in the termination of one line and the start of another with a different line number. You exit from typing mode, to get to SOS command level, by hitting the ESC key (or CNTL/[on ADDS terminals).

A more general way to invoke SOS is to type
<u>sos name.ext[P,PN]</u>
where you directly supply name, extension, and (optional) area specification. If the file has not previously been created in that area, SOS will immediately put you in line writing mode with line numbers as prompt symbols; if the file has previously been created, SOS immediately puts you at SOS command level with an asterisk prompt symbol.

At SOS command level there are a series of commands available. Some of the major commands that will be most useful to the user are summarized in Table 7-1.

The default increment for line numbers in typing mode in SOS is 100, and text lines then have number listed as 100, 200, 300, etc. An insert command will result in in-between line numbers. Line insertion in typing mode terminates either when the user types ESC (or CNTL/[), or when lines will not fit in or are out of order; to continue you either insert with a smaller line increment, or you renumber with the n command before using the insert command.

The following is an example of creating and submitting a batch control file that did not exist before, an activity that the user will need to carry out frequently (from now on comments that are not part of the computer dialogue will appear to the right of semi-colons):

Table 7-2

DEC-10 Text Editor (SOS) Commands

Name	Symbol	Syntax	Purpose of Command
print	P	p	Type current line and next 15 lines
		pn	Type line number n
		p.	Type current line (where pointer is)
		pn:m	Type lines n through m
		pn:m,s	Type lines n through m stripping line #
		p/.	Type all lines on current page
		p↑:*	Type all lines from first to last
help	H	h	Type detailed syntax info. on screen
insert	I	in	Insert lines after line number n
		in,s	Insert lines after n with increment s
number	N	n	Re-number all lines with old increment
		n,s	Re-number all lines with new increment s
delete	D	dn	Delete line n
		dn:m	Delete lines n through m
replace	R	rn	Replace line number n with a new line
		rn:m	Replace lines n through m with new lines
lineprinter	L	l	Print SOS file out on printer after exit
		l,s	Same as above, but without line numbers
exit	E	e	Exit from SOS, back to monitor level, storing file on disk (backed up)
		eq	Exit from SOS, no change in file on disk
		eb	Exit from SOS saving on disk, no back up
		es	Exit from SOS, saving without line no. but backed up on disk
worldsave	W	w	Save text file on disk in current form
transfer	T	tm,n1:n2	Transfer lines n1 thru n2 after line m
copy	C	cm,n1:n2	Copy lines n1 thru n2 after line m
substitute	S	sOLDNEWn:m	Substitute NEW string for OLD string wherever it occurs in lines n thru m ($ = ESCAPE = CONTROL [ )
join	J	jn	Join line n and the next line on line n
extend	X	xn	Start adding text to end of line n
alter	A	an	ALTER mode (inter-line edit)for line n To see ALTER mode syntax type H in SOS

```
.sos list.ctl                           ; run sos to create LIST.ctl
Input: LIST.CTL                         ; initial computer response
00100  r lister                         ; type first line to run LISTER
00200  dbname 1apr29[14,11]             ; supply visibility data base name
00300  band 6cm                         ; specify only 6cm data to be listed
00400  antennas * - 12 26               ; for all antennas but 12 and 26
00500  list scan amp/jy                 ; list amplitudes/flux densities
00600  average scan vector              ; vector average entire scans
00700  outfile lpt:1apr29               ; get labeled line printer output
00800  go matrix                        ; execute matrix form of listing
00900  finish                           ; exit from LISTER
01000  ESC                              ; get out of SOS typing mode
*e                                      ; exit from SOS
[DSK:LIST.CTL[13,11]]                   ; computer response as it exits
EXIT                                    ; from SOS after putting newly
                                        ; created text file on disk

.submit list.ctl                        ; Submit to batch queue
```

In the above example, all commands typed in from "r lister" to "e" are written into the text file LIST.CTL. They are not executed until submitted as a batch job, and the command "submit list" does the submission to the batch stream. The LISTER commands will be discussed in Chapter 8. This is a realistic example of creating a file for the first time using SOS, and then submitting it to be executed in batch. The extension CTL is the standard extension used for batch control files; other extensions may be used, in which case they must be included as part of the file specification during submission to batch.

If we wanted to substitute AMPSCALAR for vector averaging, add a specification of the sources to be listed, and execute this job directly on the terminal, the full computer dialogue could be

```
.sos list.ctl
Edit: LIST.CTL
*svector$ampscalar$600                  ; use substitute command ($ = ESC)
00600  average scan ampscala            ; SOS types the changed line
*i300                                   ; insert after line 300
00350  sources 3c286 1923+210           ; specify listing for two sources
*e                                      ; exit from SOS
```

.do list.ctl ; execute batch file on terminal now

with the result that a complete example of the terminal dialogue will appear on the screen as the batch file is executed, and this time a listing for only the two specified sources will come out on the line printer.

For jobs submitted in batch, the complete computer dialogue is placed into a so-called LOG file. In the previos example, a file named LIST.LOG will be written in disk area [13,11]. This file can be TYPEd, PRINTed, or even SOSed.

There are many more SOS commands, and powerful capabilities for intra-line editing; however, to avoid confusing the user with all the possibilities, we will not discuss them. For more details the user is refered to an SOS manual.

One can look at a file without trying to edit it by typing the following:

sos list.log/r

after which you will get the prompt "Read: LIST.LOG", and you can use the print commands in SOS to look at the contents of the file.

F. Batch Execution of Programs

We have now discussed how to run programs and how to use the text editor. We used an example of preparation of a batch file that could be executed either in batch with a SUBMIT command or interactively on a terminal with a DO command. Let us now discuss further aspects of doing data reduction with batch control files.

Once a batch control file has been prepared with SOS, the general syntax for submission to the batch queue is:

submit filnam.ext/time:hhmmss/after:+hh:mm:ss

where we have given the full syntax for two useful "switches" that specify special things about the batch job. Without the time specification, a batch job is run with a time limit of 5 minutes. The optional AFTER switch can be used to start batch execution at a specified time after the batch job is submitted; thus you can submit long jobs for delayed execution at night.

The execution of every batch job results in the production of a LOG fo statements exectuted in the job, which looks identical to what you would see on the screen if the same commands were executed interactively one by one, or with a DO command. The log file name is always the same as the batch file name, but has the extension LOG.

Before or after a batch job is submitted, the user will frequently want to examine the status of the batch queue, which can have any number of jobs, but with only three or so running in different batch streams. By typing su/f one obtains a display of the batch queue status on the terminal.

G. Handling Magnetic Tapes

Under most circumstances the users must handle their own tapes while running jobs requiring magnetic tapes. The typical user will do this for four major reasons: (1) creating data bases from MODCOMP archive tapes using the FILLER program; (2) backing up disk files (including data bases and maps) on tape using the DEC system program BACKUP (or the restoration of disk files from tape with BACKUP); (3) preparing an export tape with visibility data using the EXPVIS program, as is necessary to get visibility data into the AIPS systems; and (4) transferring image files from disk to tape and vice versa using the FITS (Flexible Image Transport System) program.

Whether the purpose is to read or write on a magnetic tape, the first step is to mount the tape. To accomplish this, the user is logged into his [13,PN] area at the operating system level, and after the usual period prompt, he can type the mount request

mount mta:name/reelid:Vnnnn

if tape number Vnnnn is to be read only, or

mount mta:name/reelid:Vnnnn/wenable

if the tape is to be written upon. The designation mta: means any of the tape drives used on the DEC-10, Vnnnn is the tape reel ID number, and "name" is a logical name specification used in some programs.

Once the request for a tape mount is typed, the user proceeds to the secondary console (DECWRITER) near the DEC-10 tape drives in the computer room, where one normally sees a typed out request for a mount of tape Vnnnn on unit m(n), where n = 0, 1, 2, 3, etc. identifies a particular tape drive. One then mounts the tape on the specified tape drive (or another free tape drive), after checking the status of the write-ring to make sure that it is removed if you only want to read the tape, and inserted if you want to write on the tape.

When you approach the tape drive, with the correct number on the middle left of the drive, the door will normally be closed, so you open the door, and then note that the tape real lock is disengaged as indicated by red being visible on the lock in the middle of the reel. Place the tape on the reel with the protrubances on the tape reel matching the slots on the tape drive, and when seated firmly, press in the lock at the center of the reel to fix the tape reel onto the drive. Then close the door, press the LOAD button on the middle of the drive, and the tape should load automatically. If it does not, try once more, and if that fails seek help. Normally the tape will auto-load, and when the BOT (beginning of tape) light comes on, you press the on-line button and go to the secondary console to type

m-n

where n is the tape drive number on which the tape has been mounted. The computer should acknowledge with a "Done", after which you can return to your terminal to run the job needing the tape.

Sometimes you will need to skip some files on the tape to get at the file you are interested in. To skip n files, you type

skip mta:n files

and when you get the period prompt again, you are ready to go with FILLER, BACKUP, etc. For the MODCOMP archive tapes, the m-th "file" requres a skip given by n = 2m - 1. For BACKUP you skip n files to get at the (n-1)-th SAVEd set on tape. You need not skip 0 files.

Rewinds to get back to the beginning of a tape are made by typing

rewind mta:

after which you can skip files, run programs, etc. again. After you are finished using a tape, you can

rewind mta: ; to rewind the tape
unload mta: ; to initiate unloading of the tape, and
deassign mta: - ; to free the tape drive for other use,

after which the tape drive will rewind and unload itself. You then go to the tape drive, disengage the tape reel lock, remove the tape, and put it in the tape storage room just off the computer room.

Tapes are check out from a supply near the door of the tape storage room. You pick a tape from the rack area indicating available tapes, fill out a form in the notebook (every free tape has a form in the section labeled "free tapes") and then place the form at the front of the notebook. Labels are nearby for placing written information on the tape reel. Every tape has a Vnnnn number, and a storage place indicated by the same number.

4. The Standard Data Base Files for Visibility, Monitor, and Map Data

A. Introduction

Before discussing any of the programs that process data in the off-line computer system, it is useful to have some idea of how data associated with an observing run are organized. The on-line computer system provides data to the off-line system in two forms: on MODCOMP archival magnetic tapes containing visibility and monitor data; and on the fixed head disk where data are written in real time. For the latter, the FILLER program runs "continuously" in the DEC-10 during observing, so visibility data can be accessed in nearly real time in the DEC-10. The FILLER program also transfers visibility data from magnetic tape to data bases on disk in the DEC-10. Similarly, the MONFIL program can be used to get monitor data from tape to a monitor data base. The phrase "data base" is a name commonly used for data written in specific formats in one or more disk files.

There are three types of data bases that the user will deal with in the DEC-10: visibility data bases, monitor data bases, and map data bases.

a. Visibility Data Bases

As mentioned above, the FILLER program writes visibility data into a data base consisting of a number of files placed in the users [14,PN] area:

dbname.INX[14,PN]	which contains an index of information global to a each particular observing scan, but no visibility data;
dbname.VIS[14,PN]	which contains visibility data and flags; and
dbname.GAI[14,PN]	which contains a table of antenna-based complex gain calibration data (g's and D's),

where DBNAME is a file name of six or fewer characters that can be assigned by the user, but is usually in the form nMONdd, where n = subarray number (1, 2, or 3), MON corresponds to the first three letters of the month, and dd = the day (IAT) the observing run begins.

Additional files are later associated with a particular data base by the running of other programs. The program FILANT adds a file named dbname.ANT[14,PN] containing antenna position information. During the off-line calibration process a file named dbname.CAL[14,PN] is created every time the ANTSOL program is run to solve for antenna-based calibration parameters. In addition, successive executions of the standard data reduction programs results in additions to a TYPEable, PRINTable, and SOSable text history file named dbnam.HST[14,PN].

b. Monitor Data Bases

A program called MONFIL can take information from the monitor data tape produced in the on-line computer system while observing and make a monitor data base. This data base consists of two files (with extensions .IND and .MON) stored in a special disk area: [11,1]. Amongst the monitor data are the measured system temperatures which are used by the GTTSYS program to carry out off-line corrections for system temperature variations.

c. Map Data Bases

Radio maps made from edited, corrected, and calibrated data in a visibility data base are kept in single files on disk in the DEC-10. These maps can be generated with the DECMAP program, but are most often generated by the MAKMAP program that initiates map-making in the MAPPER and SORTER/GRIDDER mapping systems. All of these maps may be cleaned, self-calibrated, and kept (or transfered) on disk in the DEC-10 or on magnetic tape.

5. Summary of the Major Off-line Data Reduction Programs in the DEC-10

Before discussing the details of the standard command system and the standard data reduction programs, let us summarize some of them and their purposes:

Proram Name	General Description of Purpose
FILLER	Takes visibility data from magnetic tape or fixed head disk and places the data in INX, VIS, and GAI data base files in [14,PN]
MONFIL	Takes monitor data from a monitor data tape an places it in IND and MON data base files in disk area [11,1].
MONLST	List data for monitor data points on terminal or line printer
MONPLT	Plots selected monitor data points on terminal or line printer
FILANT	Puts antenna station information in dbnam.ANT[14,PN] file
FLAGER	Modifies or lists flags in INX (antenna-based) or VIS (correlator-based) data base files
SETJY	Modifies or list flux density (Stokes parameter) information in dbname.INX[14,PN] file of a visibility data base
LISTER	List (on terminal or line printer) selected visibility amplitudes and/or phases (with optional rms)
VISPLT	Plots (on terminal or line printer) selected amplitudes and/or phases as a function of a number of independent variables

GTBCOR	Puts antenna-based corrections into gain table (.GAI file)
GTTSYS	Uses monitor data information about system temperatures to put amplitude correction factors into gain table (.GAI file)
ANTSOL	Uses selected calibrator visibility data to solve for antenna-based amplitude and phase calibration parameters which are then stored in a dbname.CAL[14,PN] file
GTBCAL	Applies selected calibration parameters in dbname.CAL[14,PN] to gain table (.GAI file)
DECMAP	Makes dirty radio maps and beams in the DEC-10 from selected visibility data in a data base, using the corrections and calibrations in the gain table
CLNMAP	Cleans (performs side-lobe subtraction) dirty maps, using dirty beams, with all computations done in the DEC-10
MAKMAP	This program accomplishes the same purpose as DECMAP, except the data are transfered to the MAPPER or SORTER/GRIDDER systems for map making. In 1982 this program also controls cleaning and self-cal done in these systems.
CLEAN	Program that (in later part of 1982) controls map cleaning done in MAPPER or SORTER/GRIDDER systems
SLFCAL	Program that (in later part of 1982) controls self-calibration done in the MAPPER or SORTER/GRIDDER systems.
CATLST	Used to obtain information about maps in network PDP 11 systems, can be used to transfer maps and clean component files between systems
DANEEL	Program inside of which any standard commands program can be run with parameter passing between programs, and prompts for each program that include the program name
BACKUP	A DEC-10 system program with its own commands and syntax that is used to back up or store data base and other files on magnetic tape, and then put them back on disk at a later time
AVGVIS	Creates one data base from another, with a longer averaging time, including only selected data
DBCON	Concatenates (or copies) selected data from one or two data bases into a third data base

Figure 7-4 is a schematic diagram showing most of the principle data reduction steps in VLA data processing, indicating which programs are used, where the data are stored, and when there is transfer of data between systems.

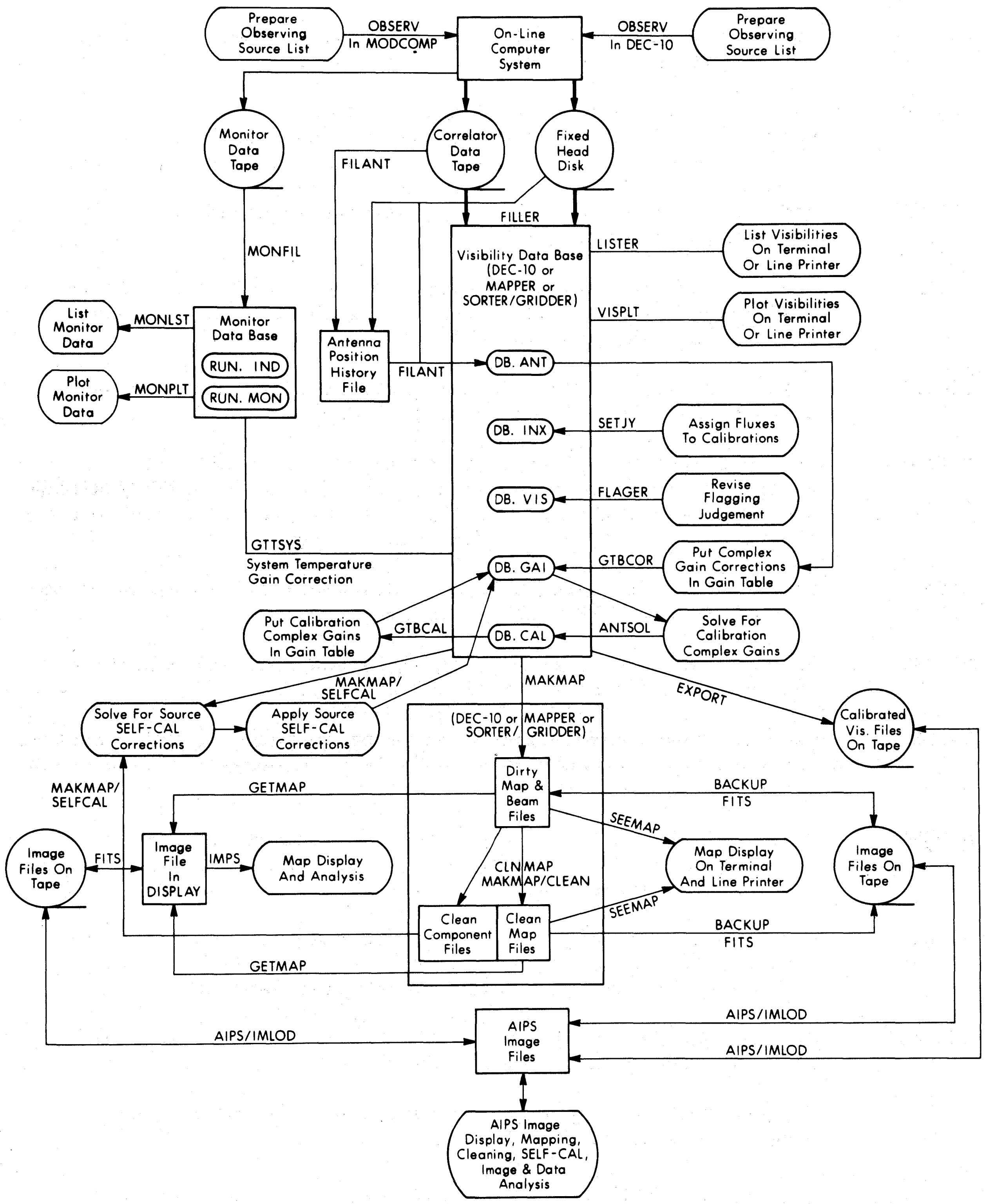

Figure 7-4. A schematic diagram of the VLA data reduction process.

6. Standard Program Syntax and Methodology

A. Introduction

Most of the programs that the user will use in carrying out off-line data reduction in the DEC-10, and some of the other network minicomputers, share common features both in commmands and syntax. All of the programs listed in the previous section, except for BACKUP, are of this type.

The syntax for standard commands is always

<command name> <optional command parameter(s)>

and all command names have so-called "minimum matching", that is, the minimum number of letters necessary to make a command name unique is all that needs to be typed. This saves a considerable amount of typing once one becomes familiar with the commands in a program.

With very few exceptions, all exection of specific tasks within a program are initiated by the special GO command, which has the syntax

GO <option>

where the option can be skipped if there is only one type of executable action in the program.

Most commands simply supply parameters that are not used for any purpose until a GO command is executed. In the case of parameter-type commands, the command name is the name of a parameter (or parameter list) and the list of parameters to be specified is supplied to the right of the command name.

Three major commands present in all programs serve to provide the user with information. These are the HELP, INPUTS, and EXPLAIN commands.
Typing HELP without an option parameter producing a listing of all the commands available in that program, together with some syntax and purpose information. Typing INPUTS without an option parameter produces a listing of all of the parameter-type commands and the current values of their parameters. Both HELP and INPUTS commands have options (listed at the beginning of each HELP output) which can be used to limit the display to a particular sub-set of parameters. Finally, the EXPLAIN command gives the user access to more detailed information about programs and miscellaneous subjects. Typing EXPLAIN without an option parameter results in a listing of information about the program being run. Typing any program name as an option for EXPLAIN will produce information about that program. The EXPLAIN files are a type of documentation intermediate between the HELP displays and the contents of the Observers Reference Manual.

A user with a reasonable knowledge of the available programs and their puproses can find out most of what is needed to run the programs from the HELP, INPUTS, and EXPLAIN displays.

b. Commmands Common to All Standard Commands Programs

The following is a summary of the standard commands that appear in all programs:

Command and Syntax	Purpose
help	Display summary information about all commands valid for the program being run
help <option>	Display summary information about a sub-set of commands of a particular type
inputs	Display all parameter-type commmands together with current values of their parameters
explain	Display more information on program being run
explain <option>	Display more information about either a program specified by name or a special topic for which an EXPLAIN file is available
savecommands	Save, in a file named <prog.name>.TMP[13,PN], a copy of all parameter-type commands and their current parameters
savecommands name.ext[13,PN]	Save, in a file named name.ext[13,PN], a copy of all the parameter-type commands and their current parameters
getcommands	Retrieve and execute all commands in the file named <prog.name>.TMP[13,PN]
getcommands name.ext[13,PN]	Retrieve and execute all commmands in the file named name.ext[13,PN]
setdefaults	Replace all parameters of parameter-type commands with defaults built into the program
finish	Finish or exit from the program
go <option>	Execute a specific option of the program, or the sole executable option of the program if no option need be specified
batch <option>	Submit this program to the batch queue with the current INPUTS parameters, with the same options as with the GO command
jobname <name.ext>	Name of batch job when submitted
jobtime hh:mm:ss	Time limit for batch job

The use of SAVECOMMANDS and GETCOMMANDS allows the user to save current values of all parameters on disk files for retrieval and execution at a later time. There is another very useful dimension of use for the GETCOMMANDS command. The files retrieved with this command are immediatedly executed in sequence. Therefore, since these files can be TYPEd, PRINTed, and SOSed, one can edit into a file any command or sequence of commands. In this way a complex sequence can be placed in a file, with GO commands at appropriate places, to accomplish something you want to prepare carefully or repeat a number of times.

With the DANEEL program, and the above-mentioned GETCOMMANDS for prepared text files, one can prepare multiple program commands in a text file, and execute these with a GET inside DANEEL.

c. Units of Command Parameters

Units of input parameters to commands can, and in some cases must, be supplied. Units are specified as suffices. The following are meaningful in the various standard commands programs:

Suffix	Description	Suffix	Description
e,E,@	power of ten indicator	d	degrees
mm	millimeter	'	arcminutes
cm	centimeter	"	arcseconds
m	meter	h	hours (angular)
km	kilometer	m	minutes (angular)
au	astronomical unit	s	seconds (angular)
pc	parsec	rad	radians
:::	time of day	turn	turns
hr	hours of time	Hz	Hertz
min	minutes of time	kHz	kilohertz
sec	seconds of time	MHz	megahertz
msec	milliseconds	GHz	gigahertz
usec	microseconds	Jy	Jansky
nsec	nanoseconds	mJy	milliJansky
psec	picoseconds	uJy	microJansky
K	degrees Kelvin	yd	year and day of year
C	degrees Centigrade	ymd	year-month-day

Time range specification will, in general, contain both dates and times. Dates can be specified in the format yyMONdd, where yy is the last two digits of the year, MON is the first three letters of the month, and dd is the day of the month. Time can be specified with one, two, or three colons. Thus for example, 78apr01 and 80JUN24 are valid dates, while 8:, 8:12, and 8:12:30 are valid expressions for the time.

d. Automatic Saving of INPUTS Parameters

All the standard commands programs save the INPUTS parameters that were in effect when FINISHing with the program. When the program is run again from the same terminal, it will derive its initial parameters from the previous INPUTS parameters. This is accomplished by an automatic SAVE of the INPUTS for a program in a file (with a name corresponding to the program name and an extension generated from the TTY number uniquely associate with a terminal). When the program is run again, there is automatic execution of a GETCOMMANDS command on this SAVEd INPUTS file. The user must be cautious about confusing parameters carried over from previous executions of a program and the default parameters for a program.

Chapter 8

VISIBILITY DATA PROCESSING

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June 1982 Edition

ABSTRACT

The main programs used to process visibility data in the DEC-10 in the VLA computer room are briefly summarized. This processing involves data display, editing, application of corrections, determination of antenna-based calibration parameters, and application of calibration parameters.

This Chapter assumes a familiarity with the general overview in Chapter 7. The methods of data reduction with these programs are treated in Chapter 13.

More detailed discussions of the visibility data processing programs can be found in the Observer's Reference Manual.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. DOCUMENTATION OF PROGRAMS USED FOR VISIBILITY DATA PROCESSING

The pages following section 2 of this chapter present brief documentation for some of the major programs in the DEC-10 off-line data reduction system. Section 2 summarizes the major uses of each program and the order in which they are generally used for visibility data reduction.

The programs are then presented in alphabetical order. The first two pages of the documentation for each program will usually be in the same format, with the program's INPUTS display on the first page and the program's HELP display on the second page. If either or both of these pages have extra space, it may be filled with additional discussion of the programs. Subsequent pages for each program will appear in odd-even pairs.

The basic idea for most of this chapter is that of a quick reference section where a brief summary of information about each program is presented. More detailed documentation for each program, including many programs not discussed in this Chapter, can be found in the Observer's Reference Manual (ORM).

The 2*n pages for individual programs in this Chapter can be independently updated in a manner similar to the approach towards the separate chapters in this Introduction.

2. Summary of Use of Each Visibility Data Reduction Program

DANEEL	A program that may be optionally used to run other programs. Use of DANEEL allows command parameters to be passed between programs.
FILLER	Used to place visibility data in DEC-10 disk data bases. Array operators use this program to fill data bases during observing. Users can re-fill data bases from MODCOMP tapes.
FILANT	Program used to create dbname.ANT[14,PN] file with antenna positions.
LISTER	Lists visibility data on terminal or line printer using a number of possible formats and levels of detail. Amplitudes and phases can be listed with or without the application of the gain table which contains calibration information.
VISPLT	Plot visibility amplitude and/or phase for selected data as a function of a large number of independent variables, with or without application of calibration in gain table.
DBCON	Take selected data from one or more data bases and put in a new data base.
AVGVIS	Take selected data from a data base and put in a new data base with a longer averaging time and less use of disk space.
FLAGER	Changes and/or lists the flags (judgements of data quality) associated with scans and/or data records in a visibility data base. Used to edit "bad" visibility data.
SETJY	Values of flux densities for sources are written into the dbaname.INX[14,PN] file. FIRST REQUIRED STEP in calibration of a visibility data base.

GTBCOR Apply miscellaneous corrections to, or reset, the gain table (dbname.GAI[14,PN]) containing antenna-based correction and calibration information. RESET should be used as the SECOND REQUIRED STEP to insure "empty" an gain table before calibration.

ANTSOL Solves for amplitude and phase calibration parameters for selected sources (calibrators), bands, antennas, etc., and places these parameters in dbname.CAL[14,PN] file. This is the THIRD REQUIRED STEP in visibility data reduction. Can also determine (BOOTSTRAP) calibrator fluxes from measurements of 3C286. Also used to list and/or plot contents of .CAL file.

GTBCAL Uses the ANTSOL results written in a dbname.CAL[14,PN] file to interpolate, into the gain table (dbname.GAI[14,PN]), the amplitude and/or phase calibration parameters for selected source data. The FOURTH REQUIRED STEP in visibility data reduction.

POLCAL Used to determine polarization calibration parameters, from data for a single calibrator source, which are written into special parameter files on disk in [13,PN] area. Requires only that: the polarization calibrator be previously calibrated with ANTSOL/GTBCAL; and observations be made at a sufficient number of parallactic angles. Polarization calibration parameters determined by POLCAL are applied to the gain table (dbname.GAI[14,PN]) using GTBCOR.

EXPREP Used to check visibility data in a data base in preparation for writing an EXPORT tape with EXPVIS. Will adjust gain codes to prevent overflows in EXPVIS when the gain table is applied to visibility data.

EXPVIS Used to write visibility data for selected sources and frequencies on magnetic tape in the EXPORT format. The corrections and calibrations in the gain table (dbname.GAI[14,PN]) are applied to the visibility data written on tape. The gain table information is NOT written on tape in any other form.

ANTSOL takes selected calibrator data from a data base (dbname[14,PN]), and solves for complex antenna gains. When ANTSOL is used to GO SOLVE, it can produce a table of complex gains as a function of time, which is stored in a file called dbname.CAL[14,PN]. When ANTSOL is used in the calibration process, the calibrators (at least 3C286) should have had correct flux densities inserted in the data base by the SETJY program. The GO LIST and GO PLOT capabilites of ANTSOL can be used to evaluate the gain solutions in dbname.CAL[14,PN].

```
ANTSOL INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . ANTSOL
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
visibilitytype. . CONTINUUM
sources . . . . . *:*
calcodes. . . . . CAL
antennas. . . . . *
refants . . . . . * (Physical IDs)
ifs . . . . . . . *
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . . UNFLAGGED
minamp. . . . . .      .0001
uvlimits. . . . . NONE
  (MISC) ===========
outfile . . . . . TTY:ANTSOL
listoptions . . . AMPLITUDE, PHASE
calibration . . . APPLY
average . . . . . SCAN VECTOR
closurelimit. . .  5.00%,5.00d
solveoption . . . CLEAR
amp/jy. . . . . . YES
resfile . . . . . NO
  (PLOT) ===========
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .   .000 TO 25.000 AMPLITUDE
```

Normally any corrections that would affect the calibrators should be applied (GTBCOR and/or GTTSYS) before solving for calibration parameters with ANTSOL. The dbname.CAL[14,PN] file produced by ANTSOL is then used, by the GTBCAL program, to apply the calibration to both calibrators and sources in the dbname.GAI[14,PN] file of the data base.

ANTSOL will work on either continuum or spectral line data bases. The type of data should be specified with the VISIBILITYTYPE command. With the SOLVEOPTION command and the TRIAL option one can solve for calibration parameters without replacing the .CAL file. The .CAL file can be deleted before solution with the CLEAR command. With EXTEND and UPDATE SOLVEOPTIONs one can add to or replace solutions in an existing dbname.CAL[14,PN] file.

ANTSOL

```
ANTSOL COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT

setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go SOLVE                                  Do solution for antenna gains.
go LIST                                   List solution from CAL file.
go BOOTSTRAP                                Find the flux of calibrators.
go PLOT                                   Plot solution on TEK terminal.
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives ANTSOL
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
visibilitytype                            Specify continuum mode or
          RESIDUALS | CONTINUUM | 2^n      number of spectral line channels
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .   Calcode(s) to be selected.
antennas <physical IDs>                   Antenna selections
refants <list of IDs> | *                 Specify reference antennas in
                                            decreasing priority.
ifs A|C|* . . .                           IFs to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .   Bands or frequencies
modes '  '|IA|<2char>|* . . .             Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                          Pass flagged data.
minamp <value>                            Minimum acceptable amplitude in
                                            actual correlation units.
uvlimits <option><umin nsec umax nsec>
                  <<vmin nsec vmax nsec>  limits on base lines
                   <position|angle d>>    tilt of major avis of uv-ellipse
                                          Options: NONE - no limit on
                                                   baselines.
                                               ANNULAR - limit baselines
                                                   to a circular or
                                                   elliptical annulus.

outfile dev:file.ext[p,pn]                Output file.
listoptions AMPLITUDE|PHASE|AMP*AMP|      Select type(s) of listings.
    A/C|ACratio|ACphasedifference
calibration NONE|APPLY|UNDO,MODCOMP       Calibration using gain table.
average <time>|SCAN  VECTOR|AMPSCALAR     Averaging time and type
```

closurelimit <amplimit> <phaselimit>	Maximum amplitude and phase closure errors without printing error message upper limit on closure error
solveoption CLEAR ..	delete the existing .CAL file if present and create a new file.
EXTEND .	the selected scan will be solved only if the old .CAL file does not have a solution for it. The new solutions will be added to the past solutions for the scans not selected.
UPDATE. .	the selected scan will be solved irrespective of the existence of previous solutions for this scan in the old .CAL file; the solutions for scans not selected are retained.
TRIAL .	Find new solution but do not modify the .CAL file.
AMP/JY YES|NO|AUTO	Divide correlator counts by flux OR do not OR divide only if setjy is set
resfile YES|NO	Create .RES file of residuals
xaxis <number> TO <number> IAT.DAYS|IAT.24HR|LST.DAYS|LST.24HR|HA|ELEVATION|AZIMUTH|PARALLACTIC|UVDISTANCE|UVANGLE	Range and kind of xaxis. Don't give range for IAT.DAYS and LST.DAYS.
yaxis <number> TO <number> AMPLITUDE|AMP*AMP|1/AMP|PHASE	Range and kind of y-axis.

ANTSOL selects data from a visibility data base on the basis of the following standard data selection commands:

DBNAME	TIMERANGE	SOURCES	CALCODES	ANTENNAS
IFS	BANDS	MODES	PASSFLAG	MINAMP
UVLIMITS				

The REFANTS command is used to select the antenna which is used for a reference antenna in solving for the system phase for other antennas. One can choose to apply all or part of the calibration in the gain table by choosing the appropriate option in the CALIBRATION command, and similarly one can use the AMP/JY command to have amplitudes divided by the flux densities stored in the dbname.INX[14,PN] file.

The GO SOLVE in ANTSOL will give meaningful solutions only if the selected sources are ones for which the formula

$$V_{jk} = S\ g_j\ g_k \exp[i(\phi_j - \phi_k)$$

is a valid approximation for the source visibilities, with g_j and ϕ_j being the amplitude and phase for the j-th antenna, and S being the total source flux density.

ANTSOL

Another major command that affects the solutions obtained by GO SOLVE is the AVERAGE command, which controls the averaging interval that is used. An averaging time shorter than the time interval in the gain table, which is set when the FILLER program produces the data base files, has no significance.

The GO BOOTSTRAP command can be used to find the flux density of calibrators if there are observations of 3C286 (1328+307) in the selected source data. These flux densities are automatically entered in the data base .INX file during the BOOTSTRAP process.

Other commands in ANTSOL affect the diagnostic, listing, or plot displays of ANTSOL. The CLOSURELIMIT command is used to suppress diagnostic output of the closure errors below the specified limits on amplitude and phase. These closure errors are displayed upon either terminal screen (TTY:), line printer (LPT:), or can be stored in a disk file (DSK:), depending upon the OUTFILE specification.

If the RESFILE command is set to YES, the closure errors are written into a dbname.RES[14,PN] file and can be examined (particulary in GO MATRIX) format with the LISTER program with VISIBILITYTYPE RESIDUALS.

The listings produced with the GO LIST command of ANTSOL are column displays of the amplitudes, phases, or A-C phase differences of the complex gains in the dbname.CAL[14,PN] file. With the LISTOPTIONS command one can choose to list any combination of AMPLITUDE, AMP*AMP, PHASE, or various measures of differences between A and C correlators. For LPT: output the amplitudes or phases for all 27 antennas for a single IF can be displayed.

The evaluation of antenna gain and phase solutions obtained by ANTSOL if of great importance in evaluating claibrator and system behavior. This is because it is much easier to make sense of N antenna gains and phases than is is to make sense of N(N-1)/2 correlator gains and phases.

