AN INTRODUCTION TO THE NRAO Very Large Array

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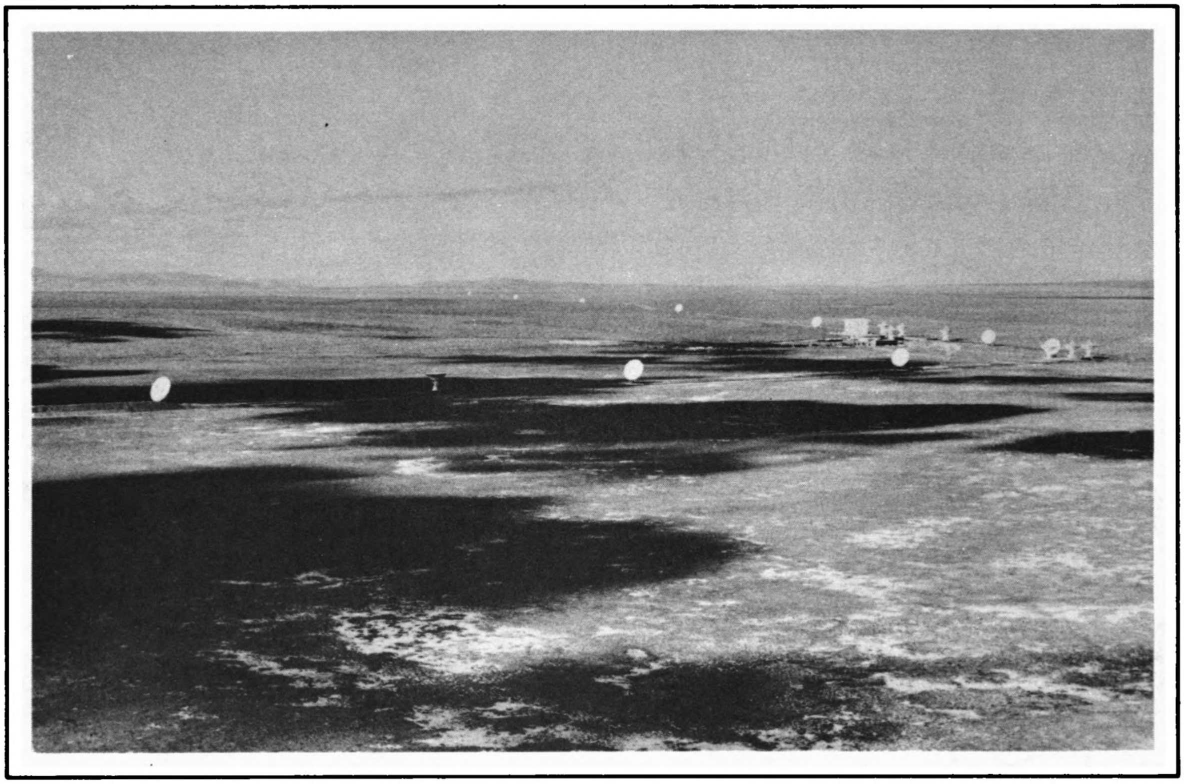


The NRAO VLA in September 1978.

C O N T E N T S

Page No.

Page No.

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 described as an introduction rather than a user's manual because no attempt is made to provide completeness of detail in any area, and because some attempt is made to provide introductory material for those who may not already be experienced at interferometry and aperture synthesis.

Because it will still be some time before the full 27-antenna VLA will be functioning with a combined continuum-spectral line system, this introduction will be talking at different times about two different instruments. Most of the time the instrument described here will be a roughly 10-antenna continuum system; however, to give the reader some idea of the growth and future of the VLA, the sections on THE BASIC INSTRUMENT and the THEORETICAL BASIS OF INTERFEROMETRY AND APERTURE SYNTHESIS will discuss both a paradigm 10-antenna system as it is operating in the summer of 1978 and the full 27-antenna VLA.

The hardware and the software described in this introduction are intended to be valid as of about October 1978.