Finally, one can plot the amplitude and phase solutions in the dbname.CAL[14,PN] file by using the GO PLOT command, with choice of type and range of x- and y-coordinates determined by the XAXIS and YAXIS commands. As of middle 1982 PLOTs can be made only on TEK 4012 (or simulated 4012) terminals.

AVGVIS is a program for selecting part or all of the data from a visibility data base and producing another data base with a different name and a longer averaging time.

```
AVGVIS INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . AVGVIS
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . . UNFLAGGED
  (MISC) ===========
outfile . . . . . DSK:You must specify me.[14,]=EXTEND
average . . . . .  0:01:00
logfile . . . . . TTY:AVGVIS.LOG[13,]=EXTEND
```

Use of AVGVIS is strongly recommeded wherever possible to decrease the amount of disk storage space being used for data bases. In general, once an initial data base has been edited one uses AVGVIS to produce the most compact data base that can be achieved without sacrificing the quality of the desired visibility information.

THE DBNAME command in AVGVIS specifies the name of the original data base, with data selection for the new data base using the commands:

SOURCES QUALIFIERS CALCODES BANDS ANTENNAS MODES PASSFLAG .

A new visibility data base named with the OUTFILE command is then "filled" with these data, with a new and larger averaging time specified by the averaging time in the AVERAGE command.

In cases where you want to put selected data in another data base without averaging, you should use the DBCON program.

AVGVIS

```
AVGVIS COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go                                      Average the file
jobname <1 to 6 chars>                  Name of batch job
jobtime <time>                          Max. time for running batch job
batch <argument>                        Same as GO <argument> but do it
                                          in batch.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives AVGVIS
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]               Database to be used
sources <sourcename>:<qual>  . . .      Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
antennas <ID list> WITH <ID list>       Baselines. Each antenna in list 1 is
                                        paired with all antennas in list 2
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
modes '  '|IA|<2char>|* . . .           Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                        Pass flagged data.
outfile  <filename[p,pn]>               Output averaged database
average <time>                          Averaging time
logfile <filespec>                      Where log data is to be written
```

The OUTFILE options of EXTEND or OVERWRITE should be chosen carefully. If one specifies OUTFILE newdb[14,PN]=EXTEND, then the newly selected and averaged data are added on to the end of any previously existing data base named newdb[14,PN]. Only if you specify OUTFILE newdb[14,PN]=OVERWRITE will an old version of newdb[14,PN] be replaced with the new one. As averaged data are written into the new data base, the source names, qualifiers, start dates, start times, bands, and numbers of initial and averaged visibility records for each scan are listed in column format on the terminal screen.

DANEEL is a program inside of which any of the standard command programs can be run. The primary purposes of DANEEL are: (1) to permit the passing of parameters between different programs; and (2) to provide program names as part of the prompt for commands.

```
DANEEL INPUTS
====== ======
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . . UNFLAGGED
```

With DANEEL a program normally run from operating the system level with the dialogue

.r progname

can be run using the dialogue

DANEEL* GO progname

with the usual results, except that the "*" prompt usually encountered inside programs is replaced by "progname *". Exits from programs result in return to the DANEEL level. Commands common to different programs are automatically passed from one program to another as these programs are run under DANEEL control.

DANEEL

```
DANEEL COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go <sub-program name>                   Run the specified sub-program.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives DANEEL
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]               Database to be used
sources <sourcename>:<qual>  . . .      Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
modes '  '|IA|<2char>|* . . .           Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                        Pass flagged data.
```

DBCON is a program for taking selected visibility data from either one or two data bases and "concatenating" these data into a different data base.

```
DBCON INPUTS
===== ======
  (GENERAL) ========
jobname . . . . . DBCON
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
visibilitytype. . CONTINUUM
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . . BOTH
  (MISC) ===========
outfile . . . . . DSK:You must specify me.[14,]*EXTEND
infiles . . . . . DSK:You must specify me.[14,]
```

The data put into the new data base are selected by the commands

SOURCES CALCODES ANTENNAS BANDS PASSFLAG MODES .

The INFILES command is used to name one or two input data bases. The OUTFILE command is used to specify the name of the new data base, and whether you wish to EXTEND or OVERWRITE any data base that already exists with that name. Unlike AVGVIS, no averaging of visibility data is possible with DBCON.

A secondary use of DBCON is the creation of a new data base with only a selected subset of the data in an old data base. This is done frequently when it is desirable to have data bases with only one frequency, or with only one source, etc.

DBCON will work with either continuum or spectral line data, with the type specified by the VISIBILITYTYPE command.

DBCON

```
DBCON COMMANDS
===== ========
getcommands <file-specification>       Do the commands in the given file.
savecommands <file-specification>      Save current inputs in given file.
inputs <kind> | <nothing>              Give display of current inputs
                                         Legal catagories of inputs are:
                                         GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                Type help text. No argument gives
                                         all help text. Legal kinds are:
                                         GENERAL,DATASELECT,MISC,PLOT
setdefaults                            Set INPUTS to original defaults
finish                                 Stop program and leave.
go                                     Concatonate the two files
jobname <1 to 6 chars>                 Name of batch job
jobtime <time>                         Max. time for running batch job
batch <argument>                       Same as GO <argument> but do it
                                         in batch.
explain <program name> | <empty>       Type explanation of the given
                                         program. <empty> gives DBCON
timerange <start> to <stop>            Time period. <start>,<stop> syntax:
                                         <date> at <time>|<date>|<time>
visibilitytype                         Specify continuum mode or
        RESIDUALS | CONTINUUM | 2^n     number of spectral line channels
sources <sourcename>:<qual>  . . .     Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
antennas <ID list> WITH <ID list>      Baselines. Each antenna in list 1 is
                                       paired with all antennas in list 2
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
modes '  '|IA|<2char>|* . . .          Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                       Pass flagged data.
outfile  <filename[p,pn]>              List concatonated database.
infiles  <dbname[p,pn]> ...            List one or two input databases.
```

One must plan use of DBCON so that there is never an attempt to write data with over-lapping IAT time ranges into the new data base. This often makes it necessary to transfer data from one or more initial data bases to the new data base using a number of steps.

EXPREP is a program run to prepare for writing visibility data on an EXPORT tape with the EXPVIS program. Since EXPVIS applies the gain table to visibility data as it is transfered to an EXPORT tape, it is possible for the resulting visibility records to "over-flow". EXPREP searches for over-flows and, when necessary, adjusts the gain codes in the dbname.INX[14,PN] file to insure that no problems will occur with EXPVIS.

```
EXPREP INPUTS
====== ======
  (DATASELECT) =====
dbname. . . . . . [14,]
passflag. . . . . UNFLAGGED
  (MISC) ===========
outfile . . . . . TTY:EXPREP
listoption. . . . DETAIL
```

The only data selection parameters in EXPREP are specified with the DBNAME and PASSFLAG commands. One can use the LISTOPTION command to obtain a DETAIL listing of the overflows that are found or a brief SUMMARY.

```
EXPREP COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go                                      Detect overflows.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives EXPREP
dbname dev:filename[p,pn]               Database to be used
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                        Pass flagged data.
outfile dev:file.ext[p,pn]              Output file.
listoption DETAIL|SUMMARY|              Format of overflow messages
```

EXPVIS

EXPVIS is a DEC-10 program used to write visibility data bases on magnetic tape, in EXPORT format, for transfer to other computer systems.

```
EXPVIS INPUTS
====== ======
  (DATASELECT) =====
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
bands . . . . . . *
passflag. . . . . UNFLAGGED
  (MISC) ===========
outfile . . . . . MTA:
listoption. . . . DETAIL
```

EXPVIS writes data selected by the commands

DBNAME SOURCES CALCODES BANDS PASSFLAG

on tape applying the gain table to the data during the transfer process. A dbname.ANT[14,PN] file must be associated with the data base (see FILANT). The LISTOPTION command allows a DETAIL or SUMMARY listing on the OUTFILE.

```
EXPVIS COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go                                        Create the export tape.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives EXPVIS
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>   . . .       Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                          Pass flagged data.
outfile dev:file.ext[p,pn]                Output file.
listoption DETAIL|SUMMARY|                Format of overflow messages
```

FILANT is a program used to create a dbname.ANT[14,PN] file which contains antenna position information. This file is used by programs like EXPVIS and GTBCOR for purposes which require antenna positions.

```
FILANT INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . FILANT
jobtime . . . . .  0:05:00
  (DATASELECT) =====
dbname. . . . . . [14,]
  (MISC) ===========
outfile . . . . . TTY:
infile. . . . . . DSK:
```

A file containing the antenna position information for each VLA configuration was begun in 1980, and is the standard source of antenna position information for the FILANT program. The user need only specify a data base with the DBNAME command, and then a GO COPY command will result in a scan of the dbname.INX[14,PN] to find the time span of the data base, and the correct antenna positions are then copied into the dbname.ANT[14,PN] file.

The GO DELETE command can be used to delete a DBNAME.ANT[14,PN] file from disk, and the GO LIST command can be used to list the contents of the DBNAME.ANT[14,PN] file.

For data bases taken before 1980 it is necessary to obtain antenna position information from the MODCOMP tapes using the FMT2 program, and then use the GO WRITE command to create the DBNAME.ANT[14,PN] file. In this case the following procedures are used:

(1) Knowing that the data for the observing run is in the n-th file of a MODCOMP tape labeled Vxyz, you compute m = 3n - 2, mount Vxyz on a DEC-10 tape drive, and skip to the correct file, according to

.mount mta:t/reelid:Vxyz

.skip mta:m files

FILANT

```
FILANT COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go                                      Create the .ANT file
   COPY                                   from the history file, or
   WRITE                                  from the input file.
   DELETE                               Delete the current .ANT file.
   LIST                                 Produce a listing of the
                                          current .ANT file.

jobname <1 to 6 chars>                  Name of batch job
jobtime <time>                          Max. time for running batch job
batch <argument>                        Same as GO <argument> but do it
                                          in batch.

explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives FILANT

dbname dev:filename[p,pn]               Database to be used
outfile dev:file.ext[p,pn]              Output file.
infile dev:file.ext[p,pn]               Specify input file.
```

(2) Then you create a file named, say, ANTENN.POS, with FMT2:

```
.r fmt2
*infile mta:antennas
*outfile antenn.pos
*go
*fin
.unload mta:
.deassign mta:
```

(3) After which you use the FILANT program to create DBNAME.ANT[14,PN]

```
.r filant
*dbname DBNAME[14,PN]
*infile antenn.pos
*go write
*fin
```

Because of the antenna position information stored in a file in the [11,1] area since 1980, most users will never need to use the FMT2 program and the GO WRITE command in FILANT.

FILLER

FILLER is a program that takes visibility data from either the real time computer system (when run in real time by the array operators) or MODCOMP archive tapes, and "fills" a DEC-10 data base, creating the dbname.INX[14,PN], dbname.VIS[14,PN], and dbname.GAI[14,PN] files.

```
FILLER INPUTS
====== ======
usernumber                ALL
detach                    NO
infile                    MTA:
log                       FILLER.LOG


subarray                  1
  gaininterval            00:10:00
  timerange               76JAN01 at 00:00:00 to 85DEC31 at 24:00:00
  dbname                  DSK:[0,0]
  passflag                UNFLAGGED
  average                 00:00:30
  refants                 NONE
```

The only circumstances under which a user should run FILLER is when is is desirable to re-create a data base from a MODCOMP data tape. Only array operators ever use the commands in FILLER that are important for running the program in real time - these commands are referred to as for WIZARDs only.

In using FILLER for tape input, the first step is to find out (from the observing logs) which "file" your data is in on tape. Let us assume that it is in the n-th file. You then calculate m = 3n - 2 and type

```
.mount mta:t/reelid:Vxyz     ;and carry out the tape mounting procedure
.skip mta:m files            ;to get to the right place on tape
.r filler                    ;and the program will tell you a tape is ready
*sub 1                       ;to specify the sub-array used in observing
```

after which the INPUTS will look something like that shown above. The TIMERANGE, PASSFLAG, and USERNUMBER commands are the only ones that determine what data is transfered from tape to disk. The USERNUMBER is the same as the PN, and is determined by the user number supplied when preparing your observing program with OBSERV. You can supply ALL for this command and then only TIMERANGE and PASSFLAG will determine what data is transferred to disk. The DBNAME command determines the name of the resulting data base.

FILLER

```
FILLER COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
usernumber <user#>|ALL                    Fill data taken for given user number
detach YES|NO                             Whether FILLER is to run detached
                                          from the user's terminal.
infile <dev>:                             Set up input device for FILLER.
log <file>                                Set up log file for FILLER.
wizard                                    User considers himself such.
pbox YES|NO                               If YES pulse Phil Dooley's BOX.
                                          WIZARDS ONLY
subarray <no.>                            Designate subarray for which the
                                          FILLER parameters pertain.
                                          CAVEAT: Specify the subarray FIRST!!!!
effective NOW|USERCHANGE|<date/time>      Tell FILLER when to implement the
                                          parameters.   WIZARDS ONLY
shutdown <subarray>                       Stop collecting data for a subarray
                                          WIZARDS ONLY
gaininterval <time>                       Set longest gain table interval
go                                        Start or resume FILLER with these inputs
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives FILLER
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
refants <list of IDs> | * | none          Specify reference antennas in
                                            decreasing priority.
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                          Pass flagged data.
average <time>|SCAN                       Averaging time
```

The AVERAGE command is used to determine the number of ten second records that will be averaged together in the data base. This should be as large as possible to save disk space. The GAININTERVAL command determines the time separation of entries in the gain table (dbname.GAI[14,PN]). Normally set to 10 minutes, it should be as short as needed for self-calibration procedures if you are certain that self-calibration will be used.

The progress of FILLER is recorded in the file named by the LOG command.

FLAGER is a program for changing and listing the values of flags associated with visibility data. FLAGER can change only the flags assigned in the DEC system. There are flags in the dbname.INX[14,PN] file which apply to entire antenna-IFs within a scan, and there are flags associated with individual visibility records.

```
FLAGER INPUTS
====== ======
  (GENERAL) =========
jobname . . . . . FLAGER
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
visibilitytype. . CONTINUUM
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
ifs . . . . . . . *
ifpairs . . . . . *
bands . . . . . . *
  (MISC) ===========
outfile . . . . . TTY:FLAGER
  (FLAGER) =========
flagoption. . . . ANTENNA
flaglocation. . . AUTO
```

FLAGER will work on either CONTINUUM or specral line data depending upon the VISIBILITYTYPE command. Data are selected for flagging, un-flagging, or listing by the data selection commands:

DBNAME TIMERANGE SOURCE CALCODES ANTENNAS IF/IFPAIRS BANDS

where the IF command is operable for FLAGOPTION ANTENNA and the IFPAIRS command is operable for FLAGOPTION CORRELATOR. The FLAGLOCATION command is usually set to AUTO so the program can flag data by the INX record flags where possible, and use the VIS record flags only when necessary. However, for FLAGOPTION CORRELATOR the FLAGLOCATION is set to VISRECORD.

FLAGER

```
FLAGER COMMANDS
====== ========
getcommands <file-specification>           Do the commands in the given file.
savecommands <file-specification>          Save current inputs in given file.
inputs <kind> | <nothing>                  Give display of current inputs
                                             Legal catagories of inputs are:
                                             GENERAL,DATASELECT,MISC,PLOT,FLAGER

help <kind> | <nothing>                    Type help text. No argument gives
                                             all help text. Legal kinds are:
                                             GENERAL,DATASELECT,MISC,PLOT,FLAGER

setdefaults                                Set INPUTS to original defaults
finish                                     Stop program and leave.
go list | flag | unflag                    List flag values or change values.
jobname <1 to 6 chars>                     Name of batch job
jobtime <time>                             Max. time for running batch job
batch <argument>                           Same as GO <argument> but do it
                                             in batch.
explain <program name> | <empty>           Type explanation of the given
                                             program. <empty> gives FLAGER
timerange <start> to <stop>                Time period. <start>,<stop> syntax:
                                             <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                  Database to be used
visibilitytype                             Specify continuum mode or
          RESIDUALS | CONTINUUM | 2^n        number of spectral line channels
sources <sourcename>:<qual>  . . .         Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .    Calcode(s) to be selected.
antennas <ID list> WITH <ID list>          Baselines. Each antenna in list 1 is
                                           paired with all antennas in list 2
ifs A|C|* . . .                            IFs to be selected.
ifpairs AA|CC|AC|CA|* . . .                IF pairs or correlators
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .    Bands or frequencies
outfile dev:file.ext[p,pn]                 Output file.
flagoption  antenna|correlator             Type of flagging.
flaglocation   inxrecord|visrecord|auto    location of flags to be operated on
```

The GO LIST command can be used to list flags for both INX and VIS records. The ANTENNAS <ID list> WITH <ID list> syntax must be used for the ANTENNAS command. Flags set with FLAGER are indicated by a D, flags set in the MODCOMP system are indicated by a M, flags set in both systems are indicated by a B, and unflagged data are indicated by a period. For example:

```
SOURCE = 3C286   DATE = 82MAY28   BAND = 20
 IAT        1- 9 1-10 1-17 9-2210-2217-22
inx flags   .... .... .... .... .... ....
 4:51:20    MMMM MMMM MMMM DDDD DDDD DDDD
 4:51:50    MMMM MMMM MMMM DDDD DDDD DDDD
 4:52:20    MMMM MMMM MMMM .... .... ....
 4:52:50    .... .... .... .... .... ....
```

Flags set with the GO FLAG command can be un-flagged with GO UNFLAG.

GTBCAL is a program that takes a table of antenna-based amplitude and phase calibration information (dbname.CAL[14,PN]), produced with the ANTSOL program, and interpolates that calibration in the gain table (dbname.GAI[14,PN]) for selected data.

```
GTBCAL INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . GTBCAL
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
ifs . . . . . . . *
band. . . . . . .  6.0cm
calsources. . . . *:*
  (MISC) ===========
outfile . . . . . TTY:GTBCAL
average . . . . .  2:00:00
caltype . . . . . AMP, PHASE
pastonly. . . . . NO
interpfunct . . . BOXCAR
weight. . . . . . UNIFORM
  (PLOT) ===========
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .   .000 TO  2.000 AMPLITUDE
```

There are two separate domains of data selection involved in the GTBCAL program: selection of the data to be calibrated; and selection of which calibrators in the calibration table (dbname.CAL[14,PN]) are to be used to calculate the entries in the gain table. Selection of calibrators is by means of the CALSOURCES command. Selection of which data are to be calibrated, by modification of the gain table, is with the standard commands:

DBNAME TIMERANGE SOURCES CALCODES ANTENNAS IFS BAND

where only on band at a time can be calibrated.

Gain table entries are computed by GTBCAL from selected calibration table entries by interpolating or taking weighted averages. One enters amplitude and/or phase calibration (specified by CALTYPE command) with the execution of the GO CALIBRATE command. The INTERPFUNCT, PASTONLY, and

GTBCAL

```
GTBCAL COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT

setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go list                                   list specified portion of gain table
go reset                                  reset specified portion of gain table
go reset amplitude                        Reset amplitude portion of gain table
go reset phase                            Reset phase portion of gain table
go calibrate                              fill up gain table with calibration
go plot                                   plot gain table on TEK
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives GTBCAL
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .   Calcode(s) to be selected.
antennas <physical IDs>                   Antenna selections
ifs A|C|* . . .                           IFs to be selected.
band 1.3cm|2cm|6cm|20cm|<freq>            Band or frequency.
calsources <sourcename>:<qual>  . . .     Specify calibration sources and qualifiers.
outfile dev:file.ext[p,pn]                Output file.
average <time>                            Averaging time
caltype AMP PHASE                         specify calibration: AMP and/or PHASE
pastonly YES | NO                         whether to use only past calibrators
interpfunct BOXCAR | 2POINT               specify type of interpolation
weight UNIFORM                            specify type of weighting
xaxis <number> TO <number> IAT.DAYS|      Range and kind of xaxis.  Don't give
      IAT.24HR|LST.DAYS|LST.24HR|HA|      range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC|
       UVDISTANCE|UVANGLE
yaxis <number> TO <number>  AMPLITUDE|    Range and kind of y-axis.
           AMP*AMP|1/AMP|AMP/JY|PHASE
```

AVERAGE commands determine how the calibration is applied. For INTERPFUNCT 2POINT the gain table calibration parameters are obtained by linear interpolation between the appropriate two entries in the calibration table. For INTERPFUNCT BOXCAR the gain table parameters are obtained by averaging all data over the time span specified by the AVERAGE command. Thus, for example, if one has AVERAGE 0:30, all cal table data 15 minutes before and 15 minutes after the time of a particular gain table entry are averaged together to determine the calibration to be applied.

The choice of whether to use BOXCAR or 2POINT interpolation depends upon your calibration strategy. If you are using sequences of CALIBRATOR-SOURCE or SOURCE-CALIBRATOR for separate frequencies, with large time gaps between calibrator observations, then BOXCAR is recommended. If you are surrounding source observations with calibrator observations, or calibrator observation are quite frequent, then 2POINT is recommended.

The normal use of GO CALIBRATE in GTBCAL requires careful specification of the sources listed for the CALSOURCES and SOURCES command. Since a calibrator listed in the CALSOURCES command will have calibration applied to its portion of the gain table at the execution of the next GO CALIBRATE command, one must name a source only once for each band. The appropriate logic to follow is to list the calibrator(s) once in the CALSOURCES list and ALL the sources to be calibrated from this calibrator information in the SOURCE list before executing GO CALIBRATE for each observing band. Repeating a source name in a CALSOURCES or SOURCES list for two GO CALIBRATE commands will result in the calibration being applied twice, which is worse than no calibration at all.

One normally has multiple execution of GO CALIBRATE for the same data base. There must be one execution for each frequency band, and if there are a number of source-calibrator groupings this requires independent calibration for each group.

The GO LIST command can be used to list the contents of the gain table on the device (TTY:, LPT:, or DSK:filnam) named with the OUTFILE command. A maximum of five columns are possible for TTY: display, and a maximum of ten columns are possible for LPT: output. Similarly, selected portions of the gain table can be plotted on a TEK 4012 (or equivalent) terminal by use of the GO PLOT command. The type and range of the x- and y-coordinates of the plot are specified with the YAXIS and XAXIS commands.

The GO RESET, GO RESET AMPLITUDE, and GO RESET PHASE commands can be used to reset all or parts of the amplitudes and phases in the gain table to 1 and 0, resectfully. In doing so you will un-do all previous modification of the gain table. Thus for example, if corrections were entered with the GTBCOR program, a RESET will undo both these corrections and any calibration applied with GTBCAL.

GTBCAL

Since the process of using ANTSOL to create calibration tables, and GTBCAL to apply this calibration to the gain table, frequently involves a number of iterations, it is often desirable to copy the dbname.GAI[14,PN] file obtained after corrections by GTBCOR (and perhaps GTTSYS) into a temporary disk file. By doing this you can avoid re-doing corrections every time you re-do the ANTSOL/GTBCAL calibration in the gain table. One way to accomplish this is to type, to the operating system:

.<u>copy dbname.GA0[14,PN] ← dbname.GAI[14,PN]</u> ; to back up corrections only

and then before you run GTBCAL to apply calibration you type

.<u>copy dbname.GAI[14,PN] ← dbname.GA)[14,PN]</u> ; to get corrected GAI file.

GTBCOR is a program that can be used to write various antenna-based corrections into the gain table of a visibility data base. These include amplitude and phase correction, and polarization calibration parameters determined with the POLCAL program.

```
GTBCOR INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . GTBCOR
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
ifs . . . . . . . *
bands . . . . . . *
  (MISC) ===========
outfile . . . . . TTY:GTBCOR
infile. . . . . . DSK:POLCAL.PRM
listoption. . . . CORRECTION
baselineerr . . .  .0000,  .0000,  .0000,  .0000 (in nsec)
laterror. . . .      .000sec
coeffsecz . . . .  .120,  .055,  .040,  .040  (20, 6, 2, 1.3cm)
positionerr . . .    .00"    .00"
freqerr . . . . .  .000000MHz,  .000000MHz,  .000000MHz,  .000000MHz(A,C,B,D)
ampfactor . . . .   1.000  1.000
phaseshift. . . .   .000d    .000d
  (PLOT) ===========
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .   .000 TO  2.000 AMPLITUDE
```

The selection of data for which correction are to be inserted in the gain table (dbname.GAI[14,PN]) of a visibility data base is based on the commands:

DBNAME TIMERANGE SOURCE CALCODES ANTENNAS IFS BANDS .

GTBCOR

```
GTBCOR COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go AMPCORR                                Correct amplitudes using 'ampfactor'
go PHASECORR                              Correct phases using 'phaseshift'
go POLTABLECOR                            Correct selected pol gains from  table
go GETPOLTABLE                            Inputs parameters from the infile
go CLEARPOLTABLE                          Clears the POLTABLECOR parameter table
go ACPHASECORR                            Do AC corr using 'phaseshift'
go BASECORR                               Correct phases using 'baselineerr'
go TIMECORR                               Correct phases using 'iaterr'
go RADECCORR                              Correct phases using 'positionerr'
go SECZCORR                               Correct amplitudes using 'coeffsecz'
go FREQCORR                               Correct frequencies using 'freqcorr'
go SHADOWCORR                             Correct amplitudes using geometrical
                                            correction for shadowing
go POLCORR                                Correct pol part of gain table using
                                            'ampfactor' and 'phaseshift'
go LIST                                   List selected antenna-IF(s) gain
                                            table entries.
go PLOT                                   Plot selected antenna-IFs on
                                            TEK terminal.
go FARADAYCOR                             Enter Faraday rotation corrections
                                          into Gain table.
go RESET                                  Reset selected portion of gain table
go RESET AMPLITUDE                        Reset amplitude portion of gain table
go RESET PHASE                            Reset phase portion of gain table
go POLRESET                               Reset selected pol part of gain table
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives GTBCOR
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .   Calcode(s) to be selected.
antennas <physical IDs>                   Antenna selections
ifs A|C|* . . .                           IFs to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .   Bands or frequencies
outfile dev:file.ext[p,pn]                Output file.
infile dev:file.ext[p,pn]                 Specify input file.
listoption NOMINAL | CORRECTION           List nominal and correction or
                                            only correction part of gain table
baselineerr <dBx>, <dBy>, <dBz>, <dBa>    Baseline error components in nsec
                                            (do not specify units)
iaterror <value>                          Specify IAT time error
coeffsecz <20cm>, <6cm>, <2cm>, <1.3cm>   Coefficients for secant z correction
                                            (no units)
positionerr <deltaRA>, <deltaDEC>         Position offsets in RA and DEC
                                            (angular units)
freqerr <deltafreq[A,C,B,D]>              frequency offsets in sense (TO-FROM)
ampfactor <start>, <stop>                 Specify starting and stopping amplitude
phaseshift <start>, <stop>                Specify starting and stopping phase
xaxis <number> TO <number> IAT.DAYS|      Range and kind of xaxis.  Don't give
      IAT.24HR|LST.DAYS|LST.24HR|HA|      range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC|
       UVDISTANCE|UVANGLE
yaxis <number> TO <number>  AMPLITUDE|    Range and kind of y-axis.
            AMP*AMP|1/AMP|AMP/JY|PHASE
```

There are many type of corrections that can be applied with the GTBCOR program. Most of these have one (or more) GO <type> commmands and accompanying commands that supply parameters. The following table summarizes the pairing of these commands:

<type>	Parameter Command	Comments
AMPCORR	AMPFACTOR <start> <stop>	Linear correction applied over TIMERANGE to AA and CC amplitudes
PHASECORR	PHASESHIFT <start> <stop>	Linear correction applied over TIMERANGE to AA and CC phases
BASECORR	BASELINEERR <dBx><dBy><dBz><dBa>	Phase correction for antenna position error and axis intersection defect
TIMECORR	IATERROR <value>	Phase correction for time error. Requires antenna file dbname.ANT[14,PN]
RADECCORR	POSITIONERROR <dRA> <dDEC>	Phase correction for change in source position. Requires antenna file dbname.ANT[14,PN]
SECZCORR	COEFFSECZ <20cm><6cm><2cm><1.3cm>	Multiply amplitudes by (1+COEFF*SEC Z)/(1+COEFF)
FREQCORR	FREQERR <Aerr><Berr><Cerr><Derr>	Correct phases for specified frequency error
SHADOWCORR		Correct amplitudes for geometric blocking factors
POLCORR	AMPFACTOR <start> <stop> PHASESHIFT <start> <stop>	Correction for instruments polarization
FARADCORR		Use info. written by FARAD program to correct for ionospheric faraday rotation
GETPOLTABLE		Get POLCAL solution from specified INFILE, then
POLTABLECOR		Apply polarization calibration to AC & CA, &
ACPHASECORR	PHASESHIFT <start> <stop>	Apply pol. P.A. correction

GTBCOR

Most of the corrections in the previous table are self-explanatory. The SECZ correction can be applied for cases where it is appropriate and where the T_{sys} has correction has NOT been applied by the on-line system or GTTSYS. The use of FARADAYCOR in conjunction with the program FARAD is discussed in detail in the Observer's Reference Manual.

The sequence GO GETPOLTABLE followed by GOPOLTABLECOR is used to apply the polarization calibration determined by the POLCAL program, and written into the .PRM file whose name must be supplied to the INFILE command. Once this calibration has been applied one can obtain the values of the AC & CA phase for calibrators like 3C286 using the LISTER program (with NEGCA LISTOPTION). When this is used to calculate the position angle correction for polarization vectors (= 66 - AC&CAphase for 3C286), this angle is supplied to the PHASESHIFT command before applying absolute position angle calibration with the GO ACPHASECORR command. The GO CLEARPOLTABLE command can be used to clear the polarization parameter table stored in arrays in the GTBCOR program.

All or part of the gain table can be reset to amplitudes of 1 and phases of zero with the various RESET commands. The GO POLRESET command resets the crossed-hands polarization gains (D_{jR} and D_{jL}) and the other RESET commands affect the amplitude and/or phase of g_{jR} and g_{jL}. Be sure to reset the appropriate parts of the gain table whenever you need to re-do any corrections or calibrations, otherwise they can be entered in the gain table more than once. It is also recommended that the entire gain table be reset before commencing the first attempts at correction or calibration.

The GO LIST command in GTBCOR can be used to list, on the devices (TTY:, LPT:, DSK:filnam) specified by the OUTFILE command, portions of the gain table. Choice of the NOMINAL part of the gain table by the LISTOPTIONS command means display of corrections already applied in the on-line system; choice of the CORRECTIONS part of the gain table means to list the parts of the gain table modified in the off-line system.

The GO PLOT command allows plots of selected gain table entries to be displayed on a TEK 4012 terminal (or equivalent), where the range and type of x- and y-coordinates are specified by the XAXIS and YAXIS commands.

GTTSYS is a program for applying corrections for gain variations due to system temperature. The corrections are made using system temperature measurements stored in a monitor data base, and they are applied to the gain table (dbname.GAI[14,PN]) as amplitude correction factors. GTTSYS is used only when the on-line computer system has not applied system temperature corrections.

```
GTTSYS INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . GTTSYS
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
refants . . . . . NONE (Physical IDs)
ifs . . . . . . . *
bands . . . . . . *
mondbname . . . . DSK:[11,1]
  (MISC) ===========
outfile . . . . . TTY:GTTSYS
infile. . . . . . DSK:TCALS.TXT
gtinterval. . . .  0:10:00
  (PLOT) ==========
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .    .000 TO  2.000 AMPLITUDE
```

The GTTSYS program plays a role like the GTBCOR program, but it applies only one type of correction. The selection of data to be corrected by GTTSYS is made with the following commands:

DBNAME TIMERANGE SOURCES CALCODES ANTENNAS IFS BANDS .

The amplitude corrections are proportional to the inverse of the square root of the system temperature recorded in the monitor data base specified with the MONDBNAME command. The constants of proportionality for this correction are obtained from the specified INFILE. See the Observer's Reference Manual for details on how to prepare this table of constants.

GTTSYS

```
GTTSYS COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT

help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go TSYSCORR                             Enter system temps into gain table
go TPOWERCORR                           Neglect system temperature,
                                            correct for external flux
go LIST                                 List gain table
go RESET                                Reset specified portion of gain table
go PLOT                                 Plot gain table on TEK
go GETOFFSETS                           Get detector offsets from
                                            infile
go CLEAROFFSETS                         Set offsets to zero
jobname <1 to 6 chars>                  Name of batch job
jobtime <time>                          Max. time for running batch job
batch <argument>                        Same as GO <argument> but do it
                                          in batch.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives GTTSYS
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]               Database to be used
sources <sourcename>:<qual>  . . .      Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
antennas <physical IDs>                 Antenna selections
refants <list of IDs> | * | none        Specify reference antennas in
                                          decreasing priority.
ifs A|C|* . . .                         IFs to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
mondbname dev:filename[p,pn]            Specify name of monitor database
outfile dev:file.ext[p,pn]              Output file.
infile dev:file.ext[p,pn]               Specify input file.
gtinterval <time>                       Gain table entry interval
xaxis <number> TO <number> IAT.DAYS|    Range and kind of xaxis.  Don't give
      IAT.24HR|LST.DAYS|LST.24HR|HA|    range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC|
       UVDISTANCE|UVANGLE
yaxis <number> TO <number>  AMPLITUDE|  Range and kind of y-axis.
           AMP*AMP|1/AMP|AMP/JY|PHASE
```

The reset, listing, and plotting capabilities of GTTSYS are the same as discussed for GTBCOR.

LISTER is a program for listing visibility data, in different formats, on terminal screens or the DEC-10 line printer. LISTER can provide listing of the following types: a summary of information about all sources observed at all or selected frequencies in a visibility data base; a sequential listing of information global to succesive scans; column listings of amplitudes, amplitudes/Jy, and/or phases as a function of time (IAT); a matrix-type listing of amplitudes, amplitudes/Jy, and/or phases (and optionally their rms if averaged) in a format allowing data display for all 27 antennas; and column or matrix listings of values of u and v.

```
LISTER INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . LISTER
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
visibilitytype. . CONTINUUM
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
ifpairs . . . . . AA, CC
channels. . . . . NONE
bands . . . . . . *
modes . . . . . . *
passflag. . . . . UNFLAGGED
uvlimits. . . . . NONE
vislimits . . . .  .000E-48 1.000E+09
  (MISC) ===========
outfiles. . . . . TTY:LISTER
listoptions . . . SCANHEADINGS
calibration . . . NONE
average . . . . .  0:00:00 VECTOR
scalefactor . . .   1.0E+00
```

LISTER will work for VISIBILITYPE CONTINUUM or for spectral line data bases. Data selection is based upon the commands:

DBNAME	TIMERANGE	SOURCES	CALCODES	ANTENNAS	IFPAIRS	CHANNELS
BANDS	MODES	PASSFLAG	UVLIMITS	VISLIMITS	.	

LISTER

```
LISTER COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go scan                                 List scan information
go summary                              List scan summary
go column                               List visibility data in columns
go matrix                               List visibility data in matrix format
go uvcolumn                              List uv data in columns
go uvmatrix                              List uv data in matrix format
jobname <1 to 6 chars>                  Name of batch job
jobtime <time>                          Max. time for running batch job
batch <argument>                        Same as GO <argument> but do it
                                          in batch.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives LISTER
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]               Database to be used
visibilitytype                          Specify continuum mode or
          RESIDUALS | CONTINUUM | 2^n    number of spectral line channels
sources <sourcename>:<qual>   . . .     Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . . Calcode(s) to be selected.
antennas <ID list> WITH <ID list>       Baselines. Each antenna in list 1 is
                                        paired with all antennas in list 2
ifpairs AA|CC|AC|CA|* . . .             IF pairs or correlators
channels     * | n ...                  Spectral line channel numbers
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
modes '  '|IA|<2char>|* . . .           Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                        Pass flagged data.
uvlimits <option> <umin/uvmin(nsec) umax/uvmax(nsec)>
                  <vmin(nsec) vmax(nsec)>
                                        Limits on baselines. Options:
                                        NONE - no limit on baselines
                                        ANNULAR - limit baselines to
                                          an annulus. Specify <uvmin(nsec)
                                          uvmax(nsec)>, e.g. uvlimits annular
                                          0nsec 100nsec
                                        RECTANGULAR - limit baselines
                                          to a rectangular area. Specify
                                          <umin(nsec) umax(nsec)>
                                          <vmin(nsec) vmax(nsec)>,
                                          e.g. uvlimits rectangular 0nsec
                                          100nsec 0nsec 200nsec
Vislimits <ampmin> <ampmax>             Limits on visibility
                                        amplitudes to be listed.
                                          type '*' to disable
outfiles dev:file.ext[p,pn] . . .       Output files.
listoptions SCANHEADINGS|AMPLITUDE|     Types of data to list
       AMP/JY|PHASE|ANTENNAS|RMS|RATIO|NEGCA
calibration NONE|APPLY|UNDO.MODCOMP     Calibration using gain table.
average <time>|SCAN|XSCAN  VECTOR|AMPSCAAveraging time and type
scalefactor <number>                    Multiply default scale by this
```

With the CALIBRATION command one can make listing which APPLY or do not apply (NONE) the gain table; one can also specify UNDO.MODCOMP as a parameter to this command, and the corrections and calibrations applied in the on-line system (NOMINAL part of gain table) will be un-done for the listed data.

The output of LISTER can be on terminal (TTY:), line printer (LPT:), or disk file (DSK:filnam), depending upon the parameters of the OUTFILE command.

The LISTOPTIONS and AVERAGE commands affect the type of listing you obtain. THe AVERAGE command can be used to request averaged data for display. If SCANHEADING is one of the LISTOPTIONS, each scan listing is preceded by a summary of header information for each scan; without this amongst the LISTOPTIONS only the source name appears. The LISTOPTIONS command can be used to select display of various types of data: AMPLITUDE or AMPLITUDE/Jy (never both at the same time); PHASE; and RMS (for GO MATRIX listing only) for requested amplitude and/or phase listings. Amplitudes are scaled by factors determined by the gaincode for a scan, but can be further scaled for convenient display with the SCALEFACTOR command, whose parameter multiplies each amplitude or amplitude/Jy. A NEGCA option is available to change the sign of the phase of IFPAIRS CA, as needed for determining the absolute position angle of polarization calibrators like 3C286.

The VISLIMITS command can be used to specify the range of amplitudes for which data are to be listed. This can be used to find spuriously low or high data points. One can further use the UVLIMITS command to specify both a type of u-v limit and the range of u-v for which data are to be listed. The type of UVLIMITS can be NONE, ANNULAR (centered on the origin of the u-v coordinate system), or RECTANGULAR. For ANNULAR one supplies two numbers (in nanoseconds) for inner and outer u-v radii, while for RECTANGULAR one supplies four numbers (in nanoseconds) specifyin u_{MIN} u_{MAX} v_{MIN} v_{MAX}.

The following are examples of some of the major types of LISTER output:

```
*go sum
  #     #Vis                                                            Gain
Scans  recs    Source:Q   C      RA(1950)       DEC(1950)       Flux   Code Band Mode
   2    7150     3C286:0   B  13h28m49.657s  30d45'58.64"  7.410Jy   3    6cm
   6   63200     SS433:0      19h09m21.285s   4d53'54.07"  1.000Jy   3    6cm
   7   14925 1923+210:0   C  19h23m49.788s  21d00'23.20"  1.500Jy   3    6cm
        ANTENNAS    1  2  3  4  5  6  7  8  9 10 11 13 14 15 16 17 18 19 20 21 22 23 24 25 27 28
```

LISTER

```
*go sc
LISTER EXECUTION    on    1982JUN02    at    10:00
====== =========
***82APR29***
  Source:Q     C  Band    Flux    StartIAT  StopIAT   StartLST   A-Obs. Freq-C
    3C286:0    B   6cm 7.410Jy  11:36:20 11:42:20  18h53m56s  4885MHz  4885MHz
    3C286:0    B   6cm 7.410Jy  11:48:40 11:53:10  19h06m18s  4885MHz  4885MHz
    SS433:0        6cm 1.000Jy  12:01:10 12:28:20  19h18m50s  4885MHz  4885MHz
1923+210:0     C   6cm 1.500Jy  12:29:30 12:32:20  19h47m14s  4885MHz  4885MHz
    . . .
1923+210:0     C   6cm 1.500Jy  15:57:20 16:00:50  23h15m38s  4885MHz  4885MHz
    SS433:0        6cm 1.000Jy  16:01:50 16:11:40  23h20m09s  4885MHz  4885MHz
*ant 17 with 1 2 3
*list scan amp/ pha
*go col
LISTER EXECUTION    on    1982JUN02    at    10:00
====== =========
***82APR29***
  Source:Q     C  Band    Flux    StartIAT  StopIAT   StartLST   A-Obs. Freq-C
   SS433:0         6cm 1.000Jy  13:02:30 13:17:10  20h20m20s  4885MHz  4885MHz
CONTINUUM
 x1.0E+03    1-17AA     1-17CC     2-17AA     2-17CC     3-17AA     3-17CC
   IAT     amp  phi   amp  phi   amp  phi   amp  phi   amp  phi   amp  phi
 13:02:50   96  175    96   61    58  -21    68   84    56   45    54   98
 13:03:20   94  170    96   59    61  -24    66   82    60   40    57   93
 13:03:50   95  178    96   66    59  -16    67   91    59   50    57  101
    . . .
 13:16:50   92  170    95   61    59   -7    66  103    58   85    55  137
 13:17:10   96  173    96   63    59   -5    62  103    58   85    57  142

*list scan amp/
*ant 21 17 10 19 9 25 4 5 1 7 2 24 15 3
*aver scan vect
*go m
LISTER EXECUTION    on    1982JUN02    at    10:00
====== =========
***82APR29***
  Source:Q     C  Band    Flux    StartIAT  StopIAT   StartLST   A-Obs. Freq-C
   SS433:0         6cm 1.000Jy  13:02:30 13:17:10  20h20m20s  4885MHz  4885MHz
Scale: x1.0E+03   AA upper right, CC lower left
  A-21---17---10---19--- 9---25--- 4--- 5--- 1--- 7--- 2---24---15--- 3--
21|        116  106  115   82   99   84   96   89   79   60   96   72   59
17|  118        102  113   80   97   83   95   92   77   59   94   70   56
10|  117  111        104   78   89   79   87   88   71   58   89   65   56
19|  129  124  122         80  102   83   97   89   80   60   94   73   57
 9|  106  101  105  111         70   81   76   74   53   61   75   47   66
25|  100   95   94  106   88         78   96   91   79   52   89   73   51
 4|   87   83   84   92  104   76         78   70   45   79   72   39   88
 5|  104  100   97  110  100   98   81        108   88   50  101   82   49
 1|   98   96   95  107   96   93   75  111         91   47  109   78   50
 7|   70   68   67   76   59   68   40   81   80         26   90  110   23
 2|   69   66   70   73   90   56   91   60   58   26         49   20   94
24|   99   99   96  106   97   89   74  108  111   81   56         86   47
15|   72   71   67   78   58   69   38   85   83   96   24   88         20
 3|   57   55   58   61   79   47   86   51   47   20  104   45   19
Data average: 13:10:05 <amp>=     2 +/-   1 <phi>= -78d +/- 116d   Navg=   5460
Matrix average:        <amp>=     2 +/-   4 <phi>= -78d +/- 637d   Navg=    182
```

POLCAL is a program used to determine, and store in temporary disk files, polarization parameters that can be applied to the gain table of a data base with the GTBCOR program. The needed input data for polarization calibration are observations of a single calibrator (for each frequency needed) over a sufficient range of parallactic angles so that a polarization solution is possible. The calibrator need not be polarized, but should be strong enough so adequate signal to noise is available for the instrumental portion of AC and CA correlators. POLCAL also solves for the percentage of linear polarization and position angle.

```
POLCAL INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . POLCAL
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . Nonsense
calcodes. . . . . *
antennas. . . . . *
refant. . . . . .  1 (Physical ID)
band. . . . . . .  6.0cm
modes . . . . . . '  '
passflag. . . . . UNFLAGGED
uvlimits. . . . . NONE
  (MISC) ===========
outfile . . . . . LPT::POL6CM
calibration . . . APPLY
average . . . . . SCAN
  (POLCAL) =========
IFidentifier. . . AR
poloption . . . . SOURCE  INCOMP NOFAR
phaseoffset . . .      .00d
```

POLCAL

```
POLCAL COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT,POLCAL

help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT,POLCAL
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go ANTENNAS                               Calculate  antenna  polarizations.
go BASELINES                              Calculate baseline polar
izations.
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives POLCAL
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .   Calcode(s) to be selected.
antennas <physical IDs>                   Antenna selections
refant <ID>                               Specify the reference antenna.
band 1.3cm|2cm|6cm|20cm|<freq>            Band or frequency.
modes '  '|IA|<2char>|* . . .             Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                          Pass flagged data.
uvlimits <option><umin/uvmin><umax/uvmax><vmin><vmax>
                                          Limits on baselines
                                          NONE - no limit on baselines
                                          ANNULAR - limit baselines to
                                                 an annulus. Specify
                                                 <uvmin><uvmax>.
                                          RECTANGULAR - limit baselines
                                                 to a rectangular area.
                                                 Specify <umin><umax>
                                                 <vmin><vmax>.
outfile dev:file.ext[p,pn]                Output file.
calibration NONE|APPLY|UNDO.MODCOMP       Calibration using gain table.
average <time>|SCAN                       Averaging time
IFidentifier AR|AL                        IF channel A right or left
                                          circularly polarized.
poloption SOURCE|NOSOURCE  COMP|INCOMP    SOURCE-solve for source pol.
                                          NOSOURCE-assume source pol.
                                          COMP-data set must be complete.
                                          INCOMP-data set can be incomplete.

                                          FAR-Apply Faraday correction.
                                          NOFAR-Do not apply Faraday correction.
phaseoffset  <angle>                      Phase to be added to IF A soln.
```

The process of polarization calibration with POLCAL is very simple although it involves a number of sequntial steps. Most observing runs where at least one calibrator is observed at a number of different angles will have a sufficient range of parallactic angles to allow determination of instrumental polarization parameters.

Data selection for the POLCAL polarization solutions use the commands:

DBNAME SOURCES CALCODES ANTENNAS REFANT BAND MODES PASSFLAG UVLIMITS

with the special restriction that only one source and one band can be used at a time. One generally sets the CALIBRATION command to apply the gain table and, although one can vary the data averaging time with the AVERAGE command, one mostly uses SCAN averaging to improve signal to noise.

Once the proper data selection parameters are set, one uses the OUTFILE DSK:filnam command to assign the name of the polarization parameter files that are created as part of the solution - this is the name supplied as the INFILE to GTBCOR when applying polarization calibration. Setting OUTFILE TTY: can be used to evaluate the polarization solution before storing the parameters on disk.

We recommend using the GO ANTENNAS command to carry out antenna-based polarization calibration. The resulting solution is written into a filnam.PRM file and summary information is written into a file named filnam, where filnam was as given with the OUTFILE command. The following is a brief excerpt of the information sent to TTY: or DSK:filname:

```
SOURCE:   1947+079 *
BAND: 6cm   FREQ:  4885.1MHz   BW:  50MHz
START                 82FEB14  at   12:15:05  IAT
STOP                  82FEB14  at   21:32:40  IAT
NUMBER OF AVERAGED TIME STAMPS: 0015.   REFERENCE ANTENNA USED:  17.
Antenna polarization paramters.
  1 A     1.56(  .04)   -160.1( 1.4)     1 C     1.70(  .04)     -64.4( 1.3)
  2 A      .45(  .04)   -170.1( 4.8)     2 C      .69(  .04)     -89.5( 3.3)
  3 A      .70(  .04)   -173.6( 3.4)     3 C     2.58(  .04)     -89.4( 1.0)
    . . .
 28 A      .74(  .04)    -97.2( 3.1)    28 C     1.15(  .04)    -106.4( 1.9)
Source polarization.
Real soln:          .25( .01)       33.9( 1.9)   RMS:      .5471
Imag. soln:         .25( .01)       15.7( 2.6)   RMS:      .5200
Avge. poln:         .25( .01)       24.8( 1.7)
Parallactic angle coverage is (angle in degress):
angle      5  15  25  35  45  55  65  75  85  95 105 115 125 135 145 155 165 175
counts        1       1   1   2   1                       3   3   1   1       1
```

POLCAL

The bottom of the previous display shows the parallactic angle coverage used in the solution. A wide range of sampling should mean a good solution. Two prime indicators of a good solution are: polarization amplitudes and phase with reasonably small rms's; and good agreement for the real and imaginary parts of the solution for source polarization (also with low rms's). If an isolates antenna-IF has very large rms's, it is best to delete that antenna and re-solve for polarization parameters (and delete it from subsequent use of polarization data, as for making Q and U Stokes parameter maps).

Once one has all the needed filnam.PRM files on disk, one runs GTBCOR to apply the polarization calibration. After setting the appropriate data selection parameters, the polarization calibration is applied by successive execution of INFILE filnam, GO GETPOLTABLE, and GO POLTABLECOR.

Next one must use LISTER to find the absolute position angle of a strong polarization calibrator like 3C286. Using LISTOPTION PHASE NEGCA, IFPAIRS AC CA, AVERAGE SCAN VECTOR, and only antennas for which a good polarization solution was possible, obtain a GO MATRIX listing which should have all nearly constant phases, and a good phase average of all correlators (= TACobs) at the bottom of the listing. Knowing the absolute position angle for the polarization calibrator, TC (66^{o} for all bands for 3C286), one computes an AC/CA phase correction TAC = TC - TACobs.

Next one applies absolute position angle calibration using GTBCOR. In addition to the usual data selection parameters, one types

PHASESHIFT TAC ; using the TAC determined as above, and

GO ACPHASECOR

to apply the position angle calibration. You have then calibrated the polarization data in your data base.

It can be reassuring to re-do the listing of the LISTOPTION PHASE NEGCA for AC and CA IFs to verify that the polarized source (like 3C286) has the correct (previously assumed) value of TC. One can also now "edit" the polarized data for other sources on the basis of LISTER or VISPLT displays.

SETJY is a program that inserts or lists flux density (I Q U V Stokes parameters) in selected dbname.INX[14,PN] files of a data base. This is done mostly for calibrators. The SETJY program is normally used to put flux densities into a data base before the ANTSOL uses the calibrator data to either BOOTSTRAP fluxes from 3C286 data and/or solve for antenna-IF amplitude gain factors. Similarly, the AMP/JY options in programs like LISTER and VISPLT will not be useful until SETJY (and GO BOOTSTRAP in ANTSOL) has inserted flux density information in the INX file.

```
SETJY INPUTS
===== ======
  (GENERAL) ========
jobname . . . . . SETJY
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . CAL
stokes. . . . . . I
band. . . . . . .  6.0cm
  (MISC) ==========
fluxes. . . . . .  .000Jy
```

The SOURCES and FLUXES commands in SETJY must have a matching number of source names and fluxes. Only a single BAND and STOKES parameter can be specified with a single GO SETJY execution. The GO RESET command can be used to reset selected flux densities to zero, and the GO LIST command allows one to list the current values of IQUV Stokes parameters for the specified sources and bands.

SETJY

```
SETJY COMMANDS
===== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go SETJY | RESET | LIST | COPY            SET, RESET, LIST or COPY fluxes
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives SETJY
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .   Calcode(s) to be selected.
Stokes FORMALI|I|Q|U|V                    Stokes parameter
band 1.3cm|2cm|6cm|20cm|<freq>            Band or frequency.
fluxes <flux>,<flux>, . . .               Specify fluxes for each source
                                            in the SOURCES command.
```

VISPLT is a program for plotting selected visibility amplitudes, amplitudes/Jy, or phases as a function of IAT days, IAT in hours, LST, hour angle, parallactic angle, antenna elevation, antenna azimuth, radial distance in the u-v plane, or angular distance in the u-v plane. Plots can be output to the line printer, ordinary terminals, or in the form of high resolution plots on a TEK 4012 (or equivalent) terminal. Data can be averaged with respect to time, and/or antenna-IF pairs, and/or various ways to combine IFs. Once can control plotting symbols, line types (if data points are to be connected by lines), and the scales and sizes of plots.

```
VISPLT INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . VISPLT
jobtime . . . . .  0:05:00
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
ifpairs . . . . . AA, CC
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . . UNFLAGGED
  (MISC) ==========
outfile . . . . . LPT:PLOT=OVERWRITE
calibration . . . NONE
average . . . . .  0:00:00 VECTOR
baselineaver. . . NONE
ifcombination . . NONE
  (PLOT) ==========
xaxis . . . . . .  IAT,DAYS
yaxis . . . . . .        .0000 TO  1000.0000 AMPLITUDE
title . . . . . . 'Visibility Data'
pointtypes. . . . LOWERCASE NOBAR
linetype. . . . . NONE SEPARATESCANS
distinguish . . . NONE
plotoptions . . . DISPLAY  STDSIZE
autoscaleopt. . . CHANGE  XRANGE  YRANGE  ALLTIMES
sizeplot. . . . . LPT  (132 by 58)
```

VISPLT

VISPLT COMMANDS

Command	Description
getcommands <file-specification>	Do the commands in the given file.
savecommands <file-specification>	Save current inputs in given file.
inputs <kind> | <nothing>	Give display of current inputs Legal catagories of inputs are: GENERAL,DATASELECT,MISC,PLOT
help <kind> | <nothing>	Type help text. No argument gives all help text. Legal kinds are: GENERAL,DATASELECT,MISC,PLOT
setdefaults	Set INPUTS to original defaults
finish	Stop program and leave.
go plot	Plot visibility data
go autoscale	Scan data & set plotting params as specified by AUTOSCALEOPT
go reshow	Redisplay the plot image
go clearpic	Kill all plots
go kill <nothing>|<plot number>	Delete last (or specified) plot
go blank <nothing>|<plot number>	Temporarily delete last (or specified) plot
go unblank <nothing>|<plot number>	Restore BLANKed plot
go savepic <nothing>|dev:file[p,pn]	Save plot in a file
go getpic <nothing>|dev:file[p,pn]	Display plot from a file
jobname <1 to 6 chars>	Name of batch job
jobtime <time>	Max. time for running batch job
batch <argument>	Same as GO <argument> but do it in batch.
explain <program name> | <empty>	Type explanation of the given program. <empty> gives VISPLT
timerange <start> to <stop>	Time period. <start>,<stop> syntax: <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]	Database to be used
sources <sourcename>:<qual> . . .	Specify sources and qualifiers.
calcodes A|B|C|D|E|F|CAL|NONCAL|* . . .	Calcode(s) to be selected.
antennas <ID list> WITH <ID list>	Baselines. Each antenna in list 1 is paired with all antennas in list 2
ifpairs AA|CC|AC|CA|* . . .	IF pairs or correlators
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .	Bands or frequencies
modes ' '|IA|<2char>|* . . .	Observing mode names
passflag UNFLAGGED | DEC | MODCOMP | BOTH	Pass flagged data.
outfile <file specification>=<type>	Output file and type
calibration NONE|APPLY|UNDO.MODCOMP	Calibration using gain table.
average <time>|SCAN VECTOR|AMPSCALAR	Averaging time and type
baselineaver NONE|VECTOR|AMPSCALAR	Type of baseline averaging
ifcombination NONE|FORMALI|I|Q|U|V |RATIO|LINEARPOL|CIRCULARPOL|AVERAGE	IF combination
xaxis <number> TO <number> IAT.DAYS| IAT.24HR|LST.DAYS|LST.24HR|HA| ELEVATION|AZIMUTH|PARALLACTIC| UVDISTANCE|UVANGLE	Range and kind of xaxis. Don't give range for IAT.DAYS and LST.DAYS.

yaxis <number> TO <number> AMPLITUDE|AMP/JY|PHASE	Range and kind of y-axis.
title <string>	Specify plot title.
pointtype NONE | VLINE | HLINE | CROSS | TRIANGLE | SQUARE | DOT | <char> | DIGITS | LOWERCASE | UPPERCASE | SYMBOLS | ALLCHARS NOBAR|RANGEBAR|RMSBAR|ERRBAR	Specify type of point to be plotted and whether or not to draw bars.
linetype NONE | SOLID | SHORTDASH | LONGDASH | DOTDASH | <char> SEPARATESCANS | CONNECTSCANS	Specify the type of line to be plotted and whether to separate scans.
distinguish NONE|SOURCES|QUALS |ANTENNAS-IFPAIRS|BANDS|PASSFLAG	What category of thing is to be plotted with different symbols
plotoptions DISPLAY|NODISPLAY	Display or not on GO PLOT
STDSIZE|MAXSIZE	Amount of image for the axis
autoscaleopt CHANGE | NOCHANGE	Change plot range or not
YRANGE | NOYRANGE	Look at Y data range or not
XRANGE | TIMERANGE | NOXRANGE	Look at X data, times, neither
SELECTEDTIMES | ALLTIMES	Range of time to look at
sizeplot LPT:|TEK:|ADDS:|SUPERBEE: |IMPS:|<width> by <height>	size of character image

The VISPLT program for plotting visibility is both complex and flexible. This is because there are a large number of plotting-oriented commands with a very large number of possible ways in which the parameters of these programs can be combined.

The selection of data for VISPLT involves the following commands:

DBNAME	TIMERANGE	SOURCES	CALCODES	ANTENNAS
IFPAIRS	BANDS	MODES	PASSFLAG .	

Plots can be made with or without the gain table applied, depending upon the CALIBRATION command. The AVERAGE command can be use to vary the degree and type of averaging with respect to time for individual baselines within scans. The BASELINEAVER command allows one to optionally average multiply specified baselines (in the ANTENNAS command) by either AMPSCALAR or VECTOR averaging. In addition, one can combine baselines specified with the IFPAIRS command in a number of ways, including those that define the four Stokes parameters and linear or circular polarization.

VISPLT

The XAXIS and YAXIS commands are used to change both the type of data plotted for each axis and the range of data for each plot. Data outside the specified ranges are indicated by symbols on the plot boundaries.

Descriptive titles can be attached to plots using the TITLE command.

The POINTTYPE command can be used to control the plotting symbols and the type of (optional) error bar to be associated with each plotted point. One can connect plotted data points with lines of different types according to the LINETYPE command. The DISTINGUISH command allows one to specify which parameters (like SOURCES, BANDS, ANTENNA-IFs, etc.) are to be distinguished by different symbols, such as different UPPERCASE or LOWERCASE characters.

The PLOTOPTIONS command can be used to turn immediate plot display on or off, and to vary the portion of the terminal screen to be used for the actual plot. Related to this, one can use the SIZEPLOT command to set a specified plot size, or invoke a standard size for different terminals and the line printer.

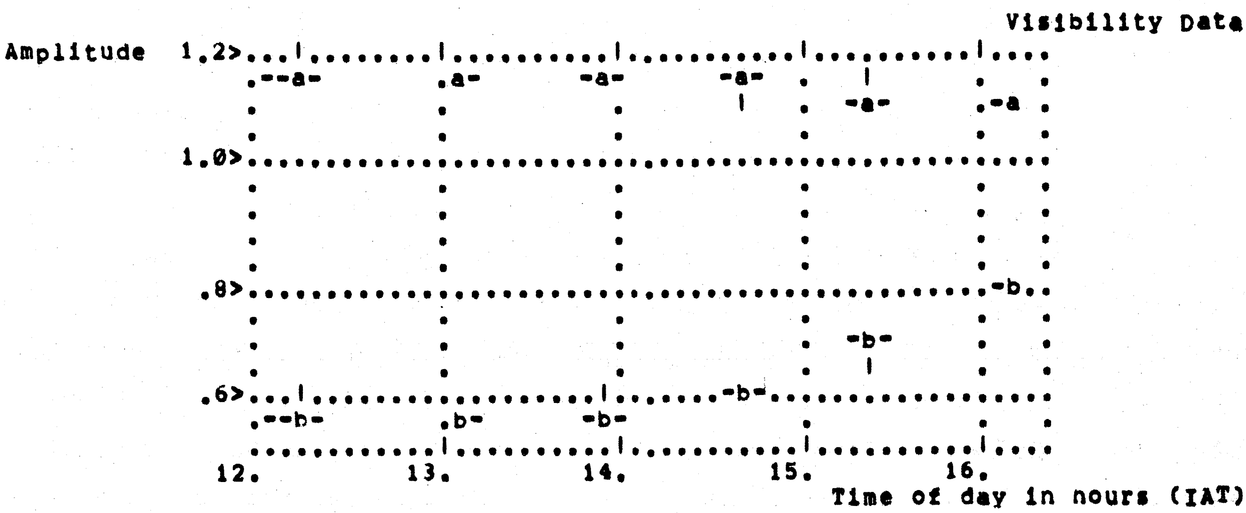
The OUTFILE command which controls the disposition of each plot has the syntax <dev>:<name>=<option>, where <dev> can be TTY, TEK, or LPT, <name> is a file name if the plot is to be stored on disk, and <option> is OVERWRITE or EXTEND, depending upon whether disk files of the same name are to be overwritten or added to when the plot is produced. For direct output to TEK: or TTY: only the device specification is used. For output to LPT: however, the plot is writin into a <name>.DAT file which must be printed out later with a PRINT command at the operating system level. It is most helpful to specify non-standard SIZELPOT parameters when the OUTFILE is LPT:, because one can make line printer plots on more than one page. The default plot size for a single LPT: page is 132 X 61. To obtain higher resolution one can make the plot come out to n full pages by setting <width> or <height> to 61 + 66(n-1), while <height> or <width> is set to 132. When <width> > 132, the plot is rotated with the x-coordinate down the page and the y-coordinate across the page.

The AUTOSCALEOPT command gives the parameters determining how the GO AUTOSCALE command is to work. GO AUTOSCALE intiates an examination of all selected data with the objective of determining the maximum and minimum values of the x- and y-coordinates. If AUTOSCALEOPT is set to CHANGE, the x- and y- ranges of the XAXIS and YAXIS commands are then modified to correspond to what GO AUTOSCALE finds. With NOCHANGE, the axis range information is only displayed on the terminal screen. Depending upon whether YRANGE or NOYRANGE is set, GO AUTOSCALE will or will not search for the YAXIS range parameters. The choice of NOXRANGE, XRANGE, or TIMERANGE means GO AUTOSCALE will not search for the range of x-coordinate data, will search for the range of x-coordinate data, or will search only for the time range of the x-coordinate data. Independent of all these, the SELECTEDTIMES or ALLTIME choice of parameters determines whether GO AUTOSCALE will carry out its search of the x-coordinate data only for the time range specified, or whether it will search all times regardless of the TIMERANGE command parameters.

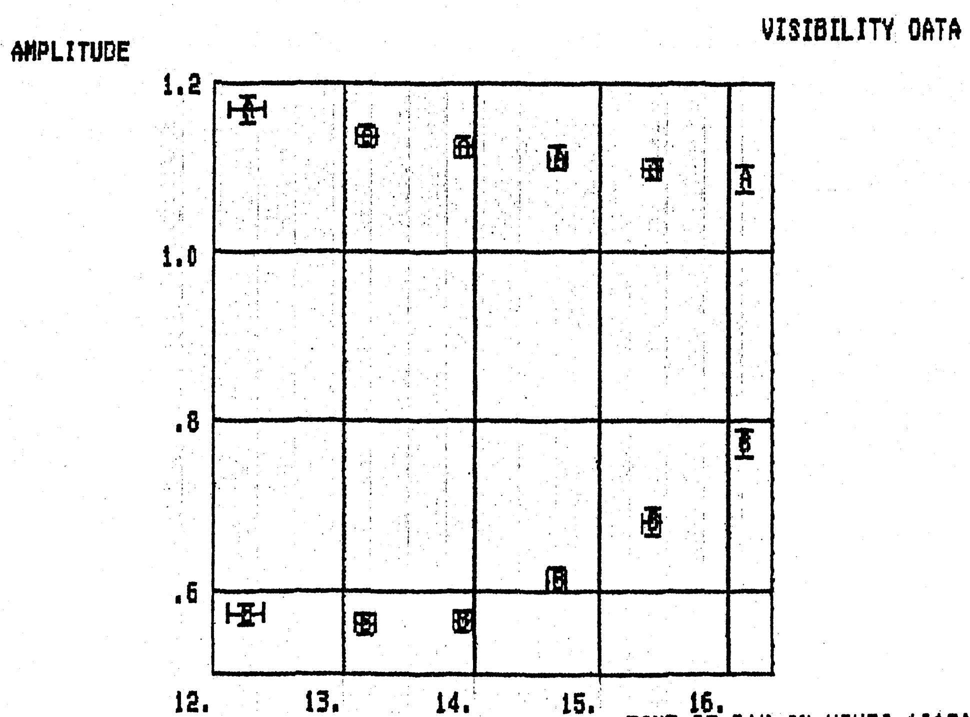
In addition to GO PLOT, which intitiates preparation of a plot, and GO AUTOSCALE which has already been discussed, there are seven other GO <type> commands in VISPLT. The GO CLEARPIC command can be used to delete all plots that have been made; otherwise new plots are added on top of old. GO CLEARPIC must be used before changing scales on the x- or y-axis. The GO BLANK and GO UNBLANK commands can be used to temporarily delete, and then restore, plots. The plot number refers to the order of successive plots. The GO SAVEPIC and GO GETPIC commands save and get plots stored on disk.

The following are examples of a character plot and a high resolution plot on a TEK 4012 (or equivalent) terminal:

VISPLT



CAPR29[14,]
1 Amp SS433:* * * 17-? AA Cal:A
TAve:Scan V BAve:N PFlg:0 Mode: Bar:RMS
Distinguished Antennas: a 17-21; b 3-17



CAPR29[14,]
1 AMP S3433:* * * 17-? CC CAL:A
TAVE:SCAN V BAVE:N PFLG:0 MODE: BAR:RMS
DISTINGUISHED ANTENNAS: A 17-21; B 3-17

Chapter 9

INITIAL IMAGE PROCESSING

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June 1982 Edition

ABSTRACT

The main programs used to do initial image processing in the DEC-10 in the VLA computer room are briefly summarized. This processing involves map-making, cleaning, self-calibration, and image display using DEC-10 programs. The computations involved in these programs are done in the DEC-10, the MAPPER system, or the SORTER/GRIDDER system, depending upon the program and the user-specified options.

This Chapter assumes a familiarity with the general overview in Chapter 7. The methods of using these programs are treated in Chapter 13.

More detailed discussions of the initial image processing programs can be found in the Observers Reference Manual.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. DOCUMENTATION OF PROGRAMS USED FOR INTIAL IMAGE PROCESSING

The pages following section 2 of this Chapter present brief documentation of some of the major programs in the DEC-10 off-line data reduction system which are used for what can be called initial image processing. Section 2 summarizes the major uses of each program and the order in which they are generally used.

The programs are presented in alphabetical order. The first two pages of the documentation for each program will be in the same format, with the program's INPUTS display on the first page and the program's HELP display on the second page. If either or both of these pages have extra space, it may be filled with additional discussion of the programs. Subsequent pages for each program will appear in odd-even pairs.

The basic idea for most of this Chapter is that of a quick reference section where a brief summary of information about each program is presented. More detailed information for each program can be found in the Observer's Reference Manual (ORM).

The 2*n pages for individual programs in this Chapter can be independently updated in a manner similar to the approach towards the separate chapters in this Introduction.

2. SUMMARY OF USE OF EACH INITIAL IMAGE PROCESSING PROGRAM

MAKMAP	Make dirty maps, dirty beams, and transfer functions for selected source data and specified mapping parameters. This program initiates the transfer of mapping parameters and visibility data to the MAPPER or SORTER/GRIDDER systems where the computations are made, and the resulting images are stored on disk.
CLEAN	Either a sub-program within MAKMAP or a separate program that can be used to specify and initiate map cleaning for images where both dirty maps and transfer functions have been made in MAPPER or SORTER/GRIDDER.
SELCAL	Either a sub-program within MAKMAP or a separate program that can be used to specify and initiate self-calibration for images which have been mapped and cleaned in MAPPER or SORTER/GRIDDER.
CATLST	A program that can be used either to derive information about maps and transfer functions stored in MAPPER or SORTER/GRIDDER systems, or to transfer maps and related information from one of these systems to the DEC-10.
PROBE	A program for determining the status of mapping/cleaning/self-cal jobs and images in the MAPPER or SORTER/GRIDDER systems.
DECMAP	A program (like MAKMAP) used to make dirty maps and beams from selected data, with computation and image storage in the DEC-10. Used only for small images.
CLNMAP	A program (like CLEAN) used to clean dirty maps, using dirty beams, stored on disk in the DEC-10. Used only for small images.
SEEMAP	A program for displaying maps stored on disk in the DEC-10. Will list summary information. Image displays are primarily contour maps and "character" maps. Generally used only for small images.

TEKDMP A non-standard program which displays contour maps on a TEK terminal, using specified plot files previously made by SEEMAP and stored as .DAT files on disk.

FITS A program used to make disk to tape or tape to disk transfers of images. Can also make summary listings of maps stored on FITS tapes. Generelly used to transfer images between any of the systems that process maps: DEC-10, MAPPER, SORTER/GRIDDER, DISPLAY, and AIPS.

A program that can be used either to derive information about maps and transfer functions stored in MAPPER or SORTER/GRIDDER systems or to transfer maps and related information from one of these systems to the DEC-10.

```
CATLST INPUTS
====== ======
  (DATASELECT) =====
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
sources . . . . . *:*
bands . . . . . . *
  (MISC) ===========
outfile . . . . . TTY:
  (CATLOG) =========
inmachine . . . . MAPPER
mapname . . . . . *
stokes. . . . . . *
typemap . . . . . *
rename. . . . . . NO
cmpstep . . . . .   50
copy. . . . . . . MAP
```

Maps, beams, transfer functions, etc. in MAPPER or SORTER/GRIDDER are organized on disk in an "area" for each user with an integer catalog number for each "image". The GO LIST command can be used to examine one line summaries of information for all images, while the GO LIST n:m command can be used to see the summaries for catalog entries n through m. The following is an example of the resulting display for a dirty map, dirty beam, transfer function, and clean map:

```
01  ASCOC.MI6  ANTARES  82APR09 04h21m14s 512 512 0005E3.MAP
02  ASCOC.BI6  ANTARES  82APR09 04h27m20s 512 512 0006C0.BEM
03  ASCOC.XI6  ANTARES  82APR09 04h33m34s 512 512 0007A2.GWT
04  ASCOC.KI6  ANTARES  82APR09 05h34m55s 512 512 001E5D.MAP
```

where: the first column shows the catalog number; the second column contains the combination of the user-specified mapname, and an extension indicating the type of image, stokes parameter, and band; the third column is the source name; the fourth and fifth columns give the date and time the image was made; the sixth and seventh columns give the X and Y dimensions of the image; and the last column gives animage designation used, with leading zeros being significant, to specify images in the CLEAN and SELCAL programs.