Thanks are due to many individuals who aided in the production of this introduction to the VLA. Marion Gallagher did all of the typing. Most of the drawings were made by Tom Coté and associates at the VLA site. Some of the drawings and all of the photographic layouts were prepared by Peggy Weems and associates in Charlottesville. Special VLA photographs were taken by Dave Rosenbush. The final

processing of photographic materials and the reproduction of the text and figures into the "book" were carried out by Ron Monk and associates in Green Bank. Finally, some 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.

CHAPTER I

THE BASIC INSTRUMENT

1. The History and Concept of the VLA

The basic concept behind the VLA is that of an instrument 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, during the period 1957 to 1962 radio astronomers 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 U. S. 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. The idea that NRAO should provide a high resolution radio picture-making instrument developed in 1961 and in 1962 the Pierce committee report recommended to the NSF that NRAO should proceed with the design of a 1' resolution array. In September 1962, D. S. Heeschen, then acting director of NRAO, distributed a memo assigning specific array design responsibilities to NRAO staff members. In the spring of 1963 the development of an 8" resolution array in Green Bank was begun as a first step in getting NRAO into the business of working 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 the first interferometer pair. In later years a third 85-foot telescope and a radio link to a 45-foot telescope were added, giving spacings up to 35 km. In the summer of 1964 detailed design studies for the VLA began at NRAO, and in August 1964 the Whitford report came out with the highest recommendation for astronomy instrumentation to be 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, 1966, and 1967, at which time there was a specific design group working at NRAO headed by G. Swenson, then on leave from the University of Illinois. In January 1966 the first progress report of this design group was released. It included the recommendation that the design goal of the instrument be 1" resolution. This 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 concept originated with 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 mostly 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 during 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 U. S. 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 this 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, and located at a high altitude. In January 1972 the VLA appeared as a line item in the Presidential budget and in August 1972 Congress appropriated three million dollars for the first year of VLA construction. The project was budgeted to cost 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 this 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 the hiring of VLA construction staff began, J. H. Lancaster was named project manager, and the initial procurements and letting of contracts occurred. This included selecting E-Systems as contractors 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 where 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 planned.

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

On March 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 began. Antenna 3 was functioning in the array, all 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 once 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 6-7 antennas, by B. Balick, R. M. Hjellming, and 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.

Completion of the full 27-antenna array, operating on all configurations as both a continuum and spectral line instrument, is not scheduled until 1981. Therefore, there are years of testing, debugging, and partial astronomical use to occur before the full VLA is working.

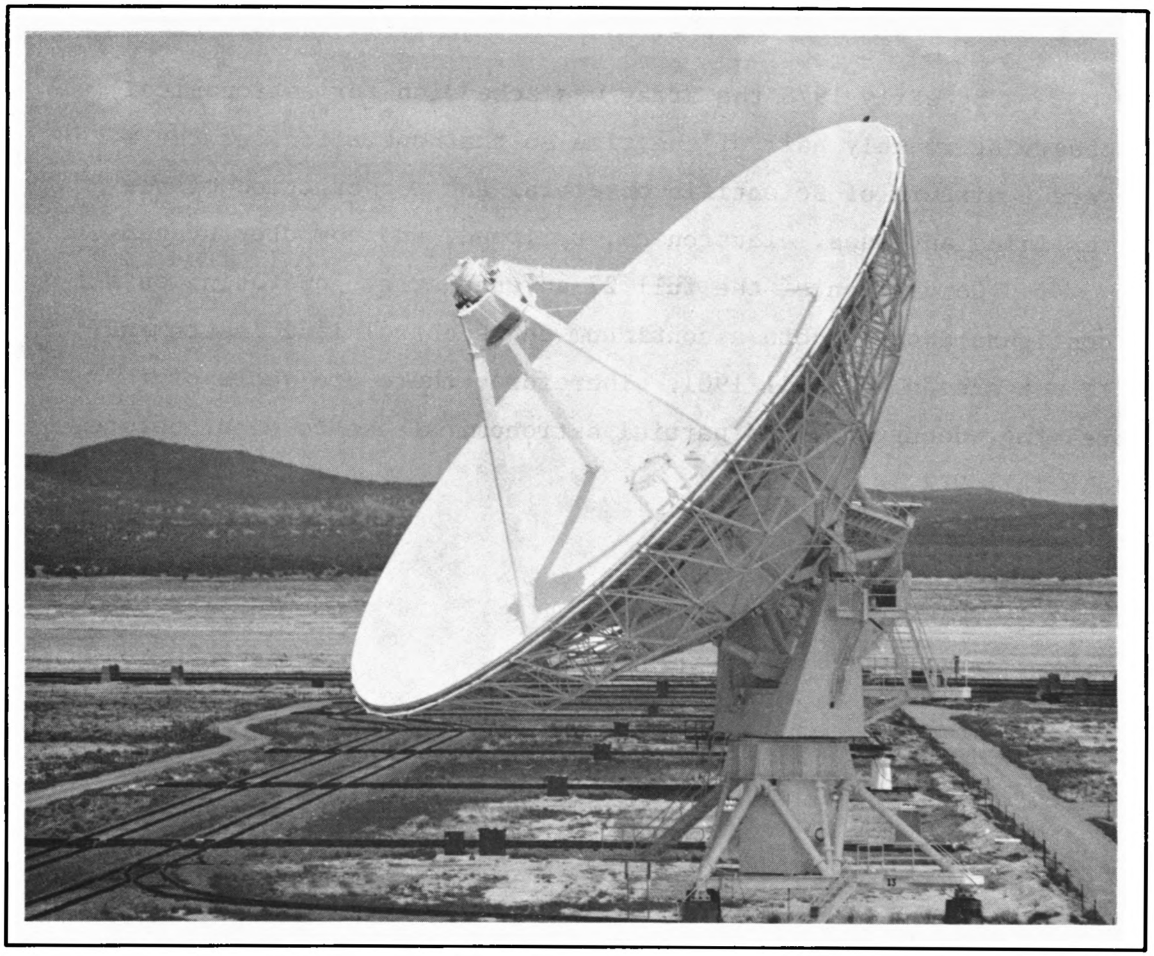


Figure I-1. A photograph of a VLA antenna, showing the Cassegrain focus system, supporting structures, and the triangular antenna base mounted on three concrete pedestals. The tracks leading to other stations are seen beyond this antenna, and the twin railroad tracks of the southwest arm are seen at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