CATLST

```
CATLST COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT,CATLOG
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT,CATLOG
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go list|delete|copy                     list or delete catalog entires
        list <start>:<stop>             list records start to stop
        index <start>:<stop>            list complete map index
        delete <start>:<stop>           delete records start to stop
        copy <start>:<stop>             copy maps from start to stop
        fits <start>:<stop>             copy map onto fits tape
        within start and stop records, mapname, stokes,band, and maptype
        limit catalog selection, * = all.

explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives CATLST
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
sources <sourcename>:<qual>  . . .      Specify sources and qualifiers.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . . Bands or frequencies
outfile dev:file.ext[p,pn]              Output file.
inmachine <input computer name>         MAPPER,DISPLAY,DEC10,SORTER
mapname                                 Map name selection
Stokes *|F|I|Q|U|V|A|C  stokes parameter selection
typemap  MAP|XFR|BEAM|AMP|COVER|CLEAN   Type of map to select
rename NO|YES                           require new mapname for copy.
cmpstep  <number>                       Go copy components lists
                                        the first 50 and then every cmpstep
                                        component on the outfile.
copy  <file type>                       Specifies file copied by GO COPY
                                        MAP,CMP,LOG,GAIN,HISTORY
```

The GO DELETE command can be used to delete maps from disk storage on the specified INMACHINE. The GO INDEX command can be used to list map header information.

The GO COPY command allows the information specified by the COPY (and CMPSTEP) command(s) to be transferred to [14,PN] areas in the DEC-10; in this way one can transfer maps, lists of clean components, lists of gain (amplitude and phase) corrections associated with a self-calibrated image, LOG, or HISTORY files.

The CLEAN program is either a sub-program of MAKMAP or a program with the same commands as the MAKMAP sub-program. CLEAN is used to initiate requests for sidelobe correction of dirty maps made in MAPPER or SORTER/GRIDDER. The CLEAN algorithm implemented in the PDP 11 systems is that formulated by B.G. Clark (Astron. Ap., 89, 355, 1980).

```
CLEAN INPUTS
***** ******
  (CLEAN) **********
dirtymap. . . . . 001E55.MAP
componentfile . . CLEAN.CMP
xfrfile . . . . . 0007C3.GWT
loopgain. . . . .   .500
limit . . . . . .  .0500
maxiteration. . .    100
restart . . . . . NO
beamoption. . . . FIT
box . . . . . . . NONE
mapname . . . . . MAPPER:MAKMAP
```

The MAPNAME command specifies both the name of the dirty map and whether the mapping was done in the MAPPER or SORTER/GRIDDER systems. The names supplied by the DIRTYMAP and XFRFILE command are the image designations (with leading zeros required) of the required dirty map and transfer file as found with the CATLST program. The LOOPGAIN command supplies the fraction of each map extrema to be subtracted as a component during the subtract phase, usually something like 0.3. The CLEAN will subtract components until either the number of components indicated by the MAXITERATION command is reached, or the fraction of the initial maximum indicated by the LIMIT command is reached.

The BEAMOPTION command can be used to have the program solve for the restoring beam parameters (FIT), have the program not restore the subtracted components (NONE), or to supply the major axis, minor axis, and position angle of the major axis for the restoring beam.

CLEAN

```
CLEAN COMMANDS
===== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,MISC,PLOT,CLEAN

help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,MISC,PLOT,CLEAN

setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go SHOW                                   Exit to SEEMAP program.
go CLEAN                                  Queue an 11/70 CLEAN request.
go KILL                                   purge current request.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives MAKMAP

dirtymap <30 char or less>                specify a dirty mapfile
componentfile                             specify a component file
xfrfile                                   specify a transfer function  file name.
loopgain  <number>                        Clean subtraction fraction (gain).
limit  <number>                           Cleaning limit fraction.
maxiteration  <number>                    Limit for total number of clean
                                          subtractions.

/noiselevel  <number>                     Diagnostic level.
restart   NO| <number>                    Begin cleaning dirty map OR
                                          continue cleaning residual map
                                          from specified component number.

beamoption  FIT|NONE|<Maj><Min><Pa>       11/70 Clean beam options.
   fit                                    Fit beam parameters.
   none                                   None means dont't restore clean beams.
   <major axis - cells|arcseconds>        Enter beam parameters .
   <minor axis - cells|arcseconds>
   <position angle - degrees>
model   NO|YES                            Make only components map.
box n x1 y1 to x2 y2 at RA DEC            Specify n-th box.
box n  x by y at RA DEC                   Alternate box specification.
```

The BOX command can be used to supply any number of areas in which map components are to be subtracted. At the very least, this command should be used to limit the cleaned area to the inner 95% of the dirty map, since otherwise spurious cleaning can occur for noise bumps inflated by the grid correction in MAKMAP.

With the RESTART command one can choose to restart anew or continue a previously completer cleaning.

The resulting cleaned map is given TYPEMAP extension "K" when cataloged on disk. The CATLST or FITS program can be used to transfer maps to the system where they can be displayed and analyzed.

CLNMAP is a program used to apply the map cleaning algorithm to all or part of a dirty map stored in the DEC-10. The resulting "cleaned" map has, in principle, been partially or fully corrected for effects of synthesized (dirty) beam sidelobes. The DEC-10 CLNMAP program is used only for small images, with restrictions on the sizes of area to be cleaned, and the number of subtracted components that can be used, during prime working hours.

```
CLNMAP INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . CLNMAP
jobtime . . . . .  0:05:00
  (DATASELECT) =====
stokes. . . . . . . I
band. . . . . . . .  6.0cm
  (CLNMAP) =========
clnsize . . . . .    32
clncenter . . . .  0, 0 (cells)
nboxes. . . . . .     0
box . . . . . . . .
subpercent. . . . 50.000
limpercent. . . .   5.00
maxiteration. . .  100
posclean. . . . .     0
fitbeam . . . . .  0d0'0.0"  0d0'0.0" 0d0'0.0"
beamdisplay . . . NONE
restartsubtract . YES
  (MAPS) ==========
dmap. . . . . . . (DIRTY MAP)
dbeam . . . . . . (DIRTY BEAM)
cmap. . . . . . . (CLEAN MAP)
rmap. . . . . . . (RESIDUE MAP)
```

The DMAP and DBEAM commands specify the dirty map and dirty beam (must be of the same size) to be used. To obtain a map with a "cleaned" area of size CLNSIZE X CLNSIZE the dirty map must be of this size or larger and the dirty beam must be at least 2*CLNSIZE X 2*CLNSIZE. The CMAP command specifies the name of the resulting cleaned map and the RMAP command specifies the name of both the residual map created during the cleaning process and the clean components file; one may optionally specify a non-standard extension for the residual map file.

The STOKES and BAND parameters must match those for the dirty map and the dirty beam.

CLNMAP

```
CLNMAP COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT,CLNMAP,MAPS
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT,CLNMAP,MAPS
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go SUBTRACT|RESTORE                     Subtract components or restore map.
jobname <1 to 6 chars>                  Name of batch job
jobtime <time>                          Max. time for running batch job
batch <argument>                        Same as GO <argument> but do it
                                          in batch.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives CLNMAP
Stokes FORMAL|I|Q|U|V  stokes parameter
band 1.3cm|2cm|6cm|20cm|<freq>          Band or frequency.
clnsize <number>                        Total area to be cleaned (in cells).
clncenter  <x0> <Y0>                    Center position of clean area in cells.
nboxes <number>                         Number of clean search boxes (<20).
box <num> <right> <left>  <bottom> <top>Boundaries of n-th box.
          RAmin   RAmax   DECmin  DECmax
subpercent  <percentage>                Clean subtraction percentage (gain).
limpercent  <percentage>                Cleaning limit percentage.
maxiteration  <number>                  Max num of iter. in one subtract pass.
posclean  <number>                      First iteration for negative component removal.
fitbeam <major> <minor> <pangle>        Fit or specify beam params(ang. units).
beamdisplay NONE|NE|NW|SE|SW            Where on clean map to display beam.
restartsubtract YES|NO                  Begin cleaning original dirty map OR
                                        continue cleaning residual map.
dmap                                    specify dirty map name
dbeam                                   specify dirty beam name
cmap                                    specify clean map name
rmap                                    specify residue map name
```

Once the map input and output files have been specified with the DMAP, DBEAM, CMAP, and RMAP commands, the first step in producing a CLEANed map is the use of the GO SUBTRACT command to fit and subtract components, each of which is serially stored in a the file RMAPname.CMP[14,PN] on disk. The parameter-type commands controlling the compenent subtraction step are:

CLNSIZE	Size of the square area of the dirty map to be cleaned
CLNCENTER	Pixel coordinates of center of area to be cleaned
NBOXES	Number of boxes, or areas of the dirty map, from which point source components are to be subtracted
BOX	Command supplying location parameters for the n boxes
SUBPERCENT	The loop gain or percentage of each map extrema to be subtracted as a component (generally something like 30 for a normal clean or 10-20 for a "gentle" clean)
LIMPERCENT	The percentage of the original maximum in the map at which compenent subtraction is to be terminated. Applies only if this limit is reached before the number of components specified by the MAXITERATIONS command
MAXITERATION	The maximum number of components to be subtracted
POSCLEAN	The first iteration for which negative components may be subtracted

Once component subtraction begins with the GO SUBTRACT command, it continues until the LIMPERCENT level of components is reached, the MAXITERATION number of components has been subtracted, or the process fails to converge. When CLNMAP is run interactively the subtraction process can also be terminated at any point by typing CNTL/C. During the execution of GO SUBTRACT the parameters of the n-th component solved for and subtracted are displayed as follows:

```
component    n subtracted from cell     j,    k, peak value = m
```

where (j,k) is the pixel location of the subtracted component and m is an integer indicating the strength of the n-th compenent. The initial value for m is given by the SUBPERCENT*100, so for a SUBPERCENT of 30 the initial component is ±3000 and all subsequent components are a fraction of this.

CLNMAP

If the RESTARTSUBTRACT command is set to NO, the execution of a GO SUBTRACT command results in a continuation from the point where the previous subtraction left off; if set to YES, then GO SUBTRACT results in component fitting and source subtraction starting from the beginning again.

You subtract components until you are satisfied with the convergence and properties of the cleaning process, generally until one is subtracting equal numbers of positive and negative compoments or the level of subtraction is no longer changing significantly.

Once the clean components have been obtained, one makes the "cleaned" map by restoring the clean components into the residual map, with a "clean" beam (gaussain) shape rather than the original dirty beam shape, and a GO RESTORE command. The FITBEAM command allows you to specify the clean beam parameters: major axis, minor axis, and position angle of the major axis. If the FITBEAM parameters are zero, the program will solve for these parameters by a fit to the central part of the dirty beam. The CLNMAP program usually fits the major and minor axes quite well, but often make major errors in determining the position angle of the major axis.

When the restoration process begins after a GO RESTORE, one first sees of display of the fitted (or supplied) clean beam parameters followed by a character display of the dirty beam and the clean beam shown side by side, allowing judgement and re-specification of the clean beam. Following this, the program displays the total flux of restored components (sum of all clean component intensities) and the maximum and minimum intensities in the resulting CLEANed map.

Cleaning is generally useful when the dirty map shows one or more sources clearly above the noise; however, it is not useful to clean maps without sources that are distinctly above the noise. Maps with compact sources can generally be cleaned with relatively few clean components; however, extended sources required very large numbers of clean components, sometimes tens of thousands. Cleaning for large maps and large numbers of components should be done with MAPPER, SORTER/GRIDDER, or AIPS systems, but not the CLNMAP program in the DEC-10.

When subtraction and restoration has been completed one can display both the CLEANed map and the residual map with SEEMAP and other programs.

DECMAP is used to make dirty maps and/or dirty beams computed and stored in the DEC-10. It is the equivalent of MAKMAP for the MAPPER and SORTER/GRIDDER systems.

```
DECMAP INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . DECMAP
jobtime . . . . .  0:05:00
  (DATASELECT) =====
dbname. . . . . . [14,]
sources . . . . . *:*
antennas. . . . . *
bands . . . . . . *
passflag. . . . . UNFLAGGED
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
  (MAPPING) ========
mapname . . . . . DECMAP
category. . . . . [no-map-category]
stokes. . . . . . I
remarks . . . . . ''
cellsize. . . . .   .500" by   .500"
mapsize . . . . .  128 by  128 cells
rotate. . . . . . NONE
uvweight. . . . . UNIFORM
uvtaper . . . . . NONE      .000km
uvconvolve. . . . BOX    1.000 cell(s)
gridcorr. . . . . YES
subsources. . . . NONE
shiftcenter . . .        0       0 (both in cells)
addmaps . . . . . NONE
typemap . . . . . MAP
```

DECMAP always applies the gain table to the selected visibility data for a single source, source qualifier, and band (or frequency) - and uses the resulting calibrated data to compute dirty maps and/or beams using the FFT algorithm. The selection of input data involves the following standard data-selection commands:

DBNAME TIMERANGE SOURCE ANTENNAS BANDS PASSFLAG TIMERANGE

with the special restriction that only one source name, one qualifier, and one band can be specified. The name for the map or beam file to be produced is specified with the MAPNAME commands, and these files have three character extensions like XYZ, where X = M or B for dirty map or dirty beam, Y = I, Q, U, or V corresponding the the supplied STOKES parameter, and Z = L, 6, 2, or U for 20cm, 6cm, 2cm, and 1.3cm BANDS. The REMARKS command can be used to supply other "labeling" information between single or double quotes.

DECMAP

```
DECMAP COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT,MAPPING
help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT,MAPPING
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go MAKE                                   Make a map on the DEC-10.
go ADD                                    Add 2 maps together.
go SEEMAP                                 Exit to SEEMAP program.
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives DECMAP
dbname dev:filename[p,pn]                 Database to be used
sources <sourcename>:<qual>  . . .        Specify sources and qualifiers.
antennas <physical IDs>                   Antenna selections
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .   Bands or frequencies
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                          Pass flagged data.
timerange <start> to <stop>               Time period. <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
name <6 char or less>                     Name to be assigned to maps.
category  <name> | <nothing>              Identify (or not) maps by an SFD name
Stokes FORMAL|I|Q|U|V|A|C                 Stokes parameter
remarks  '<character string>'             Descriptive text for map.
cellsize <dxy> | <dx> <dy>                Cell size in angular units
mapsize <Nxy> | <Nx> <Ny>                 No. of (RA*COS(DEC),DEC) cells in map
rotate <number>                           Angle to rotate u v data.
uvweight  UNIFORM|NATURAL                 Type of u-v plane weighting
uvtaper GAUSSIAN|LINEAR|NONE  <width>     Type and width of tapering, e.g. 3km
uvconvolve GAUSSIAN|BOX  <size>           type and size of u-v convolution
gridcorr YES|NO                           Apply gridding correction to map?
subsources NONE|<Ii xi yi> with 1<=i<=4   Point source subtraction parameters
shiftcenter  <xshift> <yshift>            Map center shift, arcseconds or cells
addmaps <wt1> <map1>,<wt2> <map2>|NONE    Parameters for adding two maps
typemap  MAP|XFR|BEAM|AMP|COVER           Type of map to make
```

The principle commands used to specify mapping parameters are:

CELLSIZE	Angular size for each map cell, in arcseconds, roughly $(2''/N_{pts})(\lambda_{cm}/B_{km})$ where $N_{pts} \geq 2$ pts/beam
MAPSIZE	Number of pixels ($= 2^n$) on each side of the map
ROTATE	Rotation angle for map
UVWEIGHT	UNIFORM or NATURAL weight for each cell, usually UNIFORM for mapping experiments and NATURAL for detection experiments
UVTAPER	Type (usually GAUSSIAN) and size (in KM) of taper to be applied to u-v plane
UVCONVOLVE	Type and scale of averaging for data representing a single cell. Normally use GAUSSIAN and 1 cell for this command.
GRIDCORR	Correct map intensities for gridding effects? Usually YES. Inflates noise at map edges
SUBSOURCE	Subtract up to four sources from map
SHIFTCENTER	Shift mapping center from phase reference center by specified number of cells in X and Y

When map (or beam) making proceeds, after executing the GO MAKE command, DECMAP first carries out data selection, reporting the number of visibility records found for each observing scan. The program then grids the data into a MAPSIZE by MAPSIZE u-v plane array by UNIFORM or NATURAL weighting and BOX or GAUSSIAN convolution. Finally, the radio map is computed with the FFT algorithm, optionally corrected for gridding effects, and map header and map array information is written into the map data base file.

The TYPEMAP is usually either MAP or BEAM to make dirty maps and dirty beams, however, one can make (for SEEMAP display) maps of amplitude or u-v coverage with the AMP or COVER (=XFR) options.

Two maps can be added with relative weighting parameters using the ADDMAPS command to specify the parameters of the map addition.

DECMAP

FITS is used to transfer images from disk to magnetic tape or vice versa. Generally used to transfer images between any of the systems that can process images: DEC-10, MAPPER, SORTER/GRIDDER, DISPLAY, and AIPS.

```
FITS INPUTS
==== ======
  (MISC) ===========
outfile . . . . . TTY:FITS
bitpixtotape. . . 32
  (tape) ===========
taplabel. . . . . UNLABELED
  (file) ===========
mapfile . . . . . DSK:FITS.fi[14,]
headerfile. . . . DSK:FITS.hdr[14,]
tapfile . . . . . MTA:
```

FITS can be run after mounting the tape that is to be read from or written upon. The systems at the VLA site use UNLABELED tapes and the BITPIXTOTAPE is normally 32. The MAPFILE command is used to supply the name (and extension) the map file has (or will have) on the DEC-10. The HEADERFILE command can be used to make changes in the map header information before a map is written from tape to disk or vice versa. If HEADERFILE is NONE, then the map header is generated from information stored with the map.

The GO REWIND, GO SKIPFILE N, and GO UNLOAD commands allow control of the tape drive from inside FITS. The GO LIST command can be used to obtain a listing of the contents of a FITS map header on the specified OUTFILE device, while the GO INDEX-TAPE command can be used to obtain summary information about all the images on a FITS tape.

If the HEADERFILE command specifies the name of a disk file, the GO HEADER command will read the header information from the specified MAPFILE and write it in the named disk file. One can then exit from FITS and use the text editor (SOS) to make changes in the HEADERFILE. Additional COMMENT or HISTORY cards may be added, however the last line in the file must contain the END card image. Upon re-running FITS, the execution of a GO TAPE-FROM-DISK command will result in the storage of the map on tape with the modified header information.

FITS

```
FITS COMMANDS
==== ========
getcommands <file-specification>      Do the commands in the given file.
savecommands <file-specification>     Save current inputs in given file.
inputs <kind> | <nothing>             Give display of current inputs
                                        Legal catagories of inputs are:
                                        GENERAL,DATASELECT,MISC,PLOT,tape,file
help <kind> | <nothing>               Type help text. No argument gives
                                        all help text. Legal kinds are:
                                        GENERAL,DATASELECT,MISC,PLOT,tape,file
setdefaults                           Set INPUTS to original defaults
finish                                Stop program and leave.
go TAPE-FROM-DISK                     Write Map images disk to tape
go DISK-FROM-TAPE                     Create MAP diskfile from tape
go LIST                               List the Header diskfile on outfile
go REWIND                             Rewinds the magnetic tape
go DUMP                               Writes the tape header to outfile
go UNLOAD                             Rewind and unload the tapefile
go SKIPFILE n                         Skips + or - n files on the tape
go INDEX-TAPE                         Prints to outfile summary of tape
go HEADER                             Creates a HEADERFILE with default
                                           tape header values
explain <program name> | <empty>      Type explanation of the given
                                        program. <empty> gives FITS
outfile                               File to contain tape header listing
bitpixtotape <16 | 32>                Bits per pixel going to tape
taplabel <LABELED | UNLABELED>         Is the tape labeled or unlabeled?
mapfile                               Name of diskfile containing MAP
headerfile <LPT: | TTY: >             Name of file containing tape header
tapfile <MTA: | MTn: >                The name of the tape unit
```

Note that if an SOSed map header file is created and named with the HEADERFILE command, all maps transfered to tape under these conditions will have the same header. Either change the HEADERFILE or use HEADERFILE NONE.

The GO DUMP command can be used to write the headerfile associated with an image on a FITS tape to disk, where it can be modified before the image is stored on disk with the appropriate header information.

The DEC-10 FITS program requires that image transfers be carried out one image at a time.

The MAKMAP program is used to initiate the making of dirty maps, dirty beams, and/or transfer functions in the MAPPER or SORTER/GRIDDER systems. Parameter-type commands are used to specify the data-selection and mapping parameters, then GO MAKE results in the transfer of the selected visibility data, the specified mapping parameters, and the mapping request to the machine named in the MAPNAME command.

```
MAKMAP INPUTS
====== ======
  (DATASELECT) =====
dbname. . . . . . [14,]
sources . . . . . *:*
antennas. . . . . *
bands . . . . . . *
passflag. . . . . UNFLAGGED
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
  (MAPPING) ========
mapname . . . . . MAPPER:MAKMAP
version . . . . . SYSTEM
category. . . . . [no-map-category]
remarks . . . . . ''
cellsize. . . . .   .500" by   .500"
mapsize . . . . .  256 by  256
channels. . . . . not-line-data
pbcorr. . . . . . NONE
rotate. . . . . . NONE
uvweight. . . . . UNIFORM
uvtaper . . . . . NONE
uvconvolve. . . . GAUSSIAN      .500 cell(s)
uvmin . . . . . . NONE
gridcorr. . . . . YES
subsources. . . . NONE
shiftcenter . . . NONE
transform . . . . FFT
typemap . . . . . MAP
subfile . . . . . NONE
stokes. . . . . . I
```

The selection of visibility data involves the following standard dataselection commands:

DBNAME TIMERANGE SOURCES ANTENNAS BANDS PASSFLAG TIMERANGE

with the restriction that one can specify only one source, one source qualifier, and one band.

MAKMAP

```
MAKMAP COMMANDS
====== ========
getcommands <file-specification>        Do the commands in the given file.
savecommands <file-specification>       Save current inputs in given file.
inputs <kind> | <nothing>               Give display of current inputs
                                          Legal catagories of inputs are:
                                          GENERAL,DATASELECT,MISC,PLOT,SELFCAL,CLEAN,MAPPING

help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          GENERAL,DATASELECT,MISC,PLOT,SELFCAL,CLEAN,MAPPING
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
go MAKE                                 Make a map from visibility data.
go SHOW                                Exit to SEEMAP program.
go KILL                                purge current request.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives MAKMAP
dbname dev:filename[p,pn]               Database to be used
sources <sourcename>:<qual>  . . .      Specify sources and qualifiers.
antennas <physical IDs>                 Antenna selections
bands 1.3cm|2cm|6cm|20cm|<freq>|# . . . Bands or frequencies
passflag UNFLAGGED | DEC | MODCOMP | BOTH
                                        Pass flagged data.
timerange <start> to <stop>             Time period. <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
name <12 char or less>                  Name to be assigned to maps.
version SYS|NEW|EXPerimental            New - old switch for 11 programs.
category  <name> | <nothing>            Identify (or not) maps by an SFD name
remarks  '<character string>'           Descriptive text for map.
cellsize <dxy> | <dx> <dy>              Cell size in angular units
mapsize <Nxy> | <Nx> <Ny>               No. of (RA*COS(DEC),DEC) cells in map
channels <n1> to <n2> step <n3> avg <n4>Select spectral line channels
                                        set avg to -1 for HANNING smoothing.
pbcorr NONE|<filename>                  File name for passband correction.
rotate <number>                         Angle to rotate u v data.
uvweight  UNIFORM|NATURAL               Type of u-v plane weighting
uvtaper GAUSSIAN|LINEAR|NONE  <width>   Type and width of tapering, e.g. 3km
uvconvolve GAUSSIAN|BOX  <size>         type and size of u-v convolution
uv minimum GAUSSIAN|BOX|NONE  <width>   type and width of U V minimum
gridcorr YES|NO                         Apply gridding correction to map?
subsources NONE|<Ii xi yi> with 1<=i<=4 Point source subtraction parameters
shiftcenter NONE|<xshift> <yshift>      Map center shift, arcseconds or cells
transform  FFT|DFT                      Allows selection of DFT
typemap  MAP|XFR|BEAM|AMP|COVER         Type of map to make
subsources NONE|<nsub> <subsrcfile>     Number of sources and
                                        file name of sources to be subtracted.
Stokes FORMALI|I|Q|U|V|A|C              Stokes parameter
```

The principle commands used to specify mapping parameters are:

STOKES	Type(s) of map(s) to be computed - determines data combinations used in map making
CELLSIZE	Angular size for each map cell, in arcseconds, roughly $(2''/N_{pts})(\lambda_{cm}/B_{km})$ where $N_{pts} \geq 2$ pts/beam
MAPSIZE	Number of pixels (= 2^n) on each side of the map
ROTATE	Rotation angle for map (usually none)
UVWEIGHT	UNIFORM or NATURAL weight for each cell, usually UNIFORM for mapping experiments and NATURAL for detection experiments
UVTAPER	Type (usually GAUSSIAN) and size (in KM) of taper to be applied to u-v plane
UVCONVOLVE	Type and scale of averaging for data representing a single cell. Normally use GAUSSIAN and 1 cell for this command.
GRIDCORR	Correct map intensities for gridding effects? Usually YES. Inflates noise at map edges
SUBSOURCE	Subtract up to four sources from map
SHIFTCENTER	Shift mapping center from phase reference center by specified number of cells in X and Y
UVMIN	Optional specification of type and size of an taper applying to the inner portions of the u-v plane. Used to suppress short spacing data.
TRANSFORM	Usually FFT, but a transform type of DFT may be selected if a direct transform is desired.
SUBFILE	Name of file containing the same information as can be given with the SUBSOURCES command, except more than four sources can be subtracted.
CHANNELS	Specify either that it is not line data, or the the channels and type of averaging to be used in spectral line mapping
PBCORR	Specify (for line data) the name of the file containing the pass band correction information

MAKMAP

The VERSION command can be used to control which version of software to be used in the map-making process. The MAPNAME command is used to choose whether the MAPPER or SORTER/GRIDDER system is to be used for the map making. The CATEGORY command can be used to organize map files under a particular category. The REMARKS command can be used to supply supplementary information about the map to be made.

The TYPEMAP command can be used to specify one or more types of "maps" that are to be made from the same selected data. In order to clean maps in the selected mapping system, one must specify TYPEMAP MAP XFR to obtain both a dirty map and a transfer function. Maps of the type BEAM, AMP, or COVER are optional.

Spectral line maps can be made from pseudo-continuum data bases by specifing channel combination parameters with the CHANNELS command and an optional PBCORR file name containing pass band correction information.

The PROBE program can be used to determine the status of mapping, cleaning, and self-calibration jobs previously submitted to either the MAPPER or SORTER/GRIDDER systems.

```
PROBE INPUTS
===== ======
  (MISC) ===========
outfile . . . . . TTY:
  (PROBING) ========
sequence.num. . .   1
priority. . . . .   9
inmachine . . . . MAPPER
to.be.listed. . . MINE
format. . . . . . BRIEF
```

The INMACHINE command is used to specify either the MAPPER or SORTER systems. The TO.BE.LISTED command determines the type of information to be listed and the FORMAT command indicates the level of detail to be provided when a GO LIST is executed. Some options are

TRANSFER	List status of all requests that require transfer of visibility data from the DEC-10
ACTIVE	List information about requests that are currently involved in visibility data transfer, map making, cleaning, etc.
MINE	List information about all of your own outstanding requests
COMPLETED	List those requests that have recently finished without error
BOMBED	List those requests that have recently failed due to error
WAITING	List all requests that have completed (or do not need) visibility data transfer, but have not finished processing

One can use the SEQUENCE.NUM (found from GO LIST) to specify a request that is to: undergo a specified PRIORITY change; be killed; be held; or be released - using the GO SET, GO KILL, GO HOLD, or GO RELEASE commands.

The GO MESSAGE command can be used to obtain information about recently implemented features of PROBE.

PROBE

PROBE COMMANDS
===== ========

getcommands <file-specification>	Do the commands in the given file.
savecommands <file-specification>	Save current inputs in given file.
inputs <kind> | <nothing>	Give display of current inputs Legal catagories of inputs are: GENERAL,DATASELECT,MISC,PLOT,PROBING
help <kind> | <nothing>	Type help text. No argument gives all help text. Legal kinds are: GENERAL,DATASELECT,MISC,PLOT,PROBING
setdefaults	Set INPUTS to original defaults
finish	Stop program and leave.
go	LIST, SET, HOLD, KILL, RELEASE, MESSAGE
explain <program name> | <empty>	Type explanation of the given program. <empty> gives PROBE
outfile	LPT or TTY
sequence.num <number>	An arbitrary number
priority <number>	A number from 0 to 9
inmachine <computer name>	MAPPER,SORTER
to.be.listed	TRANSFER, ACTIVE, BOMBED, MINE,COMPLETED, WAITING or LOG
format	BRIEF or LONG

The PROBE program is communicating with a program called MAPCON running in the appropriate PDP 11 system. MAPCON controls all data input, mapping, cleaning, self-cal, and map output in each system. Through PROBE the user can obtain information about all tasks controlled by MAPCON and has some capability to modify the status for requests.

There is a PDP 11 version of PROBE running in each PDP 11 system.

SELCAL is either a sub-program in MAKMAP or a program with the same commands as the MAKMAP sub-program. SELCAL initiates self-calibration request for maps that have been made and cleaned in either the MAPPER or SORTER/GRIDDER mapping systems.

```
SELCAL INPUTS
====== ======
  (SELFCAL) ==========
gainfile. . . . . SELCAL.GAI
avgtim  . . . . . 300.0sec
listoption. . . . NONE
refant. . . . . . *
uvlimits. . . . . NONE
phaseonly . . . . YES
maxcomponents . . NONE
componentfile . . CLEAN.CMP
mapname . . . . . MAPPER:MAKMAP
```

The COMPONENTFILE command specifies the image designation (found with CATLST) for the CLEANed map whose components file will be used for a model (with all or MAXCOMPONENTS components) during the self-calibration process. The AVGTIM command specifies the time span about each gain table entry for which visibility data is to be averaged before carrying out the ANTSOL-like solution which is part of the self-calibration process. The REFANT command can be used to select the antenna whose phases are to be kept constant during the self-calibration process; if an * is specified the program will select a reference antenna based upon certain criteria of goodness. The UVLIMITS command can be used to specify the u-v range for which the data are to be used in the solution for self-cal corrections. The PHASEONLY command is used to specify only phase self-calibration, or both amplitude and phase self-cal - which can be useful for a last self-cal iteration.

SELCAL

```
SELCAL COMMANDS
====== ========
getcommands <file-specification>       Do the commands in the given file.
savecommands <file-specification>      Save current inputs in given file.
inputs <kind> | <nothing>              Give display of current inputs
                                         Legal catagories of inputs are:
                                         GENERAL,MISC,PLOT,SELFCAL
help <kind> | <nothing>                Type help text. No argument gives
                                         all help text. Legal kinds are:
                                         GENERAL,MISC,PLOT,CLEAN
setdefaults                            Set INPUTS to original defaults
finish                                 Stop program and leave.
go SHOW                                Exit to SEEMAP program.
go SELFCAL                              Queue an 11/70 self-calib. request.
go KILL                                purge current request.
explain <program name> | <empty>       Type explanation of the given
                                         program. <empty> gives MAKMAP
gainfile <30 char or less>             Specify gain file
avgtim <number(sec)>                   Average window for gain solutions
listoption NONE|GAINCOR|RATIO|ALL      Specify self-cal printout
refant <number> | *                    Specify reference antenna
uvlimits <MAX> <MIN> | NONE            Limit selfcal uv range
phaseonly YES | NO                     Solve for phase only
maxcomponent <number> | NONE           Use only maxcomponents in model
componentfile                          Specify clean map with components list
mapname MAPPER:mapnam | SORTER:mapnam  Specify PDP 11 and map name
```

The GAINFILE command can be used to carry out a second self-calibration, or to specify that maps are to be made from visibility data modified by a previous self-cal iteration.

The LISTOPTION command controls the type of information sent to the DEC-10 line printer after the self-cal is completed. With the GAINCOR option the list of amplitude and phase correction will be printed out. With the RATIO option a very long listing of the ratios supplied to the least squares algorithm solving for the ANTSOL-like solutions are printed out. With the ALL option, both of the above are printed. Under normal circumstances one needs only use LISTOPTION GAINCOR.

SEEMAP is a DEC-10 program for displaying information about radio maps, beams, or u-v plane information files (made with DECMAP or transferred using CATLST or FITS) that are stored in a users [14,PN] area.

```
SEEMAP INPUTS
====== ======
  (GENERAL) ========
jobname . . . . . SEEMAP
jobtime . . . . .  0:05:00
  (DATASELECT) =====
bands . . . . . . *
stokes. . . . . . I
  (MISC) ===========
outfile . . . . . TTY:MAP.DAT=OVERWRITE
  (MAPPING) ========
category. . . . . [no-map-category]
mapname . . . . . MAKMAP[14,]
typemap . . . . . MAP
  (DISPLAY) ========
displaynow. . . . YES
fitgauss. . . . .   0   0 (cells)    3    3 (cells)
profile . . . . .   0   0     90d
Irange. . . . . . *
sumlimit. . . . .       5.00
contours. . . . . 0 ...

polarization. . . NO
polskip . . . . .     4
xyskip. . . . . .    1 (cell(s))
window. . . . . . STD
index . . . . . . CURRENT   DETAILED
center. . . . . .    0    0 (Both in cells)
```

SEEMAP provides five types of displays of map information. The GO INDEX command in SEEMAP results in a display of map header information on the designated OUTFILE device. The GO SHOW command can be used to obtain two-dimensional displays of a map where map intensities are represented by: coded characters, if the OUTFILE is TTY: or LPT:, or contour lines at levels specified by the CONTOURS command if the OUTFILE is TEK:. The GO FIT command can be used to derive and list the parameters of a two-dimensional gaussian fit to a small region of the map (or beam) specified with the FITGAUSS command. The GO PROFILE command can be used to plot cross-sections through any pixel location and position angle specified with the PROFILE command. Finally, with the GO IMAP command one can list a matrix of numbers for the intensities of the specified WINDOW parameters.

SEEMAP

```
SEEMAP COMMANDS
====== ========
getcommands <file-specification>          Do the commands in the given file.
savecommands <file-specification>         Save current inputs in given file.
inputs <kind> | <nothing>                 Give display of current inputs
                                            Legal catagories of inputs are:
                                            GENERAL,DATASELECT,MISC,PLOT,MAPPING,DISPLAY
help <kind> | <nothing>                   Type help text. No argument gives
                                            all help text. Legal kinds are:
                                            GENERAL,DATASELECT,MISC,PLOT,MAPPING,DISPLAY
setdefaults                               Set INPUTS to original defaults
finish                                    Stop program and leave.
go INDEX|SHOW|PROFILE|FITGAUSS|           Make requested display or exit to MAKMAP
           IMAP|MAKMAP
jobname <1 to 6 chars>                    Name of batch job
jobtime <time>                            Max. time for running batch job
batch <argument>                          Same as GO <argument> but do it
                                            in batch.
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives SEEMAP
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .   Bands or frequencies
Stokes FORMAL|I|Q|U|V|A|C                 Stokes parameter
outfile <dev>:<file>=EXTEND|NULL          Specify output device type.
category <name>|<nothing>                 MAKMAP map category
mapname <6 chars or less>                 MAKMAP map name
typemap MAP|BEAM|CLEAN|AMP|COVER          MAKMAP type of map
displaynow yes | no                       show TEK immediately
fitgauss <x y width height>               Parameters for Gaussian fit in region.
profile <x y pa>                          Profile centered at (x,y) at angle PA
Irange * | <Imin> <Imax>                  Min and Max I(Jy) for display
sumlimit   <percent>                      IMAP will sum cells above
                                          this fraction of IMAX
contours <count> <list>                   Give list of contours for TEK:
                                          display as percentages of Imax.
polarization YES|NO                       whether to display polarization data.
                                          Only good for TEK: and you must have
                                          made I,Q,U maps.  Set STOKES to I.
polskip                                   Interval in pixels between
                                          polarization vectors
xyskip <spacing>|<xspacing> <yspacing>    Spacing of 1=every row & col,
                                            2=every other, . . .
window <xwidth> <yheight> <Isize>|STD     Width, height and # grey scale steps
                                            or use standard based on OUTFILE
index *|CURRENT  DETAILED|BRIEF           Index everything or just cerrent map
                                            and level of detail
center <xcenter> <ycenter>                Center display at this place in map
```

The selection of a map for which information is to be displayed by the SEEMAP program requires the correct specification of information for the following commands:

MAPNAME CATEGORY TYPEMAP STOKES BAND .

The actual file name (where the map is located) is generated from the combined information supplied by these commands. TYPEMAP can be MAP, BEAM, CLEAN, AMP, or COVER depending upon whether it is a dirty map, dirty beam, clean map, image of amplitude distribution in u-v plane, or image of coverage in u-v plane.

The FITGAUSS command is used to supply the (X,Y) pixel location and the (X,Y) sizes of the region that is to be fitted by a two dimensional gaussian. The result of the GO FIT command is either a listing of the fit parameters or complaints about the failure of the fitting process.

The PROFILE command supplies the pixel coordinates and position angle that define a profile through the map for the GO PROFILE command. The IRANGE and WINDOW commands determine the intensity range and size of the map profile - which is plotted on the OUTFILE device in the form of a one-dimensional character plot. It fhe OUTFILE device is TTY:, the result is a 20 X 20 character plot for a STD WINDOW, and XWIDTH X YWIDTH plot if these parameters have been supplied by the WINDOW command (70 X 20 is the largest that can appear on a single screen). If the OUTFILE device is LPT:, the result is a plot stored on disk in a DAT file with an name supplied by the OUTFILE command. When this file is printed out using the operating system PRINT command, the plot will fill one printer page if the WINDOW was STD, or another size if parameters were supplied by the WINDOW command. If the parameter of the IRANGE command is *, the full range of data are plotted, however, the range of the profile plot can be changed with the IRANGE command.

The IRANGE, XYSKIP, CENTER, and WINDOW commands can be used to determine the characteristics of the GO SHOW output in the form of contour or character displays. Using the WINDOW, XYSKIP, and CENTER commands one can change the size, "graininess", and location of the portion of the image to be displayed. The WINDOW command can be used to choose either a STD display size or the Xsize, Ysize, and Isize of the display. For OUTFILE TTY: or LPT: the STD Isize is 21 corresponding to representing ±Imax with the character "wedge" 'jihgfedcba 123456789T' representing intensity levels -100, -90, -80, -70, -60, -50, -40, -30, -20, -10, 0, 10, 20, 30, 40, 50 , 60, 70, 80, 90, and 100% of ±Imax.

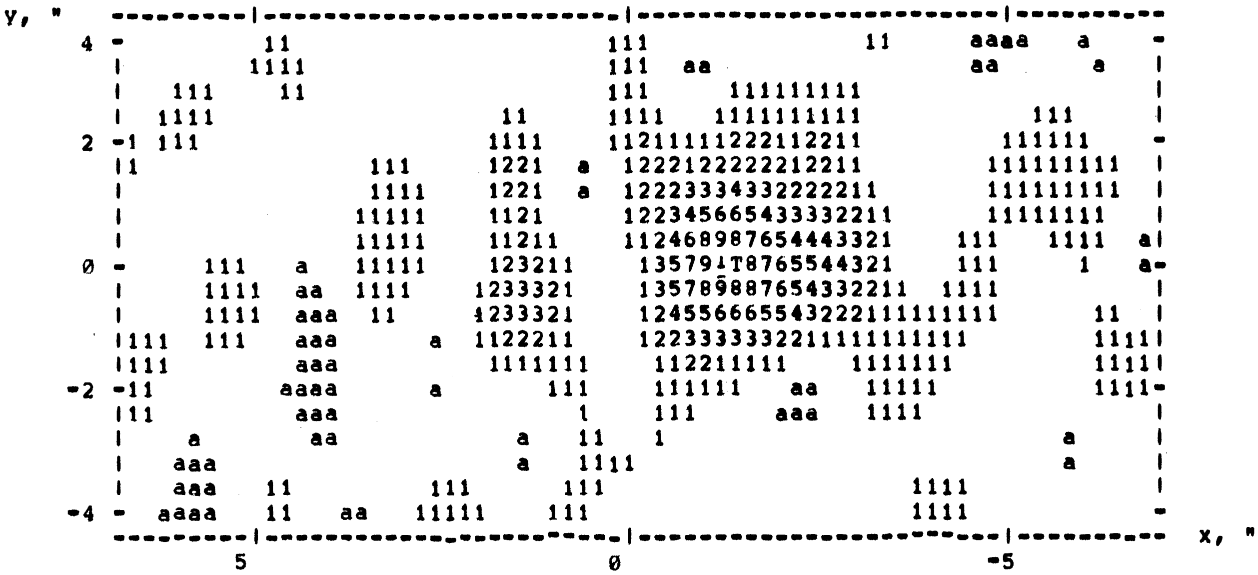
The most useful displays in SEEMAP are the contour maps obtained with GO SHOW when the OUTFILE is TEK:filnam. The STD WINDOW in this case is 128 128 1024. Changing the WINDOW size (or XYSKIP and/or CENTER) is necessary to display larger portions of the image. All contour displays are put into a square region filling the right half of a TEK 4012 (or equivalent) screen. High dynamic range maps require Isizes's of 2048 or 4096. Contour levels are specified in terms of (up to 20) integer percentages of the extreme image intensity, using the CONTOUR command and a syntax in which the number of contours precedes the list of contour percentages.

If the DISPLAYNOW parameter is set to YES, the TEK plot is displayed on the screen of your TEK 4012 (or equivalent) terminal when the plot is completed; otherwise the plot file is stored on disk in a file named by the OUTFILE command (but with the extension DAT) to be displayed later with the TEKDMP program. A copy of a TEK 4012 screen is obtained by pressing the COPY button, resulting in output of the screen image to a VERSATEC printer-plotter. If FILNAM.DAT is the name of the contour map plot file, one displays plot files stored on disk by running TEKDMP and typing the name FILNAM.DAT when prompted for the name of the plot file. Typing a carraige return after a plot has been displayed will cause the next prompt from the program to appear. TEKDMP must be exited by typing CNTL/C.

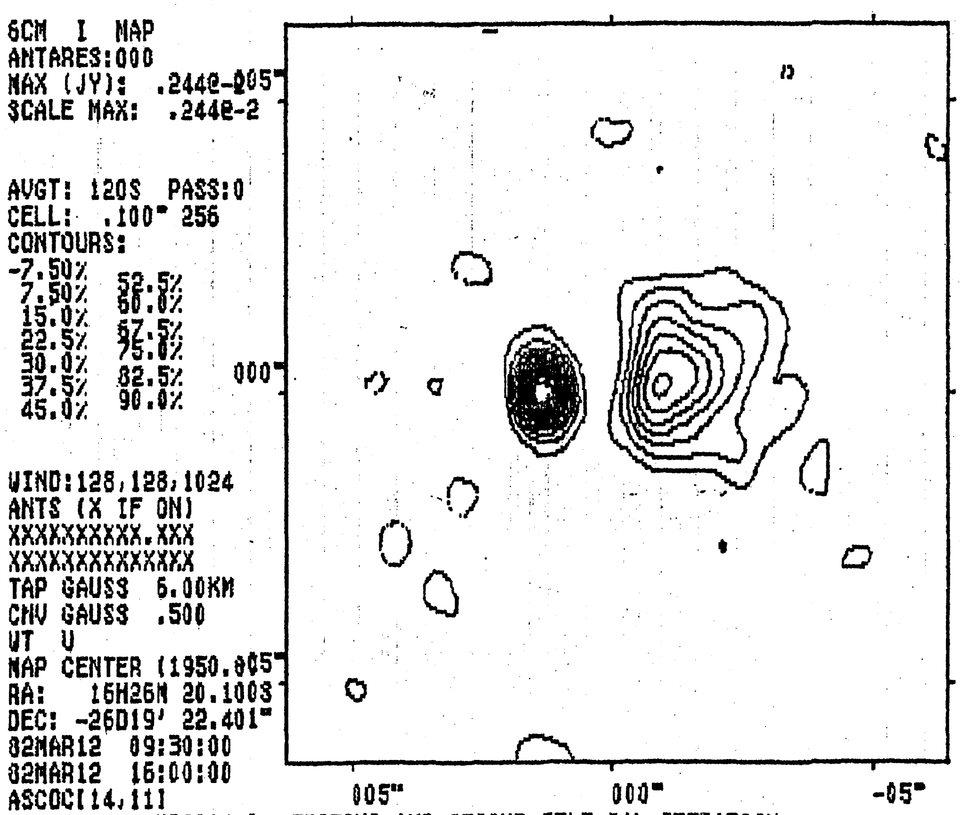
The POLARIZATION command is set to NO when STOKES I maps are to be displayed; however, if I, Q, and U maps are available with the same MAPNAME, BAND, and TYPEMAP, and the STOKES parameter is set to I, then POLARIZATION YES will result in polarization vectors being displayed on top of the contour map.

More sophisticated image displays are obtained by using the DISPLAY and AIPS systems.

The following are examples of the character map and contour displays of SEEMAP:



ANTARES 20cm



EDITING AND SECOND SELF-CAL ITERATION

Chapter 10

THE DISPLAY SYSTEM AND IMPS

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April 1982 Edition

ABSTRACT

DISPLAY is the name of an image display and analysis system implemented in a PDP 11/44 minicomputer in the computer network in the VLA computer room. DISPLAY is oriented towards map input from the MAPPER and SORTER/GRIDDER mapping systems using DECNET, or magnetic tape in the FITS format. DISPLAY is equipped with a 256^2 pixel image display system (COMTAL), a VERSATEC printer-plotter, a Zeta pen-plotter, and a DICOMED film recorder. The Interactive Map Processing System (IMPS) is a menu-oriented program for image display and analysis. DISPLAY/IMPS is primarily for use as an immediate means of displaying, and carrying out preliminary analysis of, maps made in the network; it also provides a high-resolution (up to 4096^2 pixels), high-quality, hard-copy of gray scale and color images on film. DISPLAY/IMPS is not intended to be a high-volume post-processing system - that is the primary task of AIPS.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. The DISPLAY System

Amongst the computer systems available for display and analysis of VLA images, the one directly connected to the DEC-10-based network is the DISPLAY system. The DISPLAY system in the computer room of the control building is used for display and analysis of VLA radio images made in the network. It is based upon a PDP 11/44 minicomputer with special purpose display hardware, and DISPLY is the formal name of this system in the DECNET network. Figure 10-1 shows a pair of photographs of this system running the IMPS (Interactive Maps Processing System) software. Figure 10-2 is a schematic of the hardware components in the DISPLAY system. IMPS is the primary program a user will encounter in using the DISPLAY system, and much of this chapter will be devoted to an introduction to the use of IMPS.

The user will seldom use the operating system commands in the DISPLAY system except to type

run PROGRAMNAME

where here, and in the rest of this chapter, we follow the convention of under-lining text that the user types as part of running programs. Amongst the programs that are available in DISPLAY are: IMPS, FITS, GETMAP, ACTPLT, and OUTPLT. The program called IMPS is a multi-level, menu-oriented program for display and analysis of images. FITS (Flexible Image Transport System) is a program used to read and write images on magnetic tape. GETMAP is a program for transfering maps from the MAPPER map-making system to DISPLAY in a format used by IMPS. ACTPLT and OUTPLT are programs for producing and displaying contour maps on the ZETA multi-pen plotter.

In this chapter we first discuss DISPLAY's FITS, OUTPLT, and ACTPLT, then we provide an introduction to the major capabilities of IMPS.

2. The FITS Program

The DISPLAY system, like the other computer systems at the VLA site, uses a standard format of storing and retrieving images on magnetic tape which is called FITS (Flexible Image Transport System). In the DISPLAY system one mounts a magnetic tape on the tape drive and then initiates the process of storing images on tape, or retrieving images from tape, by typing

run fits

and then typing the appropriate commands. As with most of the other computer systems at the VLA site, the main thing that the user needs to

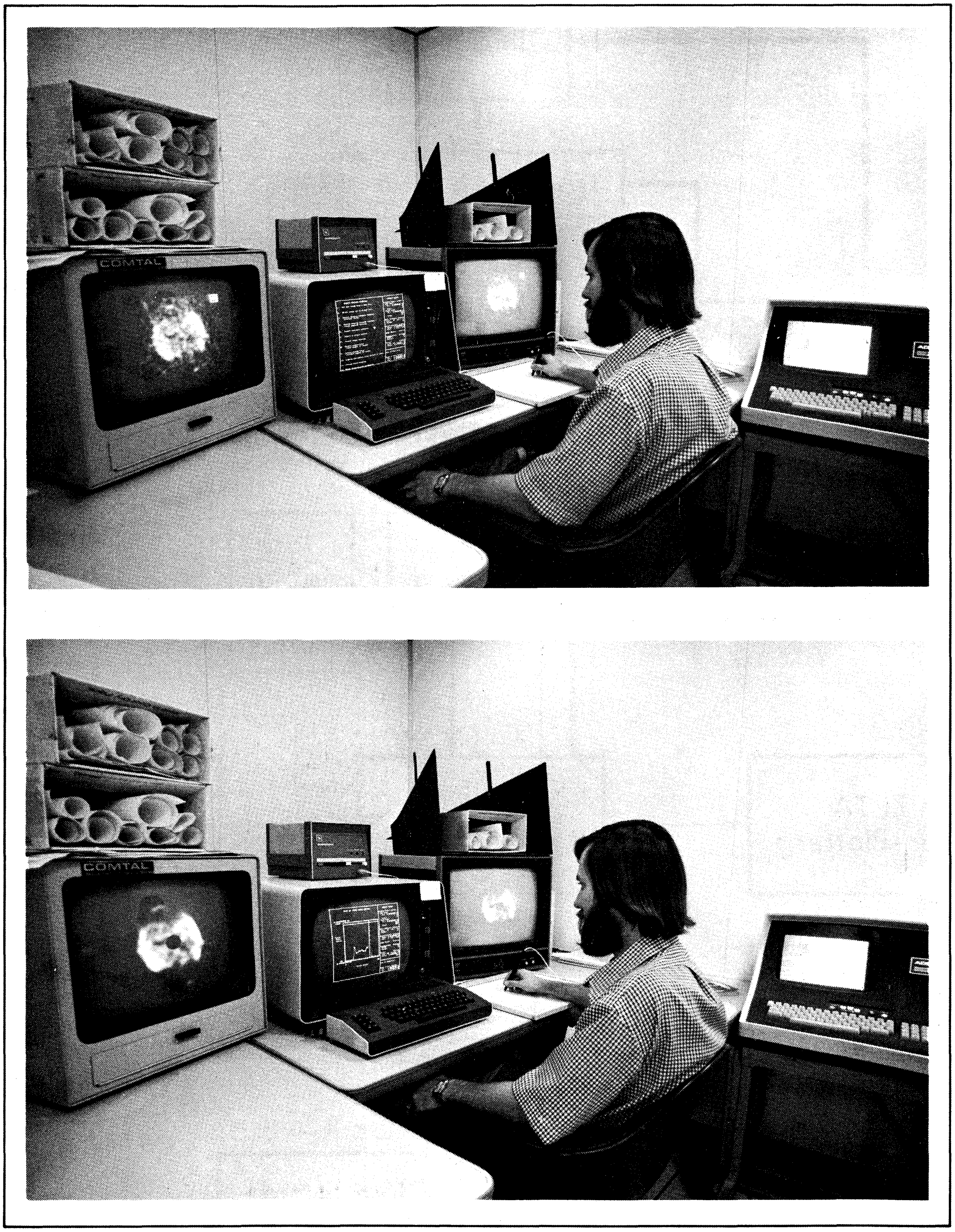

Figure 10-1 The IMPS program in use on the DISPLAY system. The two pictures show display of radio (top) and optical (bottom) images of the planetary nebula, NGC 40, on the black/white (left) and color (right) display screens. The VT11 CRT in the center is used for display of the menus of the IMPS program, and the user is shown with the pen of the data tablet, used for menu selection and data input, held in the right hand.

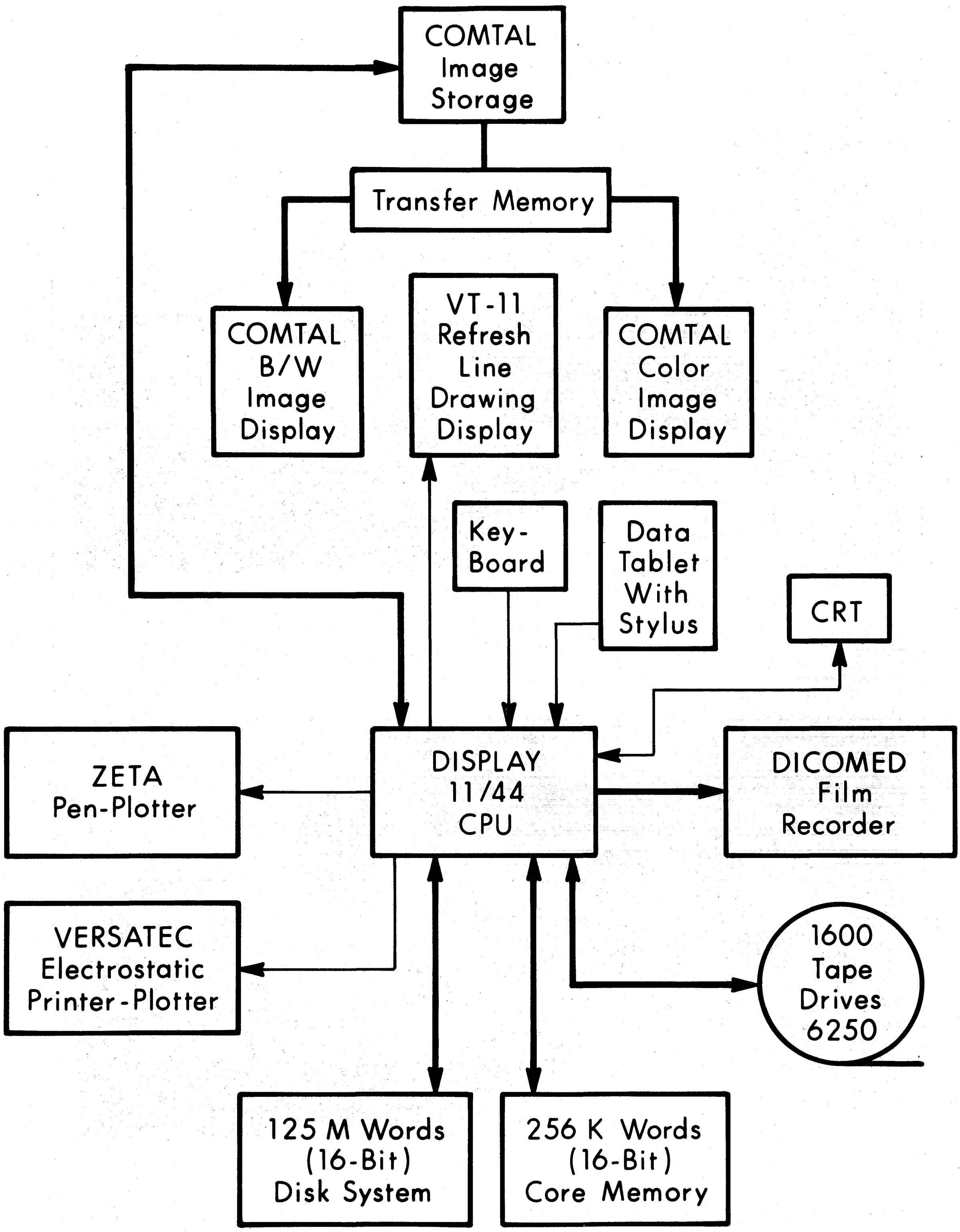

Figure 10-2. A schematic diagram showing the hardware components in the DISPLAY system.

remember is that typing HELP after running FITS will give the user a display of the things the user may do with FITS. The followingis the result of asking for FITS HELP at the time this chapter is written:

```
Commands are: (Items marked with * are not yet implemented)
 Action Commands:
    REWIND     - rewind the tape
    *UNLOAD    - unload the tape
    SKIPFILE   - skip over image file(s)
    INDEX      - show summary of tape contents
    DISK       - transfer tape image to disk
    TAPE       - transfer disk image to tape
    COMPARE    - compare one disk & tape image
    DUMP       - dump tape header to a disk file
    BACKUP     - transfer ALL disk files to tape
    RESTORE    - transfer ALL tape images to disk
    H or HELP  - show command summary
    E or EXIT  - exit from the program
  Mode Setting Commands:
    VERIFY     - set mode to do automatic COMPARE after TAPE or BACKUP
    NOVERIFY   - set mode to just write on TAPE or BACKUP
    SHOW       - set mode to show header summary when doing SKIPFILE
    NOSHOW     - no header summary on SKIPFILE (gives faster skip)
```

The above commands and their purposes are largely self-explanatory.

The tape drive used in the DISPLAY system is the nearest tape drive outside the DISPLAY room, just behind the DICOMED film recorder. Check to make sure it is labeled as a DISPLAY system component. After mounting a tape on the drive, one closes the door to the tape drive, hits the LOAD/REWIND button, and when a light appears indicating it is set at the BOT point (Beginning Of Tape), one then hits the on-line buttion, after which one returns to the DISPLAY room and runs the FITS program. When all images have been transferred to tape or disk as desired, one presses RESET and UNLOAD, and then removes the tape from the drive when ready.

It is often necessary to make a listing of the contents of a FITS tape before transferring images to disk; this is accomplished with the INDEX command. Making sure that the tape is at the beginning, often by executing a REWIND command, the typing of the INDEX command results in the following type of listing on the terminal:

File	Mapname	Source	Type	NAXIS1-NAXIS4	DATE-MAP	BITPIX
1	M31L1PO	0040+410	I	512 512	11-14-81	16

etc., and when the INDEX is completed you will be prompted with the message:

"The above list has been put into file FOR001.DAT"

which means that if you exit from FITS and ask for a directory listing of all versions of FOR001.dat,

pip for001.dat;*/l

you will see a listing for at least one version of this file. If n is the number of the latest version, you can get a copy of the INDEX by typing

pip for001.dat;n/sp

which will result in the file being spooled to the DEC-10 and printed out on its line printer. It is a good practice to make and keep a listing of the INDEX for any FITS tape after putting or adding images on a tape. Some computer systems may not have a convenient INDEX for FITS tapes.

3. The GETMAP Program for Transfering Images to IMPS

VLA radio maps produced in the MAPPER or SORTER/GRIDDER systems can be transfered directly to the DISPLAY system by using the GETMAP program. GETMAP is most useful when you have a relatively small number of images to transfer and it is not worth the trouble of using a magnetic tape and the FITS program; however, if there are a large number of images to be transfered, it may be preferable to use FITS. Using the terminal in the DISPLAY/IMPS room in the control building computer room, or any other DISPLAY terminal, one types to the operating system

set /UIC=[201,220]

which, though it may not be necessary, will insure that you are running the correct version of GETMAP. Then type

run GETMAP

and carry on a dialog with the program as follows:

TYPE IN MACHINE NAME: mapper

TYPE IN USER ID: PN

at which point a copy of your catalog of VLA maps on disk in the MAPPER system will be listed on the screen, including a column of catalog numbers. Note the catalog numbers of maps that you wish to transfer to the DISPLAY system. You are then prompted to type one of a list of options (COPY, EXIT, etc.), which you then respond to as desired, e.g.

NEXT OPTION: copy

TYPE IN CATALOG RECORD NUMBER: n

where n is the desired catalog number. Repeat as many times as necessary to copy over all the desired radio maps. After you have finished requesting the copying of the second (or later) image, or you have EXITed, you will see ENTMAP messages on the CRT telling you about the progress of the copying process. When you are finished type the EXIT option.

Transfer of a 256 X 256 image takes roughly 40 seconds. Images of other sizes will take time proportional to the total number of image pixels.

4. The OUTPLT Program for Displaying Contour Maps on the ZETA Pen-Plotter

The OUTPLT program is used to output ZETA pen-plotter map displays that have been produced, and written into plot files on disk, in any of three computer computer systems: VAX/AIPS, 11/70(Mapper), or 11/40(Display). In the VAX systems these plot files are produced by the KONTR task in AIPS, while in the other systems the plot files are produced by the ACTPLT program. Assuming that the plot files have already been made, one puts out, or "spools" the plots to the Zeta plotter from the terminal next to the plotter in the Control Building. After making sure that power is on for both terminal and plotter, set the computer selection switch next to the plotter to correspond to DISPLAY, MAPPER, or the appropriate VAX, and set the adjacent switch for PLOTTER/TERMINAL operations.

Detailed documentation on using OUTPLT and the ZETA plotter can be found in a binder next to the plotter; however, we will summarize some of the major aspects of using this device. The principle advantages of using the ZETA plotter are: (1) you can spool plots without utilizing AIPS or IMPS time for the actual plotting process; and (2) you can produce publication quality plots.

Before running the OUTPLT program, one must prepare the proper combination of pens for the plotter. Ordinarily a set of four ball-point pens of different colors are set up in the plotter, and it is recommended that the user utilize these pens unless publication quality plots are desired. If the latter is necessary, one can remove one or more ball-point pens from the plotter and insert an india-ink pen, usually with red ink, taken from the nearby plastic case. Removing pens is a simple matter of lifting them from the pen-holders. One inserts an india-ink pen by dropping it into position without additional pressures, however inserting a ball-point pen involves putting the pen in and exerting a small amount of down-ward pressure until there is a slight click. When the correct pens are in positions 1 through 4, corresponding to what was requested in the plotting program, one is ready to proceed with the OUTPLT program.

If you are spooling plots from the MAPPER or DISPLAY systems you will be logged in as soon as the terminal is turned on (unless the computer is down), and you need only

set /UIC=[201,220] ; for DISPLAY and

set /UIC=[300,20] ; for MAPPER.

However, if you are spooling plots made in one of the VAX systems, you must log on to the PLOT area, hitting ENTER to start the following dialogue;

Username: PLOT

Password: PLOT

where, as usual, the password is not echoed on the CRT, after which you will be logged on and ready to run OUTPLT.

Unless you remember or write down the names of the plot files specified when you produced the plots, or use the default name in the case of a single plot, you may need to refresh your memory about plot file names. In the VAX system you can accomplish this by typing

directory *.qlt

and in the MAPPER or DISPLAY systems you type

pip *.plt;*/li

after which a list of plot file names will be listed on the screen. Note that in the MAPPER and DISPLAY systems the plot files have the extensions PLT while in the VAX systems the extensions are QLT; however, when running OUTPLT you need to type extensions and version numbers only when duplicate names have been used.

Once you know the names of the plots you wish to spool to the Zeta plotter, you run the OUTPLT program by typing

run OUTPLT

and then carry out the appropriate dialogue with the program. The dialogue is somewhat different in each system. If for example, you wish to plot files named PLOT1 and PLOT2 produced by the KONTR task in AIPS in a VAX, the dialogue will proceed as follows:

NUMBER OF PLOTS FILES TO BE SPOOLED:

2

NAME OF PLOT FILE:

PLOT1

NAME OF PLOT FILE:

PLOT2

ZZZZZZZZZ

with the ZZZZZZZ indicating that the spooling of the first plot is proceeding. When completed, another ZZZZZZZ appears to indicate that the spooling of the second plot is proceeding. When all plots have been spooled, the program prompts the user with the question

DO YOU WANT TO SAVE PLOT FILES (Y OR N, N is the default):

and you respond with a YES or NO. If you think you will be spooling the plot more than once, as when you want an india-ink version for publication purposes, be use to answer Y.

When you are finished be sure to delete any remaining plot files using

pip pltnam.plt;*/del

in MAPPER or DISPLAY, or

delete pltnam.qlt;*

in one of the VAX systems. Then turn off the power to the Zeta plotter, restore any india-ink pens to their case, and leave the usual ball-point pens in the proper pen locations.

5. The ACTPLT Program for Producing Contour Plots for the Pen-Plotter

The program ACTPLT in the DISPLAY (and MAPPER) system is used to make contour plots for the ZETA pen-plotter from maps in IMPS.. Before running ACTPLT the user must be prepared to supply the mapname of each image file to be plotted.

One can run ACTPLT at any DISPLAY or MAPPER terminal by typing

run ACTPLT

and then responding to prompts within the program to supply parameters for the plotting program. The program can be used to prepare spool files (with extensions PLT) to be plotted later using the OUTPLT program at the terminal next to the Zeta plotter, or it can be used to directly plot one contour map at a time (without the OUTPLT program) if you run ACTPLT from the terminal to which the plotter is attached.

The ACTPLT program actually activates a series of tasks that accomplish most of the work. The first task is ACTPLX which interrogates the user for parameters and when this is done, activates the task ACTPLY. ACTPLY asks the user to choose between spooling into a plot file and plotting directly, and then carries out the preparation of the plot. It is recommended that plots be spooled to minimize the length of time the large task ACTPLY is in the system.

Most of the prompts for parameters should be self-explanatory and whenever possible defaults are set up so that a CR response will produce reasonable results. You must supply the user number (PN) and you must supply the IMPS map name. When asked for the area to be plotted, a CR response will result in the entire map being plotted. In specifying a smaller area of the map one supplies the pixel parameters for the bottom left corner (BLC) and top right corner (TRC), where (1,1) is the BLC of the map and (MAPSIZE,MAPSIZE) is the TRC of the map.

The specification of the plot scale, in arc seconds per mm. can be used to make plots as large (on multiple sheets) as necessary. The x and y plot scales can be made different, and when only one plot scale is supplied it is used for both x and y scales.

You will be asked to choose specification of contour levels in terms of either percentages of the peak in the map, or in terms of absolute values of mJY/beam. Up to 20 contours can be supplied and for each contour level you can supply; 1) the contour level; 2) a pen number (1, 2, 3, or 4), which gives a capability for multiple colors (black, blue, green, and red, respectively, for the ball point pens in standard positions); 3) and a dash length. Use of a zero for dash length results continuous contour lines, therefore the user must supply numbers greater than 1 to obtain dashed negative contour levels; a value of 5 is recommended until the user develops his own optimal values. If only one number is supplied, it is interpreted as the contour level, a continuous contour is plotted, and pen one is used. If two numbers are supplied the second number is interpreted as a pen number and a continuous contour is drawn.

Once "final" plots have been prepared and found to be satisfactory, the user can obtain "publication quality" plots by removing the ball point pen from the pen 1 position and replacing it with a red ink pen kept in a protective case next to the plotter. After finishing with the red ink pen one should return it to its protective case and replace the ball point pen in the pen holder.

The user can supply (RA,DEC) positions to be marked on contour plots in the form of large + symbols. A CR response to the appropriate questions results in no extra symbols. If you want these positions plotted, you supply RA and DEC in hh mm ss.ss... dd '' "".""... format followed by a carriage return. You can supply different scales for these position marks.

The scale for all annotation lettering can be specified, and one can choose plots to be labeled with (RA,DEC) coordinates for the original data (usually epoch 1950.0) or relative angular scale with respect to the phase reference position. Typing a Y or y in response to this question will result in relative coordinates, typing a CR or anything else will result in (RA,DEC) coordinate labels. One can supply tic mark intervals to obtain optimum spacing of coordinate information. With a choice of (RA,DEC) labeling, one can choose to have reference + marks for the coordinates in the contour plotting area.

The quality of the plots can be varied at the price of slowing down the plotting process. The speed can be specified between 1 (slow) and 20(fast) with the latter being the default.

Before the plot preparation is initiated you will be told the size of plot (in cm.) and the number of strips that will be necessary. If you do not like what it will do, or if you have changed your mind about any of the parameters, you will be asked if you want to change any parameters. Typing Y or y in response to this restarts the entire interrogation about plot parameters. You can also choose to continue or abort the entire process.

Shortly before the "bail-out" opprotunities are presented, you are asked to choose long vs. short labeling. Since the long labeling takes a longer time, you may wish to choose the short labeling.

The last question to be answered involves choosing direct plotting or spooling the plot to a PLT file. In the latter case you supply a name of six characters or less. Typing a CR will result in a default plot name. Every execution of ACTPLT in this mode results in an overwriting of this plot file. When you have your plot file(s) prepared, you run OUTPLT as described in the previous section.

6. The IMPS (Interactive Map Processing System)

A. Introduction to IMPS and the Associated Hardware

IMPS is a single program controlling a number of map display and analysis tasks. It is oriented towards selection of displayed menu items representing functions, options, or parameters of image processing requests. Once the user becomes familiar with the input mechanisms of IMPS, the menus are self-documentation for the function and parameter control available to the user.

Figure 10-1 shows photographs of IMPS running on the DISPLAY system hardware which is shown in a schematic diagram in Figure 10-2. The hardware utilized by IMPS includes: color and black/white TV monitors for displays of 256 X 256 arrays of image data; a refresh line drawing terminal (VT11) for dynamic display of menus, plots or line drawings, map related data, and numerical data derived from maps; a data tablet over which a pen or stylus is moved in an x-y grid to control the motion of cursors on either the refresh terminal or the TV monitors; and a keyboard placed in front of the refresh line drawing terminal for alphanumeric data input. A separate terminal next to the IMPS system is used to initiate the running of IMPS, after which most control of IMPS is by data tablet and keyboard.

The TV monitors in the system are displays for a COMTAL image display system, which has memory for storage of 256 X 256 8-bit image pixels and a transfer function for dynamically altering the mapping of map pixel values into displayed intensity values. The control of the COMTAL hardware, the refresh terminal, the data tablet, and the keyboard is carried out by the PDP 11/44 CPU, which has 256K words (16 bit) of core memory and a 125M word disk storage system. Additional hardware controlled by this system consists of a DICOMED film recorder with capabilities of recording up to 4096 X 4096 pixels on black/white or color film, and a VERSATEC electrostatic printer-plotter with 200 dots per inch resolution.

The user initiates execution of IMPS by typing

<u>run IMPS</u>

on the ADDS terminal on the right-hand side of the pictures in Figure 10-2. The program should then ask for the user's number, which is the same as the programmer number (PN) in the DEC-10. As in the other VLA computer systems, the user's image files are organized under the user's number on disk. If nothing appears on the VT-11 screen, make sure it is turned on and that the intensity is adjusted properly (the red indicator light on the upper right of the VT11 will be lit if it is turned on; once turned on the same knob can be used to adjust screen display intensity). The IMPS top level menu should then appear on the VT11 refresh terminal screen.

The basic control of IMPS occurs through user selection of items out of lists of menu options, which are displayed on the VT11 screen. A multiple level, tree structure of menus is used. When IMPS is started up, it displays the top level menu, which is a list of categories of available functions. The user then points to the desired function by positioning a cursor on top of it. Movements of the pen (or stylus) on the x-y coordinate system of the data tablet cause the displayed cursor to move in the x-y coordinate system of the VT11 (or COMTAL) screen. With the cursor on a selected item, the user then pushes down on the pen to indicate to IMPS that the cursor is pointing at the desired item, the system will emit an audible beep, initiate a high-lighted background for this item, and turn off the cursor. If the user is sure that the desired item is what he really wants, he then pushes down on the pen again. If he doesn't want that item, the user types on a key on the keyboard (any key will do), and IMPS will put the cursor back on the screen and allow the user to select another item. This illustrates a general convention in IMPS; pushing down on the tablet pen indicates an ackowledgement or a "yes" answer; typing a key on the keyboard at any time except when typing input information indicates cancellation or a "no" answer. After the user selects a category of functions out of the top level menu, IMPS will display the second level menu for the selected function, which may be either a list of subcategories or a more detailed list of functions. After a function has been executed, IMPS returns to the menu that initiated the function. If a user wants to exit to a higher level menu he has a choice of hitting any key on the keyboard (except when keyboard input is demanded) or selects a menu item for this purpose.