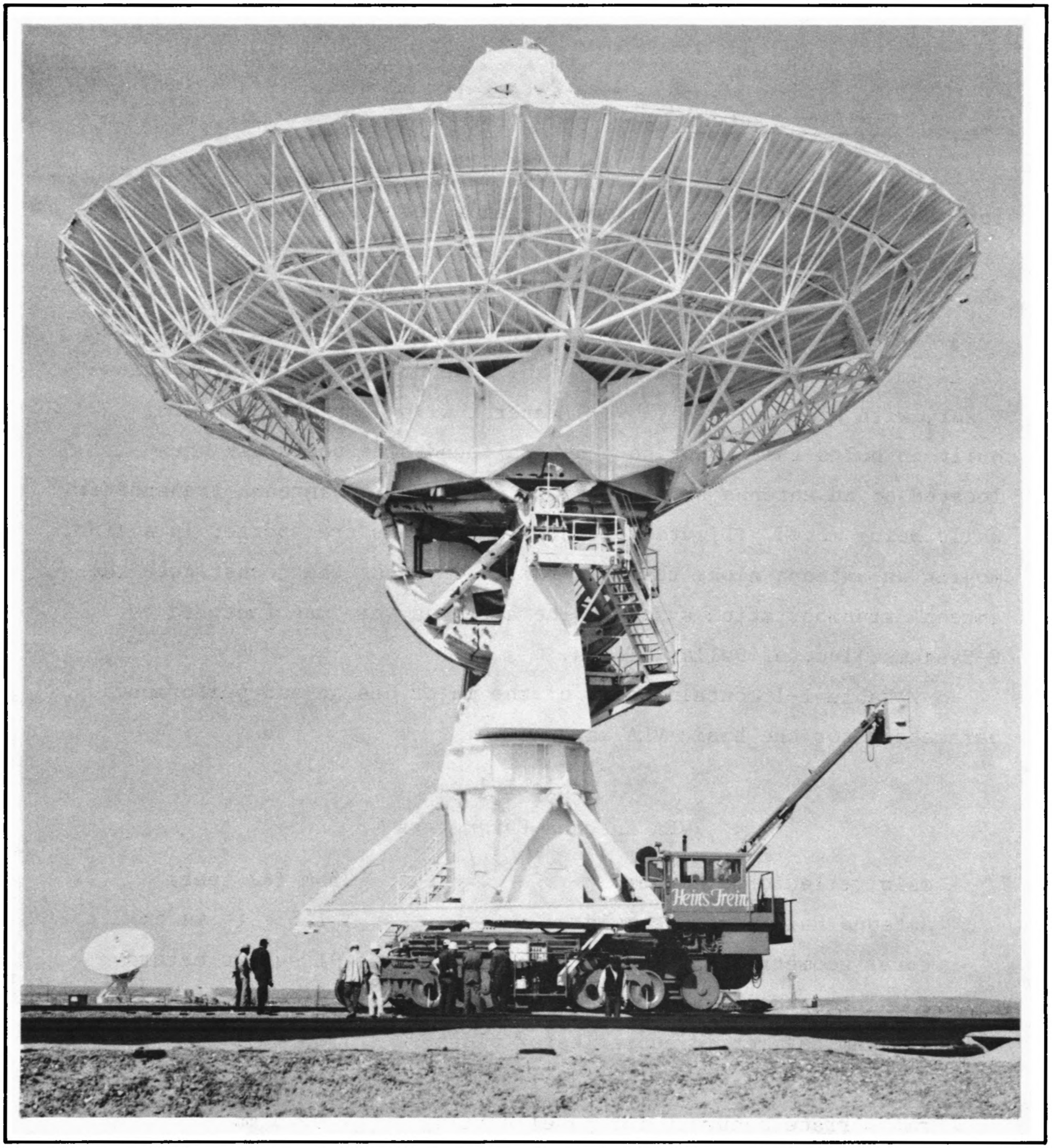


Figure I-2. A VLA transporter carrying a VLA antenna.

2. 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 I-1, the base of each antenna is triangular, with sides of length 9.75 meters, 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 I-2 shows an antenna transporter in action, moving an antenna along the twin railroad tracks that constitute the antenna transportation system. The antennas were manufactured by E-Systems, Inc. of Dallas, Texas.

Table I-1 contains some of the major design and performance parameters for the basic VLA antenna.

Table I-1

VLA Antenna Parameters

main reflector diameter	25 m (82 feet)
antenna half-power beamwidth	$\sim 1\overset{'}{.}5\ \lambda$ (λ in cm)
total geometric aperture	491 square meters
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	$\pm$ 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	< 40 mph
survival at stow	< 110 mph
(snow/ice load 20 lbs per square foot)	

Figure I-3. 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.

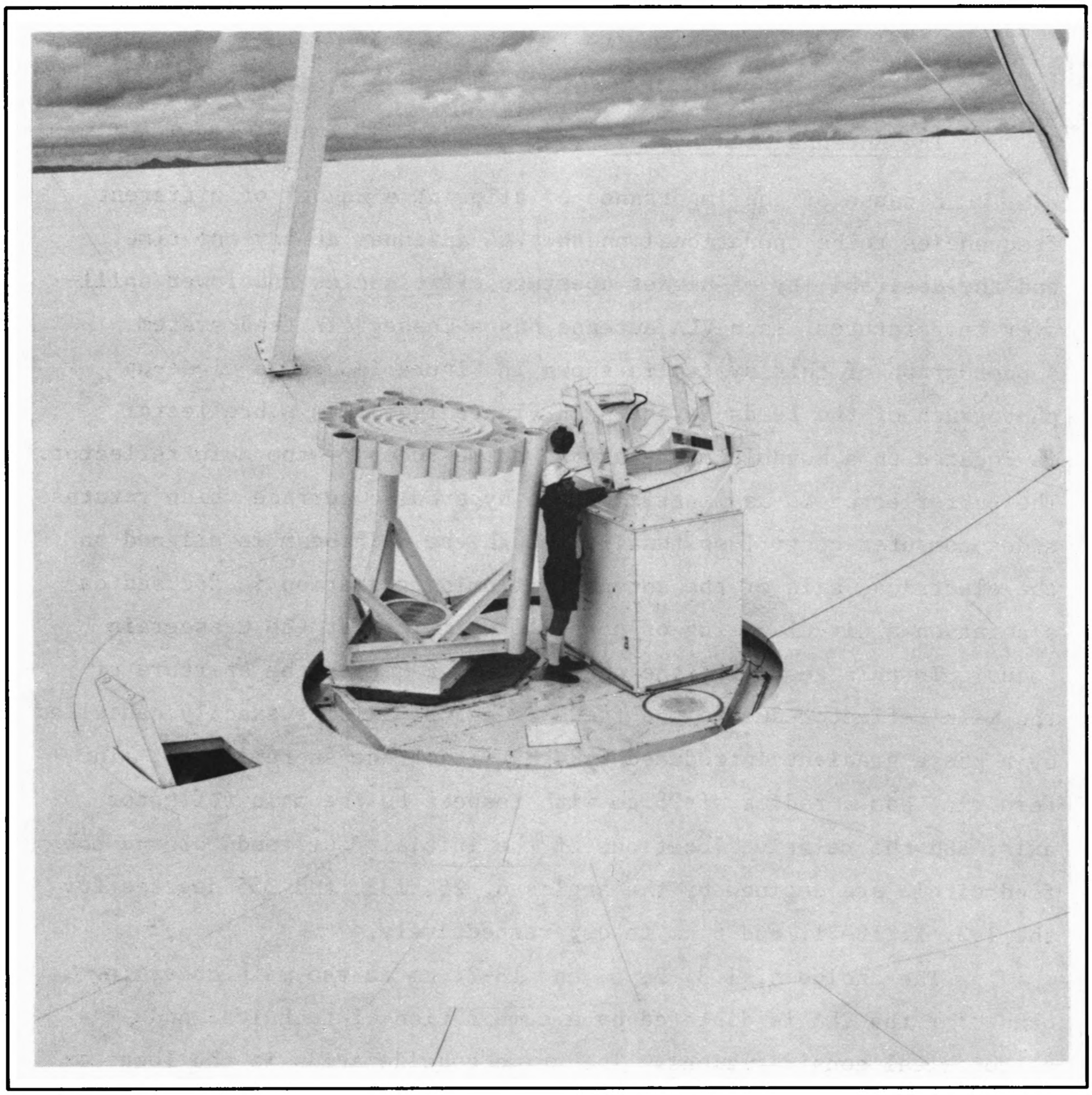


Figure I-4. Photograph of a VLA feed system with 18-21 cm lens and feed at the left and a man working on the area where 6 cm, 2 cm, and 1.3 cm feeds are located at the right.

3. The Antenna Feed System

Because of 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 spill-over temperatures, each VLA antenna has a Cassegrain feed system. A photograph of this system is shown in Figure I-3 and a close-up photograph of the feeds is shown in Figure I-4. The subreflector is located on a movable mount at the prime focus of the main reflector. The subreflector is asymmetric with a hyperbolic surface which rotates under computer control so that, although the main beam is 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, and the relative locations of the initial four feeds around the feed circle are 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 is dictated by a combination of technical and astronomical considerations. The prime consideration is the location of the radio astronomy protected bands and the various atomic and molecular lines associated with these bands as shown in Table I-2.

Table I-2

VLA OBSERVING BANDS AND ASSOCIATED LINES			
VLA Band	λ	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	15.35-15.40 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

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 wavelength 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 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 I-4, is a corrugated horn illuminating a hybrid lens of dielectric and waveguide elements. Because this system is so large, the function of the lens and waveguide elements is to introduce time retardation and acceleration so that wavefronts reach the corrugated horn at the same time.

The 6 cm feed is a corrugated horn. The 2 and 1.3 cm feeds are multi-mode horns. All feeds have changeable polarizers at the feed output 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.