Experience has shown that, with no more than 5-15 minutes of a "hands-on" introduction to IMPS, users will be able to proceed on their own. Only after some initial use of the system will the user be able to understand the use of data tablet, keyboard, refresh graphics terminal (VT11), and menus by IMPS. The use of the tablet pen or stylus in conjunction with the data tablet will be most comfortable to the user if the pen is grasped as if it were a writing instrument in the right or left hand, depending upon the handedness of the user. The data tablet can be moved either to the left or the right of the keyboard. The only two activities of the pen are motion across the x-y coordinate system of the data tablet, to cause corresponding motion of a cursor on one of the screens, and pressing down on the pen as if you were "writing" a period to select or initiate a new function.

After a menu item has been selected in IMPS, the system will prompt you to selected further options or type certain input data. It is possible to abort a function and return to a menu display at almost any point in this dialogue. This can often be done by simply hitting any key on the keyboard. If the system is asking you to type in a numerical parameter or a map name, you can abort by just typing a carraige return. In most cases there is no way to abort a function after all the parameters have been specified; however, you can abort the loading of an image on the COMTAL display, or output to the DICOMED film recorder, by typing any key on the keyboard.

Once an IMPS task is initiated you proceed with its instructions, or wait until it finishes and a menu appears on the screen again. Do not type RUN IMPS again on the ADDS terminal, since this will mess thing up.

B. Image Input to IMPS

The initial input of images for IMPS can be from many different sources. Radio images can be made in the DEC-10, the MAPPER mapping system, the SORTER/GRIDDER mapping system, or an AIPS system. As discussed earlier, the GETMAP program can be used to transfer radio maps from disk on one of the mapping systems in the network; however, the most common means of input will be from images stored on a FITS tape that are transfered to the DISPLAY disk system using the FITS program. These can be radio or any other type of images, as long as the minimum FITS conventions for storing image arrays on tape have been followed.

Once images are store on disk in DISPLAY, the user can run IMPS to carry out the display and analysis of these images.

C. Map Storage in IMPS

Many IMPS functions require specification of one or more input maps. The user is prompted to select a map from a "menu" of available maps. If you have more maps than can be displayed on the VT11 screen, selection of the bottom item of the display will give you another page of map listings.

If you want to speed up the process of map selection, you can do one of two things. If the desired map has appeared on the screen, pushing down on the data tablet pen will allow map selection from a "truncated" menu. If you know the name of your map, you can interupt the map listing by hitting a key on the keyboard, and you will then be prompted to type the mapname.

Associated with each map organized under your user number is a 12-character category which can be set by one of the IMPS utility functions. There is another IMPS function which allows you to set the current selection category. The category called NULL (the default) results in access and menu display of all your maps; however, if you set a particular selection category, only maps under that category will be listed. This capability allows you to organize you map images under logical groupings and speeds up the map selection process.

Maps accessed by IMPS in DISPLAY are described in terms of certain types of information, depending upon parameters set up when the maps were made. The following summarizes the available information about each map:

Info. type	Symbols	Meaning
Mapname	up to 12 char.	Name uniquely identifying map in data base
Category	up to 12 char.	Category associated with a map (or NULL)
Source:Qual		Source name and qualifier
Band	20, 6, 2, 1.3	Observing band
Data type	MAP	Ordinary image
	B	Dirty beam
	MOD	Model, e.g. cleaned or self-calibrated
	RES	Clean residual map
	COV	u-v coverage map
	AMP	u-v amplitude map
	PHA	u-v phase map
	GRD	u-v grid file
	GRW	u-v grid weight file
	CON	Contour plot stored as map
	TIC	Grid lineor tic-mark file
	PC	Phase closure data
	XFR	Transfer function file
	REA	u-v real part of visibility
	IM	u-v imaginary part of visibility
Map type	I, Q, U, V	Stoke parameter
	FI	Formal I Stokes parameter
	A, B, C, D	IF channel map only
	P	Polarized intensity map (SQRT(Q*Q + U*U))
	m	Percentage polarization (P/I)
	Psi	Polarization angle (0.5*arctan(U/Q))
	SI	Spectral Index (log(I1/I2)/log(Nu1/Nu1))
	OD	Optical Depth
	PI	Profile Integral
	VEL	Velocity map
	PW	Profile width
	ART	Some general arithmetic combination

Info. type	Symbols	Meaning
Model type	CR	Cleaned, residuals kept
	C	Cleaned, residuals not kept
	ME	Maximum entropy
	S	Self-calibrated
	CS	Combination of cleaning and self-calib.
Map Date	yyMONdd	Date map was created
Map Size	nnn X mmm	Number of map pixels in X and Y directions
Pixel format	R	32-bit real numbers for stored map values
	I	16-bit scaled integers
	P	8-bit byte storage for each pixel
	G	1-bit graphic overlay

The presence of the above map information depends upon the appropriate information being written into the map header during map transfer by DECNET or FITS. When there are duplicate mapnames, integers are added to the mapnames to resolve ambiguities.

D. Determining Disk Usage

Because many users share map storage space, the user may encounter problems because of lack of disk space. Typing

pip /fr

on the ADDS terminal will result in a listing of how much disk space is used and how much is available. Disk space is measured in terms of the number of 512-byte blocks. A 256 X 256 map in 16-bit format will occupy 256 blocks and a 1024 X 1024 map in 32-bit format will occupy 8192 blocks.

You can find out how much disk space is be used by each user by typing

@[201,10]space

on the ADDS terminal. A copy of this listing can then be printed out on the DEC-10 line printer by typing

pip space.lst/sp

on the ADDS terminal. If you run out of disk space for your own maps, you can delete some of your maps, convince another user to delete some maps, backup and delete some maps, or ask a VLA staff member to solve the problem.

E. The IMPS Menu Structure and IMPS Functions

a. The IMPS Top Level Menu

The following is the top level menu for IMPS at the time this is being written. This menu is displayed when IMPS is first run and whenever the user returns to the top level menu:

1. General Utility Functions
2. COMTAL Image loading Functions
3. COMTAL Image Display Modification Functions
4. Data Plotting and Printing Functions
5. Data Processing Functions
6. DICOMED Output Functions
7. VERSATEC Output Functions
8. Execute User Coded Functions
9. Exit from IMPS

The selection of menu items 1 through 7 results in the display of a more detailed sub-menu of functions. Item 8 allows one to execute functions that have not yet been linked into IMPS, but are resident as compiled code on disk. Item 9 is the normal means of ending an IMPS session.

b. The Detailed IMPS Menus

Let us list the entire menu system for IMPS.

1. General Utility Functions
   - 1.1 Set Map Category to be used
   - 1.2 Show summary of available maps
   - 1.3 *Show all header information for a map
   - 1.4 Change a map's category
   - 1.5 Delete a map
   - 1.6 *Save IMPS parameters
   - 1.7 *Restore IMPS parameters
   - 1.8 Initialize Image Display Parameters
   - 1.9 *Transfer map from DEC-10 or PDP 11/70 to PDP 11/40
   - 1.10 *Connect to the DEC-10 system
   - 1.11 Set user number for map selection

2. COMTAL Image loading Functions
   - 2.1 Load Image Into Entire Screen
   - 2.2 Clear Entire Screen
   - 2.3 Load Image into a Quadrant of the Screen
   - 2.4 Clear a Quadrant of the Screen
   - 2.5 *Load Two Images for Blink comparison
   - 2.6 Scroll Load a New Image
   - 2.7 Scroll the current image on the screen
   - 2.8 *Load Graphic Overlay Image into Entire Screen
   - 2.9 *Clear Graphic Overlay In Entire Screen
   - 2.10 *Load Graphic Overlay Image into Quadrant of Screen
   - 2.11 *Clear Graphic Overlay in Quadrant of Screen

3. COMTAL Image Display Modification Functions

4. Data Plotting and Printing Functions
   - 4.1 Plot Horizontal Cross Section of Displayed Image
   - 4.2 *Plot Arbitrary Cross Section of Displayed Image
   - 4.3 Produce Contour Map from a Map in the Data Base
   - 4.4 Produce Contour Plot and Output it Directly to the Versatec
   - 4.5 Produce Contour Plot which Includes Polarization Vectors and Output it Directly to the Versatec
   - 4.6 Output Another Copy of the Previous Plot to the Versatec (Applies to above two functions only)
   - 4.7 Print out map values on DEC-10 line printer

5. Data Processing Funtions
   - 5.1 Data Processing Utility Function
     - 5.1.1 Change Map Pixel Storage Format
     - 5.1.2 Select Subsection of a Map
     - 5.1.3 *Select Subsection of a Map that is Currently Being Displayed on the COMTAL
     - 5.1.4 Decrease Number of Pixels by Averaging
     - 5.1.5 Decrease Number of Pixels by Selecting Largest Intensity
     - 5.1.6 Increase Number of Pixels by Duplicating Pixels
     - 5.1.7 Increase Number of Pixels by Interpolating Pixels
   - 5.2 Map Arithmetic - with Transformations, etc.
     - 5.2.1 (S + M1) + T (Linear transformation with user supplied factors S and T)
     - 5.2.2 M1 + M2 (Also includes user specified linear transformation of each input map)
     - 5.2.3 M1 - M2 (Also includes user specified linear transformation of each input map)
     - 5.2.4 M1 * M2 (Also includes user specified linear transformation of each input map)
     - 5.2.5 M1 / M2 (Also includes user specified linear transformation of each input map)
     - 5.2.6 log(M1/M2)/log(Nu2/Nu1) (Includes linear transformations) (Calculates spectral index if M1 and M2 are intensity maps)
     - 5.2.7 sqrt(M1*M2 + M2*M2) (Includes linear transformations) (Linear polarization if M1 & M2 are U and Q maps)
     - 5.2.8 0.5 * arctan2(M1, M2) (Includes linear transformations) (Polarization position angle if M1 & M2 are U & Q maps)
     - 5.2.9 ln(M1/M2) (Includes linear transformation) (Optical depth if M1 & M2 are continuum & spectral line)
   - 5.3 Map Arithmetic - with default parameters
     - 5.3.1 (S + M1) + T (Linear transformation with user supplied factors S and T)
     - 5.3.2 M1 + M2
     - 5.3.3 M1 - M2
     - 5.3.4 M1 * M2
     - 5.3.5 M1 / M2
     - 5.3.6 log(M1/M2)/log(Nu2/Nu1) (Calculates spectral index if M1 and M2 are intensity maps)
     - 5.3.7 sqrt(M1*M2 + M2*M2) (Linear polarization if M1 & M2 are U and Q maps)

5.3.8 0.5 * arctan2(M1, M2)
(Polarization position angle if M1 & M2 are U & Q maps)
5.3.9 ln(M1/M2)
(Optical depth if M1 & M2 are continuum & spectral line)
5.4 Gaussian Source Fitting, Subtracting, and Restoring
5.4.1 Fit and Optionally Subtract Gaussian Sources
5.4.2 *Subtract Gaussian Sources
5.4.3 Restore Gaussian Sources
5.4.4 Print the Last Fitting/Restoring File
5.5 *Subtract a Dirty Beam Shape fro a Map
5.6 *Source Subtraction by Cleaning Small Areas
5.7 Miscellaneous Data Processing Functions
5.7.1 Calculate integral and rms over a map subsections
5.7.2 Correct for primary beam
5.8 *Re-mapping in DEC-10 and PDP 11/70
5.9 *Map Cleaning in DEC-10 and PDP 11/70

6. DICOMED Output Functions
6.1 Make DICOMED 35mm Film Copy of a Map from the Data Base
6.2 Make DICOMED 35mm Film Copy of the COMTAL Screen
6.3 Write Text on 35 mm Film
6.4 Make DICOMED 4x5 Film Copy of a Map from the Data Base
6.5 Make DICOMED 4x5 Film Copy of the COMTAL Screen

7. VERSATEC Output Functions
7.1 Make VERSATEC Grey-scale Copy of a Map from the Data Base
7.2 Make VERSATEC Copy of a Contour Map from the Data Base
7.3 Make VERSATEC Grey-scale Copy of the COMTAL Screen

8. Execute User Coded Function

9. Exit from IMPS

When finished with IMPS, the user selects the last item and the execution of IMPS is terminated. It is standard practice to turn off the image display on the VT11 when finished.

c. COMTAL Image Display Modification Functions

The selection of this top level menu item results in display of a different style of menu on the VT11 screen. One needs to experiment with each to understand their functions, but we will briefly summarize some of the possibilities.

(1) Change from black/white image display to a "spectrum-like" color display where the red to blue color spectrum is used to represent the range of maximum to minimum intensities. This can be enabled or disabled.

(2) Image inversion, which in the case of B/W images means changes from displays of positive to negative images, and vice versa. In the case color spectrum image display, it changes the display from one where

the red end of the spectrum corresponds to the maximum to one where the other end of the spectrum corresponds to the maximum.

(3) A B/W or color wedge can be inserted or removed from the top few rows of the displayed image, showing the range of color or b/w corresponding to the range of image intensities.

(4) One can select, or remove, color contouring where ranges of intensity are mapped into an arbitrary set of colors. Motion of the stylus is used to change the interval of intensities mapped into each color contour.

(5) One can change the transfer function controlling how image intensities are mapped into displayed pixel values. With the contrast sweep one can select a specific middle range of intensities to be displayed, and the image display changes dynamically to correspond to this. The x- and y-coordinate location of the stylus on the data tablet independently controls the displayed range and the slope of the displayed range; the transfer function currently in effect is always displayed at the bottom of the VT11 screen. More flexible control of the transfer function is achieved by independently changing the location of left and right "kinks" in a three segment transfer function. This provides the most powerful means of "eyeball" image analysis available in IMPS.

d. The DICOMED Film Recorder

Black and white or color images in IMPS may be recorded on film using the DICOMED file recorder. Sheet film (4" X 5"), 4" x 5" polaroid film, and 35 mm film recording are available. The 35 mm film produces high quality slides or negatives and takes appreciably less time to record than with the 4" X 5" film; therefore it is recommended that this always be used rather than 4" x 5" sheet film. Polaroid film should be used only when you have an need for immediate hard copy.

The 35 mm film transport is loaded by pulling out the dark slide completely, unscrewing the knob on one end of the transport, sliding off the cover, and loading the film according to the diagram on the inside of the cover. After loading, replace both the cover and the dark slide, make sure the cable of the transport is plugged into its control unit, and switch the power on for the transport. Advance the film a few times, reset the frame counter, and secure the transport on the DICOMED mount. Once in place, two latches should be slid to the right to secure the transport to the mount.

When the film transport is empty an orange light will glow on the transport control unit. One then makes sure the dark slide in pushed in and removes the transport from the top of the DICOMED. The film is rewound into the cassette by pulling the REWIND knob to the left and holding it until rewind is finished (counter stops moving). The ground glass assembly should always be placed on top of the mount when the film transport is taken off to prevent dust from getting into the DICOMED recorder.

If you have brought and used only your own 35 mm film, you may take it away and have it developed yourself. Normally, rolls of 35 mm Ektachrome film are available for shared use at the VLA site. In this case you manually advance the film once, use the IMPS function to write identifying information (name and address) on one frame, and then make your exposures, advancing the film transport after each exposure. If there are remaining exposures, you can close the dark slide and leave the film for others to use. When the film is all exposed it can be removed, as discussed above, and turned over to VLA staff who will arrange for processing. The appropriate slides will be sent to the person identified on the frame preceding each series of exposures.

The following is a summary of the process of using the film recorder:

(1) Use IMPS to select the image, or write the text, that is to be reocrded on film. When this is complete, the prompt

PRESS RECORD WHEN READY

should appear on the ADDS terminal. You then go and prepare the DICOMED.

(2) If you are starting a film recording session, turn on the power for the film transport, make sure the High Voltage switch on the lower panel is turned ON, and then set the correct exposure (variable pot labeled EXPOSURE on the upper panel) for the film being used:

35 mm. Ektachrome (color, 64 ASA)	:	8.00
35 mm. Ektapan (b/w, 100 ASA)	:	7.00
Polaroid 52 (b/w)	:	3.70
Polaroid 58 (color)	:	8.25 .

(3) For 35 mm film, make sure the dark slide is out (white line just showing). For polaroid you need to load the film: this involves having the appropriate film holder mounted, pushing the lever to L (for load), carefully following the instructions on how to put the film in the holder, then when a click indicates the film is all the way in, pulling the film envelope gently out to its limit.

(4) You then set the exposure type to LOG or LINEAR by pressing the appropriate button on the top panel; LOG is set by default, and is generally used, however LINEAR may give a better display of lower intensity levels.

(5) After making sure that the IMAGE WAITING light is lit, you press the RECORD button on the right of the top panel. Lights will blink and the image recording processes proceeds. When completed, the IMPS menu will reappear on the VT11 screen.

(6) If you are using 35 mm film, you then advance the film by pressing the MAN FILM ADVANCE button on the transport control unit; you can then use IMPS to select another image for recording, and repeat the above procedures. If you are using polariod film, you need to remove and develop the film. This is accomplished by pushing the film envelope back in, pushing the lever on the film holder to P, and then firmly pulling the film envelope all the way out of the holder. After waiting the recommended time for development, you (carefully, don't get chemicals all over yourself) remove the developed picture and discard all but the finished print.

(7) When finished with the 35 mm slide transport you push in the dark slide and either leave it alone or unload it, as discussed above.

(8) Switch off the High Voltage and the film transport.

Chapter 11

AIPS: THE ASTRONOMICAL IMAGE PROCESSING SYSTEM

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April 1983 Edition

ABSTRACT

The Astronomical Image Processing System (AIPS) is a collection of software and hardware used for the later stages of VLA data processing, often called post-processing. The input of data to AIPS is by magnetic tape, either calibrated visibility data in EXPORT or UVFITS format, or images in FITS format. The reduction, display and analysis capabilities in AIPS are complete enough to produce results and displays which need little further processing.

AIPS is implemented on two VAX 11/780 minicomputers at the VLA site and on a VAX 11/780 and a MODCOMP Classic minicomputer in Charlottesville. Each minicomputer system is equipped with a 512^2 pixel image display, an array processor, and other peripherals. Several users can run the AIPS programs on a system, sharing the resources of the display and array processor. There are two major types of programs in AIPS: verbs which handle the interactive programs; and tasks which handle more time-consuming programs, several of which may be run at the same time. A HELP/INPUTS-oriented system is used for supplying and explaining the parameters of the programs. AIPS also contains a programming language allowing definition of executable procedures utilizing both the primitive and high level functions in AIPS.

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*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. The AIPS/VAX Systems

A. The Role of AIPS

The AIPS system software can be conveniently entered at either of two levels. First, after editing, correcting and calibrating the data on the DEC-10 system or the Sorter/Gridder system, the visibility data can be written on magnetic tape in the EXPORT format (from the DEC-10) or UVFITS format (from Sorter/Gridder). The data are then read into the AIPS system for further processing. This processing includes data editing and plotting, mapping, cleaning, and self-calibration in order to improve image quality.

Secondly, if images are made on other systems, they can be transfered to AIPS via magnetic tape written in the FITS format, and then undergo further processing and analysis. Once high quality images are produced, AIPS contains most of the software needed to display, process, analyze, and interpret them. Images made from optical, X-ray, infra-red, etc. instruments can also be processed in AIPS, as can theoretically computed images.

B. AIPS Hardware

The AIPS software system is implemented on two VAX 11/780 minicomputers at the VLA site and a VAX 11/780 and a Modcomp Classic minicomputer in Charlottesville. Observers generally use the VLA site VAX systems for post-processing immediately after a VLA observing run. For subsequent post-processing they may work at the VLA site, Charlottesville, or other data reduction facilities. Each NRAO system runs the same AIPS software and has nearly identical hardware. Figure 1 shows both a photograph of AIPS peripherals in use at the VLA site and a photograph of a VAX system with tape drives on either side of the CPU, memory, etc. Figure 2 is a schematic diagram showing the hardware components of a VAX-based AIPS system. The VAX is a 32-bit machine configured with at least 750K words of memory, a 225M word (or more) disk system, tape drives capable of nine track tape I/O with densities of 800, 1600, or 6250 bpi, a printer-plotter for hard copy output, TEK 4025 CRTs for running programs, a 512^2 pixel image display system, and an array processor. Every AIPS or VAX user has a TEK 4025 CRT for running programs, including AIPS.

The AIPS image display system shown in Figure 11-2 is based upon I^2S (Image Interpretation Systems) hardware with a 512^2 pixel color or gray scale TV display, up to four separate storage areas (planes) for 512^2 pixel image

Figure 11-1. The top photographs shows two users running AIPS on a single VAX. Both are running AIPS on TEK 4025 terminals, but sharing use of the TEK 4012 graphics terminal in the center, the image display CRT at the far right, an array processor, a VERSATEC printer-plotter, and tape drives. Each user has an AIPS task-monitoring CRT; for the user at the left it is on a table to the left, while for the user at the right it is on top of the I^2S 512^2 image display screen.

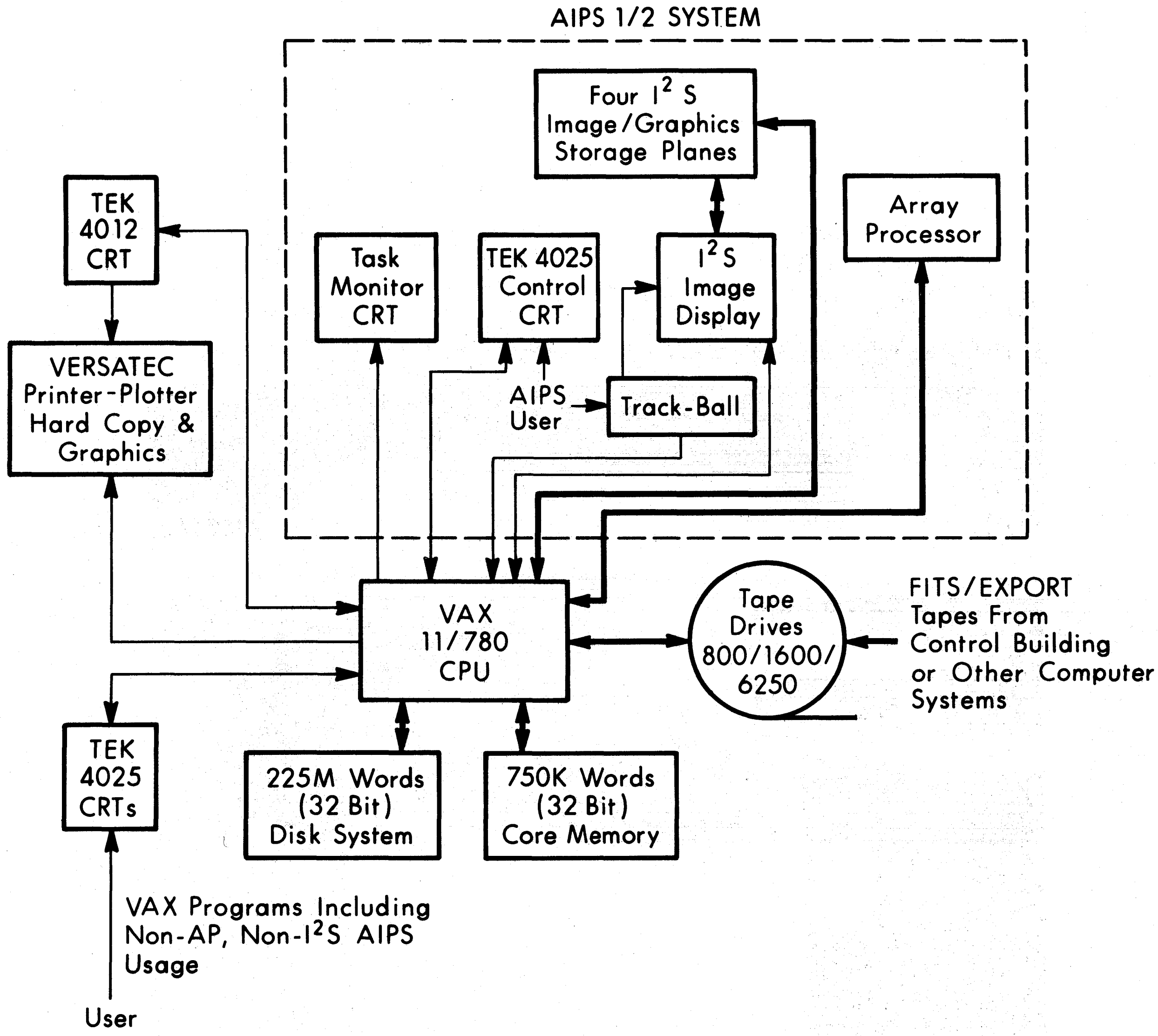

Figure 11-2. A schematic diagram showing the hardware associated with a VAX-based AIPS system. AIPS 1 and AIPS 2 users have their own TEK 4025 control CRT and task monitor CRT, but share an array processor and the 512^2 pixel image display system consisting of a Color or Gray scale TV display, a track-ball for cursor control, and four image and graphics memory storage planes. They and other users share usage of disks, memory, tape drives, a TEK graphics CRT, and a VERSATEC printer-plotter.

and (1-bit) graphics storage, and a software or track-ball controllable cursor that can be displayed and moved on the TV screen.

C. AIPS Usage

Because of the heavy load on the VAX's at the VLA and in Charlottesville, the number of simultaneous users of AIPS and their time allotment are carefully scheduled. The user with primary access to the array processor and image display is called the AIPS 1 user; however, a secondary user, called AIPS 2, does have full access to the power of the VAX as long as the AIPS 2 user does not unduly limit the ability of the AIPS 1 user to reduce the data. Some of the priority of the AIPS 1 user is built into the software; some of the sharing of resources is accomplished verbally. Light use of AIPS is available in AIPS 3 which can be run on other terminals. There is also a batch mode in AIPS in which processing can be run at a designated time in the future. Batch has low priority and must not interfere with the AIPS 1 user. If the array processor is used in batch, the user must sign up for AIPS 1 time during the anticipated running period.

The executable functions in AIPS are either "verbs" which are short time scale in execution, with input and output to the TEK 4025 terminal, or "tasks" which have longer time scales for execution and are "shed" to run semi-independently of the TEK 4025 terminal, with status information for each previously shed task displayed on a task monitor CRT.

The array processor is used for computation-intensive functions in AIPS such as image-making, cleaning, image arithmetic, image self-calibration, etc. Usage of the array processor is build into certain AIPS tasks and the user need not be aware of its role or operation, except with regard to the sharing of this resource between AIPS 1, AIPS 2, and batch.

D. AIPS Logistics

The AIPS computers, located in the Library/Office building west of the Control building, are heavily in demand; therefore users share usage of the same hardware by means of a scheduling system. Each AIPS 1 and AIPS 2 user has an sign-up sheet whereby they can reserve AIPS processing time in advance. For batch jobs using the array processor users must sign up for AIPS 1 time. NRAO staff can schedule returning users for AIPS time when travel for a post-processing session is approved and arranged. Aside from this pre-arranged time, users sign up for blocks of AIPS time, on a first come, first served basis. Specific rules govern this process, particularly the amount of time a person or group can sign up for. A group of people working on a single project is counted as a single user. Details on sign-up rules are posted near each system, with enforcement mainly by users pointing out to each other when rules are violated to achieve an unfair advantage. In cases of irreconcilable conflict or special needs there are people at each site authorized to make decisons in these matters.

E. AIPS Documentation

The principle documentation for AIPS users consists of an AIPS Cookbook, the HELP facilities, and a series of more detailed AIPS manuals which discuss all AIPS functions, AIPS as a language, AIPS data base design, and how to write FORTRAN programs for AIPS. The later is intended for those involved in AIPS software development, or for those transfering AIPS to other computer systems.

Most users will need only the AIPS Cookbook to guide them in their use of AIPS. Copies of this Cookbook are maintained near each AIPS system. Individuals can obtain copies in Charllottesville, the VLA site, or from the NRAO conputer division.

Because AIPS is oriented towards supplying command information by typing HELP nnnnnn, where nnnnnn is the name of a subject, verb, task, adverb, etc. the user will find it to be largely self-documenting. The list of verbs and tasks at the end of the Cookbook are all things about which one can obtain information by typing HELP and then the verb or task name. Hard copy of the HELP files may also be obtained. Closely related to the HELP capabilities are the INPUTS displays that can be obtained by typing INPUTS nnnnnn ; in this case one obtains a display of the current values of all parameters (adverbs) for the verb or task. Once a user becomes familar with AIPS, almost the only things needed are the list of verb and task names and the knowledge of when to ask for HELP or INPUTS.

Chapter 12

SPECTRAL LINE SYSTEM

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April 1983 Edition

ABSTRACT

The characteristics of the VLA spectral line system are discussed. This system is limited partially by available hardware, but mostly by the available software.

*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. INTRODUCTION

The VLA spectral line system is still under development in 1983-84. You should therefore always plan to bring yourself up to date upon arrival at the VLA site. Because the system is both complicated and still under development, with limited documentation, the user should make extensive use of the advice of VLA staff experienced in using the spectral line system.

Because of its complexity, a special guide has been written by A. Rots: "A Short Guide for VLA Spectral Line Observers". This guide attempts to document all the various aspects of a spectral line observing run, from preparing the observing file to carrying out profile analysis on the final results. In addition, information about the spectral line system can be obtained from VLA Technical Report No. 39 (The Correlator System Observer's Manual), the Observer's Reference Manual, and the VLA Observational Status Report.

The principle limitation of the spectral line system at the present is the number of channels that the software can handle. In other words, there is a limit on the product of the number of antenna pairs and the number of frequency channels. How these limitations are implemented, and the available choices, are described below.

2. SYSTEM SPECIFICATIONS AND LIMITATIONS

A. Single IF Operation

Only two IF channels (A and C) are available, and in the spectral line system only one is available at a time, so you can observe with only one polarization at a time. If IF A is in use, one, two, or four quadrants of the correlator system can be utilized; however, if IF C is in use, you can utilize only two or four quadrants.

B. Choice of Bandwidth, Mode, and Velocity Resolution

When you are planning an observation, you must first decide what total velocity coverage and velocity resolution you want. For each total bandwidth three different modes (leading to different resolution) are available. These are tabulated in Table 12-1. The velocity resolution is thus fixed when you choose the total bandwidth (bandwidth code) and mode. However, you can always use less than the total number of channels available, provided the number you use is expressable as a power of 2. In several cases a given combination can be obtained in more than one way, e.g. if you want a resolution of 48.8 kHz and a velocity coverage of 3.125 MHz, you can get it with: (1) bandwidth code 4, mode 4, total number of channels 64; or bandwidth code 3, mode 1 (A or C), and only 64 out of 128 channels. In this case you would prefer the second case, since the edge channels of the band are usually bad. When possible one uses only the central part of the band containing "good" channels.

Six observing modes, designated 1A, 1C, 2A, 2C, 4, and 4A, are available. These modes are specified on the observing source list cards as prepared with the OBSERV program. Modes 4 and 4A are equivalent, although they represent different implementations in the correlator system. Table 12-1 list the various channel separations and numbers of channels attainable for different combinations of bandwidth and observing mode. In Table 1 Single IF Mode refers to the 1A and 1C modes, Two IF Mode refers to the 2A and 2C modes, and Four IF Mode refers to the 4 and 4A modes. Note that for bandwidths of 0.39 MHz the first half of the band is useless.

The frequency resolution is 1.2 times the channel separation as listed in Table 12-1. With Hanning smoothing, the resolution of the data is 2.0 times the channel separation. Frequency increases with channel number. Table 12-1 also list the number of frequency channels produced by the Array Processor in the on-line computer system for each combination of bandwidth and correlator mode. If n is the number of frequency channels, the channels are numbered from 0 through 2^n-1, and the center of the observing band is at channel 2^{n-1}. As we will discuss, you can select a sub-set of these channels for actual data collection and processing.

Table 12-1

Channel Characteristics for Combinations of Bandwidths and Correlator Modes

		SINGLE IF MODE		TWO IF MODE		FOUR IF MODE	
BW Code	Chan BW [MHz]	# Chan.[1]	Freq. Separ. [kHz]	# Chan.[1] Per IF	Freq. Separ. [kHz]	# Chan.[1] Per IF	Freq. Separ. [kHz]
0	50	16	3125.0	8	6250.0	4	12500.0
1	25.0	32	781.25	16	1562.5	8	3125.0
2	12.5	64	195.313	32	390.625	16	781.25
3	6.25	128	48.828	64	97.656	32	195.313
4	3.125	256	12.207	128	24.414	64	48.828
5	1.5625	512[2]	3.052	256	6.104	128	12.207
6	0.78125	512[2]	1.526	256	3.052	128	6.104
8[3]	0.390625	512[2]	0.763	256	1.526	128	3.052
9	0.1953125	512[2]	0.381	256	0.763	128	1.526

[1] These are the numbers of frequency channels produced in the AP. One can select any number of channels that is a power of 2, is greater than 8, and is less than or equal to the number in the table (with a maximum[2] of 256). This parameter is specified on the LI card using the OBSERV program.

[2] Although 512 channels can be produced in the AP, only 256 channels are passed on to the rest of the on-line computer system. The selected channels are specified on the LI card using the OBSERV program.

[3] Only the upper half of the band is usable. Also, for reasons we will not discuss, there is no channel bandwidth code of 7, rather 8 plays the role of 7 and 9 plays the role of 8.

The principle limitation of the experimental spectral line system is the limit on the product of the the number of antenna pairs and the number of frequency channels. If one wants to exchange channels for antennae, i.e. a trade-off beween frequency coverage and u-v coverage (or sensitivity), one can select (on the LI card with OBSERV) any number of channels that is a power of 2, anywhere in the band, and only these channels will be included in the data output for the array. The channels outside this selected region are irretrievably lost. However, channel 0 always contains the average of the central 75% of the originally available band, independent of the number of channels selected.

Therefore

Number of Frequency Frequency Channels	Allowable Number of Antennas
8	All 27
16	All 27
32	21
64	15
128	11
256	8

In spectral line observing no system temperature corrections are applied on-line to the data; this correction can be applied later by the observer; however, if there is a spectral line signal that contributes significantly to the system temperature, extra complications should be anticipated (see the Spectral Line Guide).

The following formula describes the rms noise for a single IF and frequency channel:

$$\Delta S = a/[N(N-1)\ \Delta t_{hr}\ \Delta\nu_{kHz})]^{1/2} \quad \text{mJy/beam} \qquad (12\text{-}1)$$

where N is the number of antennas, Δt_{hr} is the integration time in hours, $\Delta\nu_{kHz}$ is the signal bandwidth in kHz, and the constant a is as follows for the four VLA observing bands:

Band	a
20cm	620
6cm	420
2cm	1100
1.3cm	4500

The values of a are based upon average maps produced with uniform weighting and only apply to point sources. The sensitivity for an extended source is difficult to predict since it depends upon the source structure and the u-v plane coverage. The sensitivity described for 2 cm applies to the antennas equipped with the new 2 cm FETs. For other antennas the constant a is about a factor of three larger.

3. THE GUIDE FOR VLA SPECTRAL LINE OBSERVERS

Because of the experimental and evolving nature of the VLA spectral line system, the documentation describing the details involved in using this system is even more variable than normal. These details are described in a Guide for Spectral Line Observers written by A.H. Rots. Spectral line observers should obtain the latest versions upon arrival at the VLA site.

Chapter 13

DATA PROCESSING METHODS

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June 1982 Edition

ABSTRACT

Possible methods of VLA data processing are discussed in a Cookbook-like fashion. This includes: (1) a guide to a recommended sequence of procedures for editing and calibrating continuum data, with examples from an observing run; (2) a description of a "batch" approach to data processing; and (3) discussion of data processing methods for special types of problems.

*The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation.

1. Introduction

There are probably many more ways to carry out VLA data reduction than there are ways do radio astronomy with the VLA. Despite this, there are regular steps in the data reduction process that are common to most observing programs. In this Chapter we describe various methods of VLA data reduction.

2. A Cook-book Approach to Editing and Calibration of Continuum Data

A. Why a Cook-Book Approach Is Recommended

In this section we will discuss one approach to the editing and calibration of VLA continuum data that will aid the inexperienced user. This will emphasize an interactive approach to running programs. Numerous variations to this procedure exist, and each observer develops a favorite way of analyzing data as they gain experience. The user need not follow the recommeded procedures in this section, but is encouraged to do so until sufficient experience is developed.

It is important to carry out VLA data reduction in an optimum manner. This is both because the large amounts of data involved require a disciplined approach to avoid getting lost in the details, and because VLA data reduction is only a means to a scientific end. Unfortunately it is all too easy to get bogged down in the details, and the phrase "terminal astronomer" has been used to designate a commonly observed phenomena.

Almost all the time the observer can carry out all the steps of data reduction, all the way through mapping, cleaning, and self-calibration before stopping and carrying out editing of data. This is because the amount of "good" data so overwhelms the small amounts of "bad" data, that the first order results of VLA observing are almost always rather good. We emphasize this to make a point for the inexperienced observer: it is hard to go wrong in initially following "cook-book" recipes, because of the high probability of most of the data being "good".

B. How the Data Are Organized

As discussed in Chapter 7, there are several files associated with the data of one observing program, and we describe these files as a "data base". The files are treated as one unit when you specify the data base name in a standard analysis program. The name of a data base is assigned by the VLA operator, or whoever puts the data base on disk in the DEC-10, and is usually something like 1APR29, where April 29 is the date of the observing run, and the 1 indicates that data were taken in subarray 1. Each file in the data base has the same name but a different different extension reflecting the nature of the file. These data base files in the DEC-10 are:

(1) dbname.INX
(2) dbname.VIS
(3) dbname.GAI

where DBNAME is the data base name. The extensions stand for INDEX, VISIBILITY, and GAIN. The index file (1) contains the header information relavant to all the data gathered during one scan. A scan length is defined by two adjacent stop times as specified in the OBSERV file. The visibility file (2) contains the visibility data, and the gain file (3) consists of complex antenna gains for scaling the visibility data. More details on this can be found in Chapter 7. It should be emphasized that the calibration procedure modifies ONLY the entries in the gain file. The visibility data in the VIS file are never modified during DEC-10 data reduction. The gain corrections are applied as necessary in analysis and mapping programs, but the visibility data are never altered. Thus is is always possible to alter a previous correction or calibration by changing the contents of the gain file.

Data bases are stored in the user data area designated [14,Programmer Number] and are accessed by the data reduction programs. The Programmer Number or PN is assigned the first time a user arrives at the VLA site, and is written on an information sheet supplied at that time. When supplying a data base name to a program, you may need to append the designation [14,PN] to the data base name. Thus, the complete data base designation is

dbname[14,PN]

where a typical example looks like 1MAY20[14,313]. If you are using a data base with a PN the same as the PN with which you logged on the DEC-10, the

[14,PN] suffix can be omitted. The data reduction programs will use the appropriate files in the data base as necessary.

Four additional files are created as part of the data base as calibration proceeds. These are the history, calibration, residuals, and antennas files designated as

dbname.HST

dbname.CAL

dbname.RES

dbname.ANT .

The history file is a continuing chhronological record of the running of all programs which have changed or modified any part of the data base. This history file includes a listing of the parameters used for each program run and can be printed out at any time by typing (on a DEC-10 terminal)

PRINT dbname.HST[14,pn]

after which you can retrieve the results from the line printer in the VLA computer room. Characters typed at the terminal can be either upper or lower case.

The calibration file (dbname.CAL[14,PN]), created by the progam ANTSOL, is a collection of complex gains derived from observations of calibrator sources. This file is used later in the calculation of the amplitude and phase calibration applied to the gain file (dbname.GAI[14,PN]) by the GTBCAL program. One can also choose an option in ANTSOL so that closure errors are written into a visibility-like file, named dbname.RES[14,PN], which can be listed with the LISTER program.

The antennas file (dbname.ANT[14,PN]) contains the positions of the antennas during the observing run. It is created by the program FILANT and is used for some visibility corrections in GTBCOR and as part of preparation of an EXPORT tape when data is to be analyzed in other computer systems.

C. Cook-book for Editing and Calibration

Before beginning the actual process of editing and calibration there are a number of preliminary steps that should be done. The first step is to obtain, and write down, information that will be needed during the data reduction process.

Having planned the observing with its calibration strategy, you know in advance what calibrators and frequencies you will be dealing with. Using either your own past experience with these calibrators, or the information in the Calibrator Manual (copies of which are in most of the observer's rooms at the VLA site), make a list of properties of each calibrator at each frequency. This should include at least an estimate of the flux density and the information about the useful range of the u-v plane where the calibrators behave like proper point sources.

Next you should become familiar with basic information about your observing run. This includes basic information about: your data tapes; the name of the data base created in the DEC-10 by the array operations staff; antenna locations; and obvious problems that indicate that data editing may be necessary. There are three obvious sources for this information: (1) the observing log which will record information about both visibility and monitor data tapes, unusual problems noticed during the observing process, and the name of your filled data base; (2) conversations with the operators during and after observing; and (3) a file of information written by the array operators into your [13,PN] area with a name corresponding to your data base name. The latter file contains a list of approximate antenna locations, a "map" showing where the antennas are located on the "Y", a table of baseline lengths for each antenna pair, and a short "Operator's Status Sheet" that will report most known equipment problems. It is useful to write down the list of operational antennas, both in order of ID number, and in order of approximate radial distance from the center. Both lists will be used at various steps in data reduction when you provide antennas lists for various purposes.

The above sources of information will frequently tell you that some antenna-IFs are bad, and should be edited out as the first real step in data reduction. The operators may be able to provide you with the so-called CHECK output which contains ANTSOL solutions for system gains and phases for antennas, or you may wish to use LISTER to examine listings of scan averages for sources, particularly calibrators. Normally the CHECK output will be sufficient to carry out the first data editing.

During the 1APR29 observing run on SS433, which we will use to give examples of editing and calibration, the array was in the A-configuration. The source 1923+210 was used as a prime calibrator, and 3C286 was observed at all the frequencies used in the observing run, 6cm and 2cm, for polarization angle and flux density calibration. Antenna 12 was out of the array because it was undergoing maintenance in the Antenna Maintenance Building, and antenna 26 was out of the array for all but the last 20 minutes of the observing run because of a problem with the ACU (antenna control unit) that was fixed during the observing run. The observing logs and the the disk file 1APR29[13,11] were sufficient to find out this basic information. Thus the operational antenna list mentioned above were

1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

or

21 17 10 19 6 13 23 22 11 26 28 9 25 27 16 20 14 4 5 8 18 1 7 2 24 15 3

for a list approximately ordered in distance from the center. Because antenna 26 came into the array too late to be properly calibrated, it was decided that all antenna 26 data should be flagged. According to all other indications, the rest of the data were good.

The flagging of antenna 26 was carried out with the following dialogue (note that hereafter the user's contribution to the dialogue will be underlined, and we will frequently put explanatory material, NOT TO BE TYPED INTO ANY PROGRAM, to the right of a line of computer dialogue, following a semi-colon):

```
.r flager                                ; to run program
*setdef                                  ; set defaults with SETDEFAULTS
*db 1apr29                               ; data base specifcation
*bands *                                 ; all frequency bands
*sources *                               ; any and all sources
*ifs a c                                 ; flag both IFs
*ant 26 with *                           ; set antenna to be flagged
*time  82apr29 at 0: to 82APR29 at 24:   ; all data during run
*flagoption ant                          ; antenna-based flagging
*inp                                     ; DOUBLE-CHECK BEFORE FLAGGING
   . . .                                 ; skipping INPUTS display here
*go flag                                 ; to execute specified flagging
*fin                                     ; to exit from program
```

and the data will be flagged. Note that most of the parameters set above were actually the defaults set by SETDEFAULTS, but we repeated them here to emphasize the correct parameters. Always double-check the correctness of your INPUTS parameters before carrying out flagging.

The next step is to use the SETJY program to assign flux densities. The dialogue to accomplish this (for 6 cm only) is:

```
.r setjy                          ; run SETJY program
*db 1apr29                        ; assign data base name
*band 6cm                         ; set for 6cm flux densities
*source 3c286 1923+210            ; specify the two calibrator names
*fluxes 7.41  1.5                 ; specify fluxes form Calib. Manual
*go setjy                         ; put fluxes in 1apr29.inx[14,PN]
*go list                          ; check results for each 6cm scan
```

Source:Qual	Scan IAT	Band	I	Q	U	V
	82APR29					
3C286: 0	11:36:20	6cm	7.410	.000	.000	.000
3C286:0	11:48:40	6cm	7.410	.000	.000	.000
1923+210:0	12:29:30	6cm	1.500	.000	.000	.000
1923+210:0	12:57:50	6cm	1.500	.000	.000	.000
1923+210:0	13:42:40	6cm	1.500	.000	.000	.000

```
   . . .
*fin                              ; and exit from program
```

It is wise to check results with the GO LIST, because one can spell a calibrator name incorrectly and its flux will then not be entered into the data base.

The next step is to RESET the gain table (dbname.GAI[14,PN]) to clear out any un-wanted information, and apply any known corrections, using the GTBCOR program. In the 1APR29 observing run no corrections (except for polarizationcalibration), were needed so only the following dialogue was used insure a cleared gain table:

```
.r gtbcor                         ; to run program
*setdef                           ; set defaults which cover all data
*dbn 1apr29                       ; specify the data base name
*go reset                         ; to insure a cleared gain table
*fin                              ; to exit from program
```

The next step is to use ANTSOL to solve for and list the antenna calibration parameters. This can be accomplished with the following dialogue:

```
.r antsol                         ; run program
*setdefa                          ; set defaults to insure start para.
*db 1apr29
*ant * - 12 26                    ; specify all antennas but 12 & 26
*refant 17 21 10                  ; reference ant. in preferred order
*band 6cm 2cm                     ; all observ. bands used in run
*sources 3c286 1923+210           ; list all calibrators
*go solve                         ; start solution for calib. param.
   . . .                          ; next abbreviated closure displays
   . . .
```

```
82APR29
Observing Mode:  CONT.
12:31:03 1923+210    C AA  1-11          -5%  1-20           6%  1-24           6%
                           2-16           5% 16-18           6%
Observing Mode:  CONT.
12:31:03 1923+210    C CC
Observing Mode:  CONT.
12:35:10 1923+210    U AA  1- 4           5%  1- 5          10%  1- 6           6%
                           1- 8          -5%  1-13          -5%  1-16     5d
                           1-17           6%  1-22          -6%  2- 7           5%
                           2-14           7%  4-15           5%  6-16           5%
                           7-15           7%  9-10          -8%  9-13          -6%
                           9-16           6% 14-15           5%
          . . .
```

```
*listopt ampl phase          ; list both amplitude and phase
*band 6cm                    ; plan listing 6cm calib. param.
*outfile lpt:1apr29          ; to line printer
*go list                     ; produce listing
   . . .
*band 2cm                    ; now for 2cm
*go list                     ; and produce that listing
*fin                         ; and exit from ANTSOL
```

One should then go to the line printer in the VLA computer room and retrieve the listing of the amplitudes and phases in the dbname.CAL[14,PN] file. We see reasonably small closure errors (closure display limits were set at 5% for amplitudes and ±5 degrees for phases), and a partial listing of the CAL table printed out (for 6cm amplitudes and phases) is the following:

LISTING OF ANTENNA VOLTAGE GAINS: AMPLITUDES (* 10*sqrt(1000)

TIME	BAND	SOURCE	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	13A	14A	15A	16A	17A
82APR29																		
11:39:25	6	3C286:00	95	87	105	99	94	98	98	91	84	93	116	101	102	102	100	98
11:51:00	6	3C286:00	95	87	106	99	96	98	98	91	84	92	116	101	103	102	100	98
12:31:03	6	1923+210:00	98	87	105	97	97	98	97	90	85	93	116	101	101	102	98	99
12:59:40	6	1923+210:00	97	87	105	97	97	98	97	90	85	93	115	101	101	101	98	100
13:43:20	6	1923+210:00	97	87	105	96	97	97	98	90	82	93	115	101	101	102	98	100
13:45:15	6	1923+210:00	98	88	105	97	97	97	97	89	84	93	114	100	101	102	98	99
14:29:20	6	1923+210:00	97	86	105	97	97	97	98	89	84	93	112	100	101	103	97	99
15:14:10	6	1923+210:00	95	86	104	97	96	97	98	89	83	93	112	100	102	103	98	99
15:59:10	6	1923+210:00	95	86	104	97	96	97	98	90	82	93	112	99	102	102	98	99

. . .

. . .

LISTING OF ANTENNA VOLTAGE GAINS; PHASES (degrees)

TIME	BAND	SOURCE	1C	2C	3C	4C	5C	6C	7C	8C	9C	10C	11C	13C	14C	15C	16C	17C
82APR29																		
11:39:25	6	3C286:00	-63	11	-138	154	26	-70	-4	-174	31	-107	95	-34	8	162	-88	0
11:51:00	6	3C286:00	-57	-13	-166	146	46	-60	15	-165	21	-107	87	-38	7	-174	-90	0
12:31:03	6	1923+210:00	114	97	149	-172	144	-67	-139	130	93	-105	-6	-40	-11	-34	-28	0
12:59:40	6	1923+210:00	101	81	146	-171	133	-72	-159	111	90	-105	-2	-40	-47	-65	-33	0
13:43:20	6	1923+210:00	146	69	157	177	176	-66	-140	128	85	-111	5	-43	-33	-21	-40	0
13:45:15	6	1923+210:00	142	56	150	178	174	-62	-138	129	90	-111	12	-40	-35	-20	-38	0
14:29:20	6	1923+210:00	92	51	139	-170	133	-62	-121	144	87	-113	38	-36	-31	12	-41	0
15:14:10	6	1923+210:00	58	48	165	-175	102	-66	-115	143	71	-110	43	-34	-27	18	-55	0
15:59:10	6	1923+210:00	49	61	-157	-167	97	-56	-94	151	67	-106	72	-27	-27	61	-47	0

. . .

In the above listing, the amplitudes are very good, and the lack of jumps between calibrators means the flux for 1923+210 was quite good. If there are amplitude jumps between calibrators, one should improve the assigned flux densities. This can be done for any data base containing 3C286 by using the GO BOOTSTRAP program in ANTSOL - this will result in a solution for fluxes based upon assuming contain antenna amplitude, and the results are automatically inserted in the dbname.INX[14,PN] file. You must then re-do the above ANTSOL solution and listing. The phases in the above listing of the CAL table shows some drifting with time; however, since it appeared to be a smooth type of variation, without phase jumps that would need to be corrected for in GTBCOR, the application of this calibration will remove most of this variation. The rest will be removed in the end by using self-calibration procedures on the program source - SS433.

The next and last important step is the application of the calibration in the dbname.CAL[14,PN] file, just found with ANTSOL, to the gain table (dbname.GAI[14,PN]) using the GTBCAL program. This was accomplished with the following dialogue:

```
.r gtbcal                                ; to run calibration applicator prog
*setdef                                  ; usually good habit to SETDEFAULTS
*db 1apr29                               ; specify data base again
*anten * - 12 26                         ; all antennas but 12 & 26
*time 82apr29 at 0: to 82apr29 at 24:    ; all times, sometimes limited range
*caltype amp pha                         ; apply both ampl. & phase calib.
```

```
*band 6cm                          ; 6cm calib. for SS433 first
*interp box                        ; do BOXCAR averaging for 6cm
*calsources 1923+210               ; specify SS433 calibrator
*sources  ss433                    ; calib. for both 1923+210 & SS433
*aver 2:00:00                      ; 2 hour boxcar averaging
*go calibrate                      ; putting calibration in gain table
   . . .                           ; you will get messages about
   . . .                           ; antennas on and off line
   . . .                           ; which we don't repeat here
*band 2cm                          ; do 2cm for same sources
*interp 2point                     ; do 2POINT interpolation
*go calib                          ; and put calib. in gain table
   . . .
*source 3C286                      ; now calibrate 3C286 on itself
*cals 3c286
*interp boxcar                     ; back to boxcar averaging
*band 6cm                          ; first for one band
*go calib
   . . .
*band 2cm                          ; then the other
*go calibrat
   . . .
*finish                            ; and exit program
```

We used 2POINT interpolation for the 2cm observations because each fifteen minute scan on SS433 was surrounded by a 2cm calibrator observation. We used BOXCAR for 6cm (and all 3C286) because in the roughly one hour between scans things can change quite a bit.

The next step that we will discuss is optional. Examination of the scan averages for calibrators (and strong, well understood sources) can help evalute whether any problems exist that require further editing. Doing scan averages of amplitudes with the rms option is a quick way to find out if there are discrepancies between scans and within scans. The following is an example carrying out this type of evaluation:

```
.r lister                          ; to run listing program
*setdef
*db lapr29                         ; once more the data base name
*anten 21 17 10 19 6 13 22 11 26 29 9 25 27 16 20 14 4 5 8 18 1 7 2 24 15 3
                                   ; ant. list with short spacings 1st
*scalefactor 0.1                   ; scale amp, improve listings looks
*calib apply                       ; list data with calibration applied
*sour 3c286 1923+210               ; list calibrators first
*aver scan ampscalar               ; ampscalar averaging of ampl.
*band 6cm                          ; separate 6cm data from 2cm
*list scan amp/Jy rms                  ; list ant. "gains" with rms
*out lpt:lapr29                    ; line printer output with label
*go matrix                         ; do matrix type listing
```

*list scan phase rms	; list phases with rms
*go mat	; list matrix of calibrator phases
*scale 1.0	; change amp scale for weaker source
*source ss433	; list program source
*aver scan vector	; extended source, vect. avg. best
*list scan amp/ rms	; only amp avg info is useful
*go m	; initial SS433 amplitude listing
*scalefactor 0.1	; scale amp, improve calib. listing
*sour 3c286 1923+210	; list calibrators first again
*aver scan ampscalar	; ampscalar averaging of ampl.
*band 2cm	; now do 2cm listing
*list scan amp/ rms	; list ant. "gains" with rms
*go matrix	; do matrix type listing
*list scan phase rms	; list phases with rms
*go mat	; initiate listing of calibrator pha
*scale 1.0	; change amp scale for weaker source
*source ss433	; list program source at 2cm
*aver scan vector	; extended source, vect. avg. best
*list scan amp/ rms	; only amp avg info is useful
*go m	; final 2cm SS433 ampl. listing
*quit	; exit from program

After retrieval of the listing from the DEC-10 line printer, one has the a long listing, of which the following is a brief except for one calibrator scan:

```
***82APR29***

  source:Q     C  Band    Flux    StartIAT  StopIAT    StartLST    A-Obs, Freq-C     A-Bandwidth-C      RA(obs)     DEC(obs)
1923+210:0     C   6cm 1.500Jy   12:29:30 12:32:20   19h47m14s   4885MHz   4885MHz 50.0MHz 50.0MHz 19h25m13s   21d04'04"
Scale: x1.0E+02    AA upper right, CC lower left
  A-21--17--10--19-- 6--13--23--22--11--26--28-- 9--25--27--16--20--14-- 4-- 5-- 8--18-- 1-- 7-- 2--24--15-- 3-
21|     103 101 101 101  99 102 101 101     100  99 102  98 100 101 101 100 102 101 101  99 100  99 100 100  98
17| 102     100 101 101 102 102 101  98     100  98 102  99 103 102 100  99 100 101  99  96  97 100 101  99  99
10| 101 100     101 102 103 103  99 102      99 100 101 100  96 100  99  99 101  97  99 103  99 101 101 100 101
19| 100 100 100     101 101 102 100 101      98  99 103  99  99 101 100  99 101 101 101 100 100 100 100  99  98
 6| 100 101 102 102      99 101 103  99      99  99 100 101  97 101 100 100 100 100 101 106 102  99  99  99  99
13|  99 101 101 101  99     102  99 103      98  99 100 100  96 101 101  98 100  99  97 104 101 100 101 100  99
23| 101 101 100 102 101 101      99 100      99  99 102 100  99 101 101  99 101 101 100  96 101  98 101 101  99
22| 101 100 102  99 101  99 102     101     102  99 100 102 104 100  99 101  99 101 101  98 100  98 100  99 102
11| 101 102 100 101  98 101 100  97         103 105 101 101 104 101  98 103 101  96 101  96  98 100 101 101 102
26|
28|  99 100 100  99 100  99 102 103 100         101  98 102 101  99 100 101  99 101 101 102 103  97 100 101 102
     . . .
 2|  98  99 101 101  99 100  98  98 101     100 100 100 103 102 100 100 100 101 101 102  99 103     100  99 102
24| 102 101 101 100  99 100 101  99 101      99 101 101 100  99 102  99 100 101  99 100 102  99 100      99  99
15|  97 100  98  99  99 100  99  99 100     100 101  98 102 103  98 100 100 100 103 101 100 103 102 100     100
 3|  98 100  99  99  98 100 100 101 100     102 100  98 103 102  99 103 101  99 101  99  99 102 103  99 101
Data average: 12:31:05 <amp>=   100 +/-   2 <phi>=   0d +/-   3d   Navg=   3850
Matrix average:        <amp>=   100 +/-   2 <phi>=   0d +/-   7d   Navg=    650

RMS for above matrix
  A-21--17--10--19-- 6--13--23--22--11--26--28-- 9--25--27--16--20--14-- 4-- 5-- 8--18-- 1-- 7-- 2--24--15-- 3-
21|       1   0   1   1   0   1   1   1       1   1   0   1   1   0   1   0   1   1   3   1   1   1   1   1   1
17|   1       1   1   1   1   1   1   1       1   1   2   1   1   1   1   1   1   0   2   2   1   1   1   1   1
10|   1   1       1   1   1   0   1   1       1   1   2   1   1   2   1   1   1   2   0   1   1   2   1   0   1
19|   1   1   1       1   1   1   2   1       1   1   1   1   1   1   0   1   1   1   1   1   0   1   1   1   1
        . . .
```

```
  Source:Q     C  Band    Flux    StartIAT  StopIAT   StartLST   A-Obs. Freq-C    A-Bandwidth-C     RA(obs)   DEC(obs)
1923+210:Ø     C   2cm 2.45ØJy  12:53:3Ø 12:57:2Ø  2Øh11m18s 14965MHz 14965MHz 5Ø.ØMHz 5Ø.ØMHz 19h25m13s  21dØ4'Ø4"
AA upper right, CC lower left
  p-21--17--10--19-- 6--13--23--22--11--26--28-- 9--25--27--16--20--14-- 4-- 5-- 8--18-- 1-- 7-- 2--24--15-- 3-
21|        1   Ø   1   Ø   3   Ø   Ø   1       1  -1  -1   2  -1  -2  -2   Ø   Ø   Ø   Ø   3  -1  -1   1  -3  -3
17|   Ø        1   1   1   1   Ø  -1  -3       Ø   2   1   Ø  -1   1  -4   1   Ø   1   1  -2   1   1   Ø   Ø   1
1Ø|   2   -1       Ø   Ø   1   1   3   3       1   1   Ø   3  -2   Ø   2  -4   Ø   Ø   Ø  -2   Ø   Ø  -2   1  -4
19|   Ø   -1   1       1   1   1   1  -1       Ø   1  -1   Ø  -3   1  -1  -1   1   1  -1  -2   Ø  -3   Ø  -1  -1
 6|  -1    1   Ø  -1      -2  -1   Ø  -2       Ø   Ø   Ø   Ø   1   Ø   3   Ø  -1   2   1   3  -1  -1   Ø   3   Ø
13|   Ø    Ø   Ø  -1  -2       3  -3  -7       3  -2   Ø  -1  -1   2   3  -4  -3   Ø   Ø  -6   Ø  -1   Ø   4  -6
23|   1    Ø   1   Ø  -2   2       Ø   1       1   Ø   1   Ø  -3  -1  -1   Ø  -1   1  -1   4   1  -1  -1  -1   2
22|   Ø    1   2   Ø   1   3   2      -2       Ø   1   Ø   Ø   1  -1  -1   Ø   1   2  -1   1   1   1  -1   2  -1
11|  -1    1   1  -1   2   1   Ø   Ø           1  -1   Ø  -1   1   2  -1   2  -2  -1   Ø  -4   1  -2   1   2   1
26|
28|   2    1   2   Ø   1   2   Ø   Ø   1           1  -2  -1   4   2   1   Ø   1   Ø   Ø   3   2  -2   1  -1   Ø
      .  .  .
24|   1    Ø   1   Ø  -1   2  -3  -1  -1       1   Ø   Ø  -1  -1   Ø  -2  -1   1  -1  -1   Ø   1  -1       Ø  -2
15|  -1    Ø   2  -1   2   1  -1   Ø   1       1   1   Ø  -3  -1  -1  -1   Ø  -1   2  -1   1   1   1   1       1
 3|  -1   -1  -3  -1   1  -2   3  -1  -3       Ø  -2  -2   Ø  -1  -1  -1  -1  -1   Ø   Ø   1  -2   Ø  -1  -1
Data average: 12:55:35 <amp>=    25 +/-   1 <phi>=  Ød +/-   2d    Navg=   52ØØ
Matrix average:        <amp>=    25 +/-   Ø <phi>=  Ød +/-   6d    Navg=    65Ø
```

where we have shown only parts of the display for a single scan. The first thing to notice is that, allowing for the amplitude SCALEFACTOR, the amplitudes/Jy are near unity and the phases are near zero, which is as it should be. Although the results are in part circular, due to human error in it is not uncommon to make a mistake and find un-calibrated data when one thinks calibration has been completed. Also, we see no obviously high rms's for the amplitudes. If we did, it would be a sign of bad data inside a scan.

An alternate technique is to do a GO COLUMN average for one reference antenna versus all other antennas for first one IF, then another. This will provide similar information about problems with data; however, the matrix and rms approach is not biased by potential problems with a reference antenna. Both approaches have advantages, and every user soon adopts the methods that seem most suitable.

These and similar evaluations may result in further flagging of data. If the extra flagging affects calibrators, it usually necessary to repeat the previous steps, starting with resetting the gain table in GTBCOR.

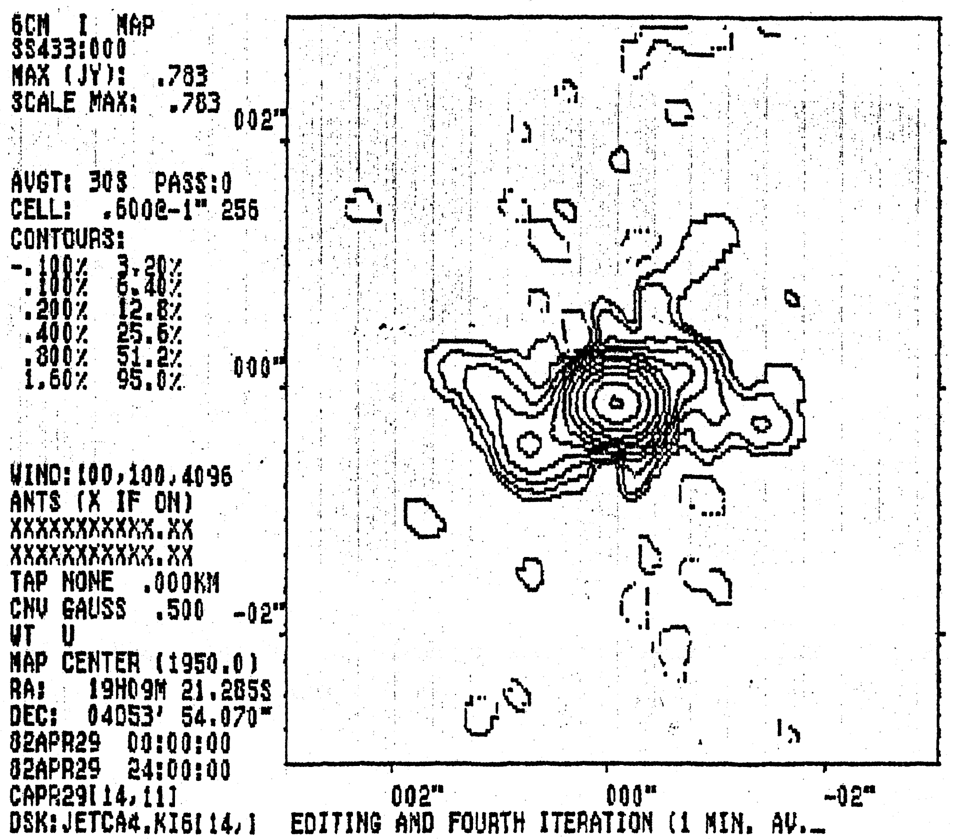
However, even if it is noted that one wants to repeat the calibration process, after editing, and perhaps with other approaches, it is often a good idea to proceed with mapping, cleaning, etc. before returning to clear up loose ends. This is because the evaluation of mapping results is often the best way to tell how close you are to obtaining desired scientific results, and this helps you decide about the amount of further work on editing and calibration that is desirable.

D. Processing of Calibrated Data

Once data have been sufficiently edited and calibrated, one can proceed to the more interesting stage of analysis of results. This usually means computing, and perhaps correcting or improving, radio maps made from data. Some users may choose to immediately make EXPORT tapes and carry out the remaining analysis in the AIPS or other data reduction systems; however, until you ar certain that you are finished with the editing and calibration process, it is often wise to carry out initial image processing with the facilities available in the DEC-10 and associated MAPPER, SORTER/GRIDDER, and DISPLAY systems.

We will not discuss the processing of calibrated data in detail in the rest of this section; however, we will briefly outline the normal course of events.

The SS433 program used as an example in this chapter is a very straightforward data reduction problem that reflect what is commonly done with strong, extended sources. The first step, using DEC-10, MAPPER, SORTER/GRIDDER, or AIPS systems is to map and clean the source. Because the data were taken in the A-array at 6cm and 2cm, the predicted (and actual) synthesized beams were 0.33" and 0.12", respectively, in diameter. The data were mapped using mapsizes of 256 by 256 with 0.06" and 0.03" cell sizes. and then cleaned. The resulting maps at 6cm and 2cm had a dynamic range of roughly 3% and 10%, respectively. After cleaning, the models inherent in the clean components used during the cleaning process were used to carry out an initial phase of self-calibration using an initial self-cal averaging time of several minutes. The subsequent maps showed improved dynamic range, and the process of mapping, cleaning, and self-calibration were carried out for two more cycles involving phase self-calibration, and when that had converged, one last step of both amplitude and phase self-calibration were carried out with 30 seconds averaging time during the self-cal step. The final result was a roughly 1000 to 1 dynamic range map at 6cm, with a restored flux and map maximum that increased during every self-cal step, although quite slowly near the end. The following is a contour map display of the final map made with the DEC-10 SEEMAP program.



The process of mapping, cleaning, and self-calibration (in the case of sources stronger than a few tens of milli-Janskies) is highly dependent upon the nature of the source. In cases where one knows the approximate size, structure, and extent of a source, the needed parameters are predictable. In cases of unknown sources, or unknown fields surrounding sources, it is wise to first map the fields out to at least the antenna half-power beam width (1.5' X wavelength in cm) with at least 2 points per synthesized beam (cell size of roughly 1" times the wavelength in cm, divided by the maximum baseline, or taper size, in km). This is because it is wise to know about other significant sources in the field - which can affect the maps of the smaller sources near the center of the field. For example, the VLA D-array will typically have roughly 20 significant sources in a 20cm field, and smaller arrays and wavelengths will have smaller, but still realistically probable numbers of background sources, historically called "confusing" sources.

Once the field of sources in the antenna field of view are understood, one can concentrate on mapping and analysis of the sources of interest.

3. A "Batch" or "Pipeline" Approach to VLA Data Reduction

Early in this chapter we asserted that most of the time one can carry out VLA data reduction throught the stages of mapping, cleaning, and self-calibration before stopping to take care of editing and other details. This means that one can plan ahead, and execute, a complete sequence of data reduction before pausing to take care of minor problems In this section we discuss a "batch" or "pipeline" approach, which we will illustrate with control files that can be run in the DEC-10. This approach assumes that one learns to use at least the elementary features of the DEC-10 text editor (SOS), and that one edits a sequence of "batch-like" data reduction files which are then executed in sequence. For those who may wish to take this approach, the sample data reduction files that we will discuss are stored in the [11,12] area of the DEC-10 with names that we will mention as the files are individually discussed. We assume that the use of FLAGER is done as discussed above, and we will deal with the sequence of batch files that carry out the other data reduction procedures. The batch files will consist of the following:

File Name	Program Used	Purpose
lmondd.sjy	SETJY	Assign flux densities for calibrators
lmondd.cor	GTBCOR	Reset gain table and/or make corrections
lmondd.sol	ANTSOL	Solve for calibration parameters
lmondd.app	GTBCAL	Apply calibration parameters
lmondd.lis	LISTER	List visibility data
lmondd.snu	DBCON	Make DB's for each frequency

For these files we will use the word "lmondd" to correspond to the data base name, e.g. lapr29, both in the file names and inside the files. You can obtain copies of these files in your own area, which you should do before trying this approach, by using the copy commands

copy lmondd.* ← lmondd.*[11,12]

and you can then use the operating systems RENAME command to change to your real data base name, or any other name you wish to use.

The last stages of mapping and cleaning are best done, not in the DEC-10 system using the programs we will illustrate in the batch files, but in the MAPPER, SORTER/GRIDDER, or AIPS systems; however, since one cannot "pipeline" the operations in these systems, we will discuss entirely DEC-10 oriented processing. The basic mapping and cleaning procedures will be similar in all but details in the other systems.

The following is an edited file carrying out the process of entering flux densities for 3C286 and one other calibrator, 1923+210:

```
;lmondd.sjy
.r setjy
setdef
db lmondd
;*timerange 82apr29 at 0: to 82apr29 at 24:
calc *
band 20cm
sources 3c286  1923+210
fluxes  14.51  1.3
go setjy
go list
band 6cm
flux     7.41   1.5
go setjy
go list
band 2cm
fluxes   3.44   2.45
go set
go list
band 1.3cm
flux     2.53   2.8
go setjy
go list
fin
.submit lmondd.cor
```

The above file (stored as lmondd.SJY[11,12]) can be executed by typing

submit lmondd.sjy

and it will be submitted to the batch stream for execution. The last thing it will do is submit the next step in data reduction. One can edit this file, adding or changing sources and fluxes. One can also turn any line in the file into a "comment", so that the appropriate command will not be executed, by beginning that line with a semi-colon (followed by an asterisk in the case of a command inside a program). The first line in the file is an example of a "comment" identifying the external file name and the fifth line, involving the timerange command, is an example of a "comment" for a program command inside a batch file. When executed in batch a log file named lmondd.LOG will be left in your [13,PN] area, and this file can be TYPEd or PRINTed at the operating system level to see a record of the results - that is why a GO LIST is included for each band.

The next step is to use GTBCOR to reset the gain table (and carry out known corrections), for which the initial batch file (lmondd.COR[11,12]) is:

```
;lmondd.cor
setdef
db lmondd
go reset
fin
.submit lmondd.sol/time:1500
```

which is, in itself, trivial; however, when one later discovers corrections that need to be made, this file can be edited to add necessary corrections. In this way the process of data reduction can be viewed as editing self-documenting batch files, each of which represent the last and best step of the appropriate data reduction stage.

Next one carries out the ANTSOL solutiion solving for calibration parameters and printing out the resulting calibration table. A batch file stored in lmondd.SOL[11,12], which carries out this step for one example involving all four frequencies, is submitted by the above lmondd.COR file, and its contents are the following:

```
;lmondd.sol
.r antsol
setdef
db lmondd
refant 17 21 10
band 20cm 6cm 2cm 1.3cm
source 3c286 1923+210
out tty:lmondd
inputs
go solve
```

```
outfile lpt:lmondd
list ampl pha
band 20cm
go list
band 6cm
go list
band 2cm
go list
band 1.3cm
go list
fin
.submit lmondd.app
```

which will carry out and list the amplitude and phase solutions for all four bands. In using this file you will need to: change the sources command to list all calibrators, name your own reference antennas if necessary, and, of course, put in the correct data base name. The above file will submit, unless you delete the last line or turn it into a comment by putting a semi-colon at the beginning, the file the applies calibration with GTBCAL. We give this batch file the extension APP (for application) to avoid confusion with the fundamental calibration file lmondd.CAL[14,PN] produced by GO SOLVE in ANTSOL.

The next step is to apply calibration with GTBCAL, with the following being an example (lmondd.APP[11,12]) for one source-calibrator pair, 3C286, and four frequencies:

```
.r gtbcal
setdef
db lmondd
caltype ampl phase
inter 2point
cals 1923+210
sour ss433
band 20cm
go calib
band 6cm
go calib
band 2cm
go calib
band 1.3cm
go calib
interp boxcar
aver 1:00:00
cals 3c286
sour 3c286
band 20cm
go calib
band 6cm
go calib
```

```
band 2cm
go calib
band 1.3cm
go calib
fin
.submit lmondd.snu/time:1000
```

If everything works correctly, after this file is "executed" the data base (lmondd[14,PN]) will be calibrated, at least to first order, and one can proceed to examine, re-edit, map, clean, etc. calibrated data. Batch files can be set up to make LISTER and/or VISPLT displays of data, if desired, however we will not discuss such examples here.

The last step in the above batch file was to submit another batch file that will make separate data bases for each frequency. This tends to be useful, although it is not absolutely necessary.

A batch file (lmondd.SNU[11,12]) that separates an initial lmondd[14,PN] into four data bases, named (for the sake of the current example) lmondd, cmondd, umondd, and kmondd, contains the following:

```
;lmondd.snu
.r dbcon
setdef
infile lmondd
passflag unflagged
sources *
band 20cm
outfile lmondd
go
band 6cm
outfile cmondd
go
band 2cm
outfile umondd
go
band 1.3cm
outfile kmondd
go
fin
```

When one does separation into data bases with different frequencies, one later deletes the original data base using the operating system delete command: DELETE lmondd.*[14,PN].

The next stages of mapping, cleaning, and self-calibration are not as amenable to "batch" pipelining because they are usually best done the MAPPER, SORTER/GRIDDER, or AIPS systems.

Users wishing to start out with this batch approach to calibration will need to make (or copy) these files in their [13,PN] area, and modify each file to suit their data reduction situation, using the SOS text editor. The sections dealing with observing bands not used in an observing run will need to be deleted (or turned into comments), or else the jobs will "bomb" through failure to find appropriate data.

All of the above batch files can be prepared as we have discussed, and may be executed interactively using the DO command in place of the SUBMIT command. In this case, if the SUBMITs inside each file are deleted (or turned into comments) one can sequentially type

do lmondd.sjy
do lmondd.cor
do lmondd.sol
do lmondd.app
do lmoddd.snu

and one will see, on the CRT screen, the results of line by line execution of the file, with all program results listed on the screen. The screen display is essentially the same as is written in a LOG file during batch execution. The advantage of the DO over the SUBMIT is that one can see errors, CNTL/C the execution of the file, fix the errors in the file (or adopt different strategies), and then re-DO the execution of the batch file. The disadvantage is that you tie up a terminal, and you do not obtain the hard copy listing of the data reduction process that is written into the lmondd.LOG file. A common strategy is to first make the entire pipeline work with DO execution, then switch to SUBMIT execution once the "pipeline" is "de-bugged".

Once the data reduction sequence is finished in batch (with SUBMITS of each file), the log file named lmonddd.LOG contains the history of the commands and their results for the entire sequence. One can then PRINT lmondd.LOG and examine the printout. This listing, the listing of the lmondd.CAL[14,PN] file obtained with the last part of the lmondd.SOL execution, and any LISTER or VISPLT displays that are deemed useful, provide extensive documentation of the data reduction process. Use of these displays sometimes results in more data editing with FLAGER, and a repeat of the last stages of the "pipeline" that are affected by the flagging changes.

APPENDIX 1

PROCEDURES FOR USE OF NRAO FACILITIES

1. OBSERVING REQUESTS

A. Procedures

The use of NRAO instruments is based upon observing requests submitted to the Director of NRAO. These requests or proposals should be sent to:

Dr. Morton S. Roberts, Director
National Radio Astronomy Observatory
Edgemont Road
Charlottesville, VA 22901

Observing requests should be brief (no more than three pages and less that 1000 words) and emphasize the scientific justification for the proposed observing program. A proposal cover sheet, providing basic information and listing instrumental requirements, should accompany the observing request. A blank sample (for copying) of this form is included following page A-2.

All observing requests, including those from NRAO staff members, are evaluated and rated by non-NRAO referees. The granting of observing time is based upon a combination of their evaluations, the availability of observing time for each quarter, and considerations of technical feasibility for the period requested. It is advantageous to submit proposals in advance, since this allows time to respond to the referee's comments before scheduling. Closing dates for observing requests for specific quarters and configurations are listed in the following section.

Proposals will also be accepted for programs that will benefit from (or not be harmed by) the use of non-standard configurations that can be achieved during reconfiguration.

Proposals may be scheduled, delayed for consideration in a subsequent quarter, or rejected. Proposers who are not scheduled for observing will be informed about the evaluation of their proposal, and they may choose to respond or re-submit.

B. Student Observing Requests

Requests for observing time from graduate students should be accompanied by a supporting statement from their faculty advisor, indicating that the student is in good standing at their institution and is fully capable of carrying out the observations.

C. Configurations and Deadlines

A tentative schedule for VLA configurations are given in the NRAO newsletter and the newsletter prepared by the American Astronomical Society. Proposals are scheduled on a quarterly basis with deadlines on Jan. 15, Apr. 15, July 15, and Oct. 15. Prospective users will find it is advantageous to submit their proposals well in advance of, and certainly no later than, the deadlines.

Normally the four confiugurations of the VLA will occur approximately once a year. However, the actual length of each configuration will be varied in response to proposal pressure. Observations are also scheduled during the reconfiguration process. Observations suited to mixed configurations are: point source monitoring and detection programs; and observations of low elevation sources with the North arm in the next larger configuration. For declinations less than roughly -15^{o} the longer North arm hybrid gives a more circular beam and reduces shadowing; therefore it may be advantageous for an observer to request a hybrid configuration for such sources.

VLA observers are urged to arrange their travel as soon as possible after being scheduled, and no later than three weeks before arrival at the VLA site.

NRAO use only

A

received:

VLA OBSERVING APPLICATION

SEND TO: Director NRAO Edgemont Rd. Charlottesville, Va. 22901

DEADLINES: 15th of Jan., Apr., July, Oct. for Q 2, 3, 4, 1 respectively

(1) Date:

(2) Title of Proposal:

(3) Authors	Institution	Who will observe?	Grad Student?	Observations for PhD Thesis?	Anticipated PhD Year

(4) Contact author for scheduling:

Address:

(5) Telephone: or TWX:

(6) Any related VLA proposal:

(7) Scientific category: ☐ planetary, ☐ solar, ☐ stellar, ☐ galactic, ☐ extragalactic

(8) Preferred Configuration(s) (A, B, C, D, Any, Special)					Alternate(s) if any ____________
(9) Wavelength (20 18 6 2 1.3 cm)					
(10) Time requested (hours or days)					

(11) Type of observation: ☐ mapping, ☐ point source, ☐ monitoring, ☐ continuum, ☐ lin poln, ☐ circ poln, ☐ spectral line, ☐ solar, ☐ VLBI, ☐ phased array, ☐ other ____________________

(12) ABSTRACT (do not write outside this space):

NRAO use only

(13) Reduction: Number of maps ________ Maximum size of maps ________________ Self-cal maps __________

(14) Off-site reduction: ☐ none, ☐ post map, ☐ post calibration, ☐ everything.

(15) Help required: ☐ none, ☐ consultation, ☐ friend, ☐ absentee observing, ☐ staff collaborator.

(16) Spectral line only:

transitions to be observed				
channel bandwidth (KHz) (Δ)				
observing frequency (±Δ/2)				
number of channels				
number of antennas				
rms noise after 1 hour (mJy)				

(17) Number of sources _____ (If more than 10 sources please attach list. If more than 30 give only selection criteria and LST range(s).)

Name	coord (1950.0) RA hh mm	Dec ±xx°.x	Config.	Band (cm)	Band width (MHz)	Total flux (Jy)	Largest ang. size	Weakest signal (mJy/beam)	Required dynamic range	Possible LST range hh - hh	Time requested
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											

(18) Special hardware, software, or operating requirements:

(19) Preferred range of dates for scheduling:

(20) Dates which are not acceptable:

(21) Please attach a self-contained Scientific Justification not in excess of 1000 words.

When your proposal is scheduled, the contents of this cover sheet become public information. (Any supporting documents are for refereeing only)

2. REIMBURSEMENT FOR TRAVEL FOR OBSERVING AND DATA REDUCTION

In addition to providing radio astronomy instrumentation and data reduction facilities to all users without charge, NRAO will provide partial payment for travel expenses for scheduled observing sessions and a single data reduction session subsequent to observing for investigators from U.S. institutions.

A. Reimbursement for Observing Travel

The following is the current policy on observing travel reimbursement for investigators from U.S. institutions: limited to no more than two observers per observing session; covering travel only from places within the continental United States, Puerto Rico, or Hawaii; reimbursing the cost of actual round trip air fare (not to exceed less than first class fare), minus a deductible, which will be the greater of $150 or ($300 + airfare)/2 (thus, for coach air fare costs of $1000, $500, and $200, NRAO will reimburse $675, $300, and $50). NRAO provides a pool of cars for travel from Albuquerque to the VLA site (and return).

Reimbursement forms signed by the VLA site director are given to the sponsoring institution which shall submit original ticket receipts when requesting reimbursement. Payment is made to the institution.

B. Reimbursement for Travel for VLA Data Reduction

All of the general rules that apply to reimbursement for observing travel will also apply to reimbursement for VLA data reduction travel, with the addition of the following specific guidelines: the program will be equally applicable to the NRAO computing facilities in Charlottesville or at the VLA site, although users are encouraged to use the Charlottesville facilities; NRAO will reimburse the user's institution for all air fare in excess of 25% deductible; each scientific proposal carried out with the VLA will be entitled to support for one data-reduction visit for up to two scientists; at the VLA, scientists are responsible for room and board charges, just as during observing trips, however, although the same applies in Charlottesville, the cost of lodging is reimbursable up to $20 per day per person for a maximum of 10 days, reflecting the increased room costs in Charlottesville; Ed Fomalont in Socorro (505-772-4247) will arrange the scheduling of these return visits for both facilities; and scheduling and travel plans should be arranged at least one month in advance.

APPENDIX 2

LOGISTICS OF TRAVEL AND STAYING AT THE VLA SITE

1. TRANSPORTATION

A. Travel to the VLA Site

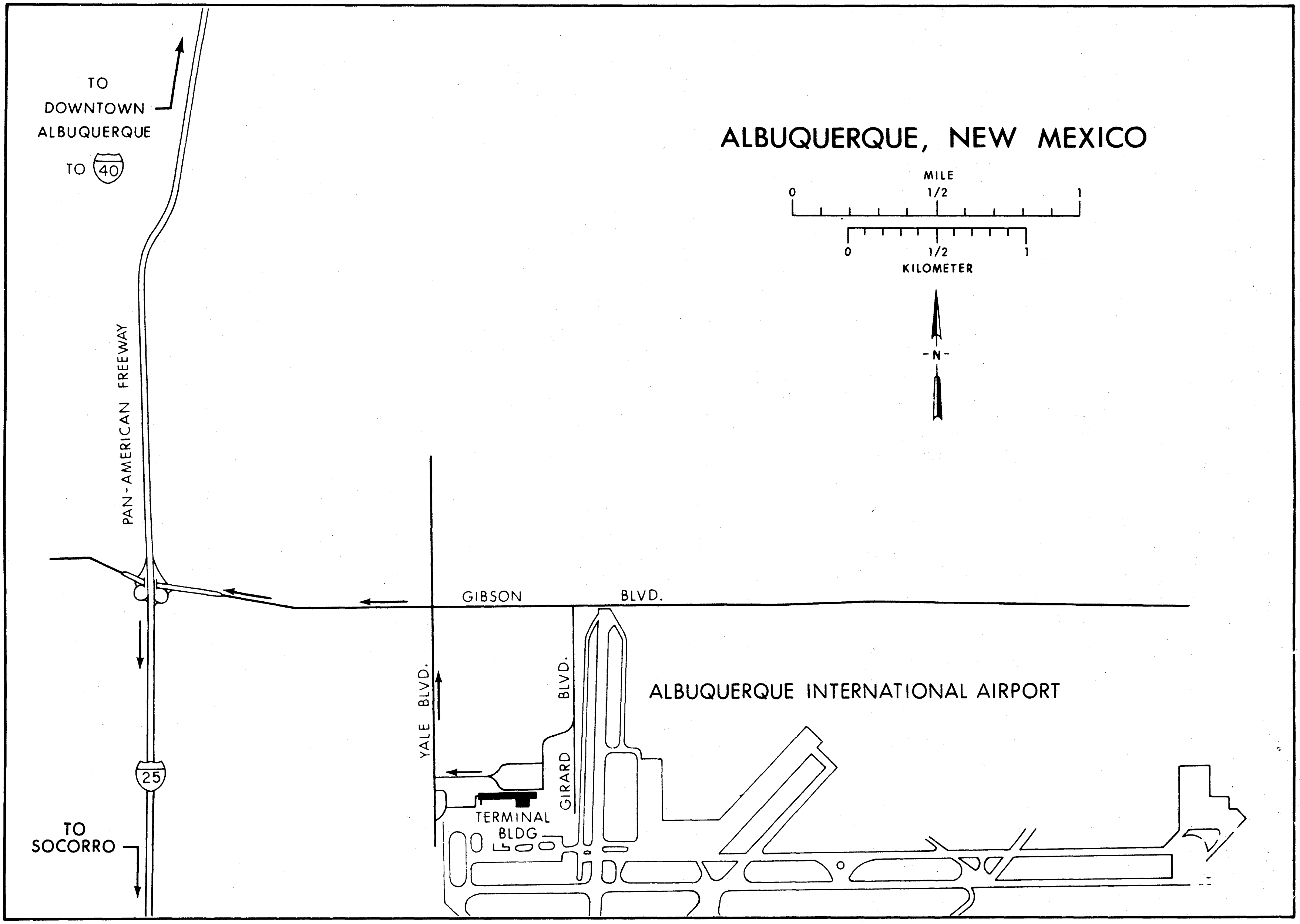
The primary means of access to the VLA site begins with an airline flight to the Albuquerque airport. From there one travels to Socorro and the VLA site by car. Users should call the VLA site on FTS 476-8357 or commercial 505-772-4357 at least two weeks before a planned trip so that a car can be reserved. At the Albuquerque airport the Dollar Rent A Car desk (open seven days a week from 7:00 a.m. to 11:00 p.m., 10:30 p.m. on Saturdays) will assign you a pool car, either GSA or rental. A valid drivers license is required. No pool cars will be dispatched without a prior reservation made through NRAO. If no reservation is made, you will be responsible for your own transportation arrangements and costs. If a rental car is provided, you should decline all extra insurance and keep the rental contract with the vehicle.

The driving time between Albuquerque airport and Socorro (78 miles) is approximately one hour and twenty minutes; driving time between Socorro and the VLA site (54 miles) is an additonal one hour. The maps on pages A-6 through A-8 show the major details involved in making the trip to the VLA site. When arriving during the day, the observer will generally be able to see the center of the array and the building complex some 15 miles away. The turn-off on NM 78 is after mile marker 94; although this turn has all the appropriate signs, including a green Highway Department sign pointing the way to the VLA, it is not uncommon to over-shoot the turn at night. If one misses the right turn from NM 78 on to the site entrance road (part of old US 60), it will be noticeable because of the sudden change from pavement to dirt. The map on page A-8 shows the major site roads. The user will find it most convenient to turn right, go past the visitor's center building, and park in the parking lots near the cafeteria and the control building.

During normal working hours the receptionist on the first floor of the Control building will direct users to their keys, mailbox, registration cards, etc. The receptionist should also be given the car keys and any rental contract. You will have a vehicle reserved for your return to Albuquerque and may pick up the keys from the receptionist between 8:30 a.m. and 4:00 p.m.

Monday through Friday except for holidays. If you are returning a Dollar car you will be given the rental contract with the keys. Return the car to the Dollar Rent A Car parking space at the East end of the terminal. Record the mileage if it is a Dollar car and return the keys with any rental contract to the Dollar desk. You will not need to retain a copy of the Rental Contract. For visitors not reimbursed for travel there will be a fixed charge of $75 for this car service; this charge will be included on your lodging bill and may be paid prior to departure from the VLA site.

During off-hours, when the Control building is locked, there is a phone outside the main (SE) entrance door that may be used to call the array operator in the control room (Ext. 251/252); they will let you in the building and show you where to obtain keys, etc.


ALBUQUERQUE, NEW MEXICO
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KILOMETER
N
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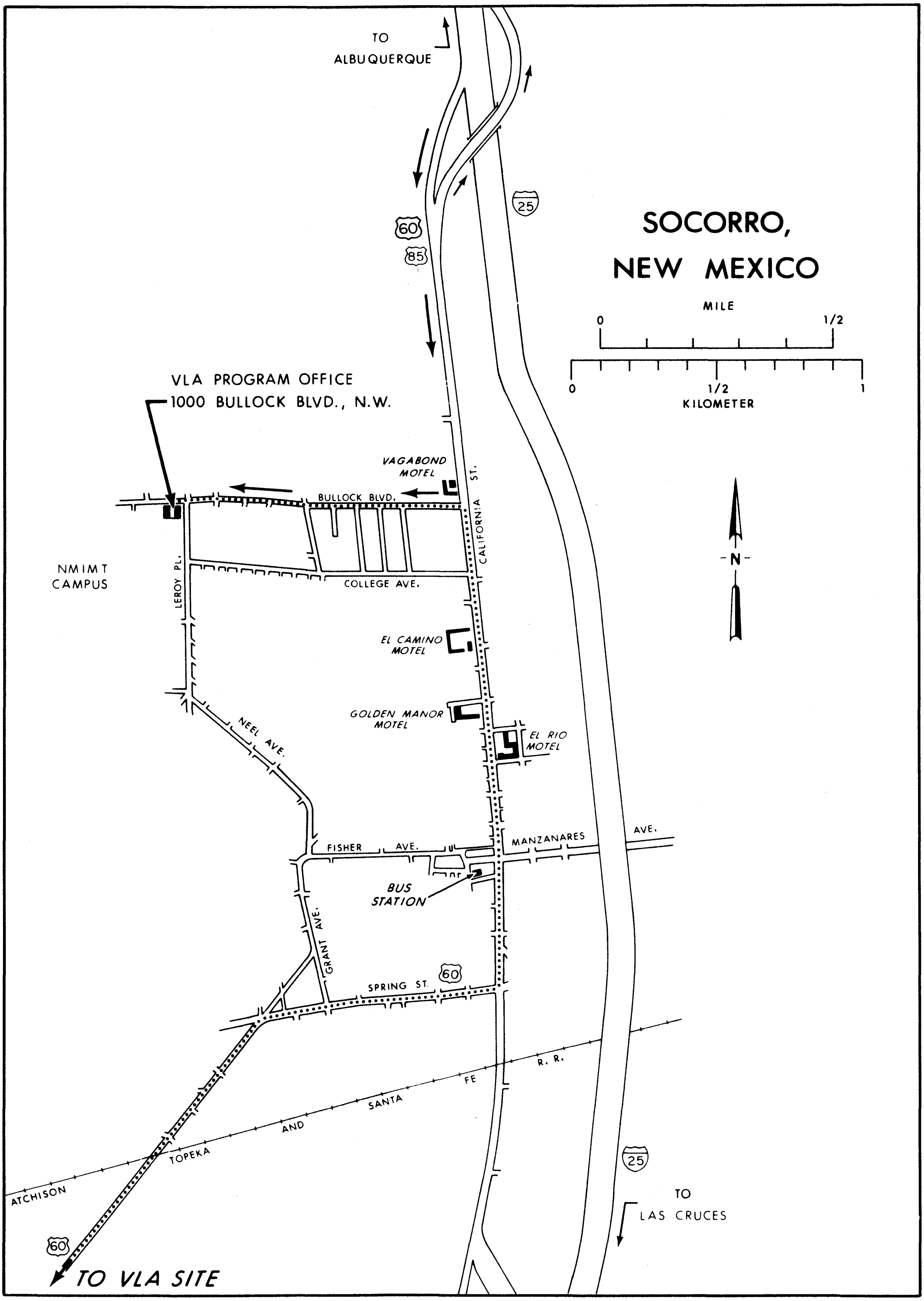
DOWNTOWN
ALBUQUERQUE
TO 40
PAN-AMERICAN FREEWAY
GIBSON
BLVD.
YALE BLVD.
GIRARD
BLVD.
ALBUQUERQUE INTERNATIONAL AIRPORT
TERMINAL
BLDG
25
TO
SOCORRO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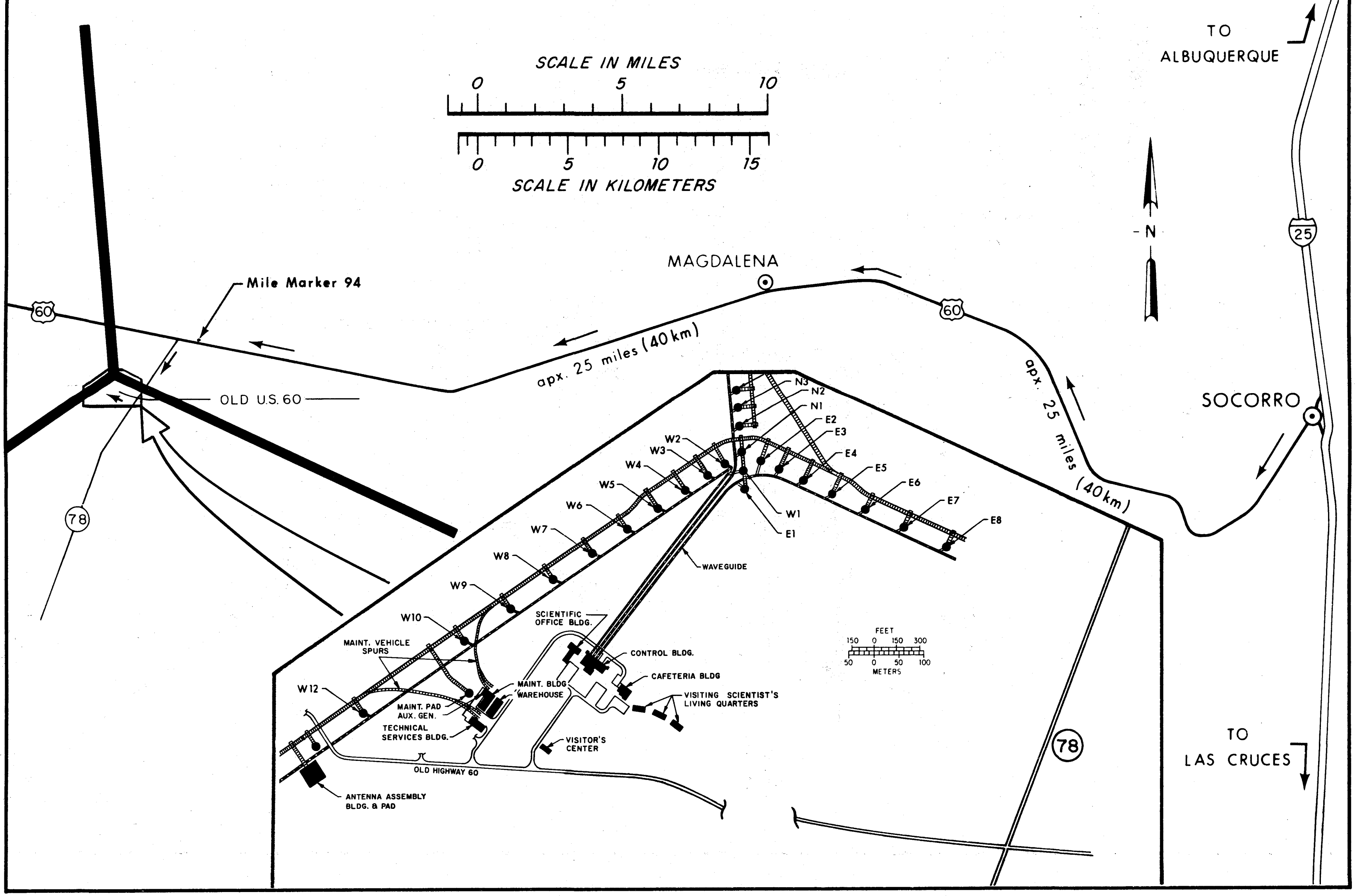
1000 BULLOCK BLVD., N.W.
VAGABOND
MOTEL
BULLOCK BLVD.
CALIFORNIA ST.
N
NMIMT
CAMPUS
LEROY PL.
COLLEGE AVE.
EL CAMINO
MOTEL
GOLDEN MANOR
MOTEL
EL RIO
MOTEL
NEEL AVE.
FISHER AVE.
MANZANARES AVE.
BUS
STATION
GRANT AVE.
SPRING ST.
60
ATCHISON TOPEKA AND SANTA FE R. R.
25
TO
LAS CRUCES
60
TO VLA SITE

ROUTE TO THE VERY LARGE ARRAY (VLA) SITE



B. Travel Between the Site, Socorro, Datil, and Magdelena

On normal working days there there are the following means of travel between the Socorro VLA offices and the VLA site :

Depart Socorro	Depart VLA Site	Type of Transportation
6:25 a.m.	8:00 a.m.	Array operator's Van (approx. times)
7:30 a.m.		Buses leave Socorro office
8:30 a.m.		Car/Van (dependent upon a driver going)
10:00 a.m.		Car/Van (dependent upon a driver going)
12:00 noon	12:00 noon	Shuttles from Site and Socorro office (dependent upon a driver going)
2:25 p.m.	4:00 p.m.	Array operator's Van (approx. times)
	4:30 p.m.	Buses leave VLA site
	5:30 p.m.	Car/van (times vary, availability depends on 8:30 shuttle)
	7:00 p.m.	Car/van (times vary, availability depends on 10:00 shuttle)
10:25 p.m.	12:00 Mid.	Array operator's Van (approx. times)

Pool cars may be reserved through the receptionist for travel to Magdelena or Datil for dinner, but should not be used for any other non-official business. Your keys will be placed on the key board by the recpetionist and should be returned to that location following use. An AUI-owned car is kept at the VLA site for additional transportation. Other abnormal transportation requirements should be discussed with the site director. Special problems can be dealt with by the secretary at the reception area in the Control building.

2. MEALS

A cafeteria is available at the VLA site with the following services:

Regular Work Day:

Breakfast	8:30 a.m. - 10:00 a.m.
Lunch	12:00 noon - 1:00 p.m.
After hours meal pickup	Prior to 2:30 p.m

Weekends and Holidays:

Breakfast	8:30 p.m. - 10:00 a.m.
Lunch	12:00 noon - 1:30 p.m.
After hours meal pickup	Before 2:00 p.m.

There is an Observer's kitchen in the cafeteria, with a refrigerator in which the cooks can place meals requested for after hours. Some staples are stored in cabinets and other items, in addition to those requested from the cooks, are supplied in the refrigerator.

Outside of lunch hours, all meals and food items are obtained by filling out appropriate menu/price sheets, and leaving them with the cooks or near the cash register or refrigerator. Payment is made during lunch hours when the cash register is in service, or later when you pay room charges.

There is a (propane) barbeque on the patio beside the cafeteria which can be used to cook food either brought by the observer or ordered from the kitchen during normal working hours. There are restaurants in Magdelena and Datil (the latter are not open on Sunday).

3. LIVING QUARTERS AND LAUNDRY

Reservations for rooms in the Visiting Scientist's Quarters should be made well in advance by calling (505-772-4357), usually at the same time car reservations are made. Three motel-like buildings with 12 single rooms and 4 double rooms are available by reservation only. Under overflow conditions, four rooms are available in a bunk-house trailer. Each VSQ room has full bathroom facilities, and each building has a laundry room available to users at all times except from 8:30 a.m. to noon.

4. TELEPHONE USE AND SPECIAL TELEPHONE NUMBERS

The VLA site and the Socorro offices have both commercial and Federal Telecommunications System (FTS) telephones. Use of the FTS system is for official government business only. When calling from site or Socorro office telephones on commercial lines, you are requested to use either your telephone credit card number, or call collect. If this is not possible, there are forms near each telephone that should be filled out and left at the switchboard.

The following are general numbers for reaching personnel at the VLA site and at the Socorro offices (during normal working hours):

Place	Commercial	FTS
Site Switchboard	505-772-4011	476-8011
Site extensions	505-772-4 + Ext.	476-8 + Ext.
Socorro Office	505-835-2924	474-3653, 474-3654, 474-3647

The following are special site extensions:

	Extension	Location
Array Operators	251/252	VLA Control Room
Switchboard operator	011	Tech. Services or Control BLdg.
Site Reception Area	332	Lobby, Control Bldg.
Ron Ekers, Site Director	297	Room 105, Control Bldg.
Eva Fomalont, Exec. Secretary	284/357	Room 104, Control Bldg.
Guard	276	Room 7, Tech. Service Bldg.
Food Service	235	Cafeteria Bldg.
Plant Maintenance	261	Room 4, Tech. Service Bldg.
AIPS (VAX) Room	295	VAX Room, Off./Library Bldg.
Remote Observing DEC-10 Line	346	

5. BILLING PROCEDURES

If your departure from the VLA occurs during normal working hours, you may pick up your bill for room and board at the reception desk. Payment should be made to the cashier (Room 209, VLA control building) before leaving the VLA site. If this is not possible, the charges will be be deducted from your travel reimbursement.

6. LIBRARY, OFFICE, AND OTHER FACILITIES

Some library facilities are available in the library/office building west of the VLA control building. Major astronomical journals are available from recent years, with selected journals like the Astrophysical Journal going back much further. Many standard catalogs are available, as is a modest selection of technical books, but the user is advised to not depend upon obtaining critical information at the VLA site. Such data, particularly source positions for observing, should be in hand when arriving at the VLA site.

A set of National Geographic-Palomar prints is available and a set of ESO prints for the sourthern hemisphere is on order and may be available. A computer-controlled measuring engine for determining star positions from Palomar prints is also available.

Users will generally be assigned a desk and office space in either the Control building or the Library/Office building when they arrive at the VLA site. There are a number of offices specially reserved for visiting observers. In practice the user will spend a considerable amount of time using the terminals and other computer facilties at various locations in the Control and Library/Office buildings.

You will be assigned a VLA "friend" or staff contact, based upon your responses on the proposal cover sheet. This person will aid you as necessary before and after you arrive at the VLA site.

7. DATA ARCHIVING AND MAGNETIC TAPES

All data obtained at the VLA, as written on magnetic tape by the on-line computer system, are archived at the VLA site. Observers have exclusive use of the data obtained with the VLA until 12 months after the completion of their observations. Users may check out numbered tapes for storage of calibrated data, maps, and other disk files. These tapes are initially assigned to the user for at least one year - they become due at the end of the year following the year in whch they were checked out. Tapes may be renewed for longer periods if written justification is provided before the due date. ALL TAPES NOT RENEWED BEFORE THEIR DUE DATE WILL BE AUTOMATICALLY RE-CYCLED AND DATA ON THEM WILL BE LOST! Users are provided with a list of all their assigned tapes in July and September of each year.

Numbered tapes (Vnnnn series tapes) are to be used if they are to be archived at the VLA site; numbered tapes must NOT be removed from the site. Unnumbered tapes are available for removing data, maps, or other files from the site.

Observers are asked to use as few tapes as possible, and to return tapes for re-use when they are no longer needed (both numbered and unnumbered tapes. Current costs for tapes are approaching $75,000 a year, and it may be necessary in the future to charge for tapes.

APPENDIX 3

PROCEDURES FOR PUBLICATION WHERE NRAO FACILITIES ARE USED

1. OBLIGATIONS OF THE USER

Because NRAO is a national obervatory funded by the National Science Foundation, the use of NRAO instruments places a few obligations upon the user. There is the informal obligation to publish results in scientific journals as soon as feasible and practicable. When papers using observational material taken with NRAO instruments, or papers where a significant portion of the work was done at NRAO, are submitted for publication, two formal obligations should be met:

A. Proper acknowledgement to NRAO and NSF should be included in these publications; and

B. Pre-prints of such publications should be sent to NRAO.

Proper acknowledgement to NRAO and NSF is achieved by including a footnote where NRAO or its instruments are first mentioned in the paper, or, if required by the format of the journal, by putting the equivalent of the footnote in the appropriate paragraph of acknowledgements. The footnote or acknowledgement should read as follows:

> "The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation".

For non-U.S. journals it is appropriate to preface the N.S.F. reference in the above acknowledgement by "U.S.".

At the time that a paper is submitted for publication the user should send three prepublication copies (one for the Director's office and two for NRAO libraries) of the paper to Ms. Sarah Stevens-Rayburn, Librarian, NRAO, Edgemont Road, Charlottesville, VA 22901. The journal for which the paper is intended should be identified. The NRAO does not distribute reprints, and has no formal system for the distribution of preprints, but it does request the privilege of including visitor publications in its preprint listings.

The NRAO does not wish to referee visitor's publications. All other scientific and administrative communications concerning publications should be kept between the authors and the journals, with the exception of arranging for NRAO's partial support of page charge.

2. PAGE CHARGE PAYMENTS FOR NRAO VISITORS

The NRAO will pay one-half of the page charges for visitor publications when a significant portion of the work was done, or the observational material taken, at the NRAO. At the time of acceptance for publication, please notify the above-mentioned Librarian in Charlottesville of the proposed date of publication and the apportionment of page charges, so that necessary purchase orders can be initiated. Failure to comply with this procedure will result in nonpayment of page charges by the NRAO.

3. THESIS STUDENTS

If observations at the NRAO are a significant fraction of a Ph.D. thesis, it is the responsibility of the student to ensure that one copy of the thesis is sent to the NRAO library in Charlottesville as soon as practicable following completion of the thesis. If needed, the NRAO library can pay for reproduction costs.

4. OPEN ACCESS POLICY

Although the National Radio Astronomy Observatory is funded wholly by the U.S. government, observing time is granted on the basis of the most promising research without regard to national affiliation of the investigators. Believing astronomical research to be an international endeavor of interest to all, NRAO urges all observatories to subscribe to a policy of open access.

VLA

NATIONAL RADIO ASTRONOMY OBSERVATORY

OPERATED BY ASSOCIATED UNIVERSITIES, INC.,

UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION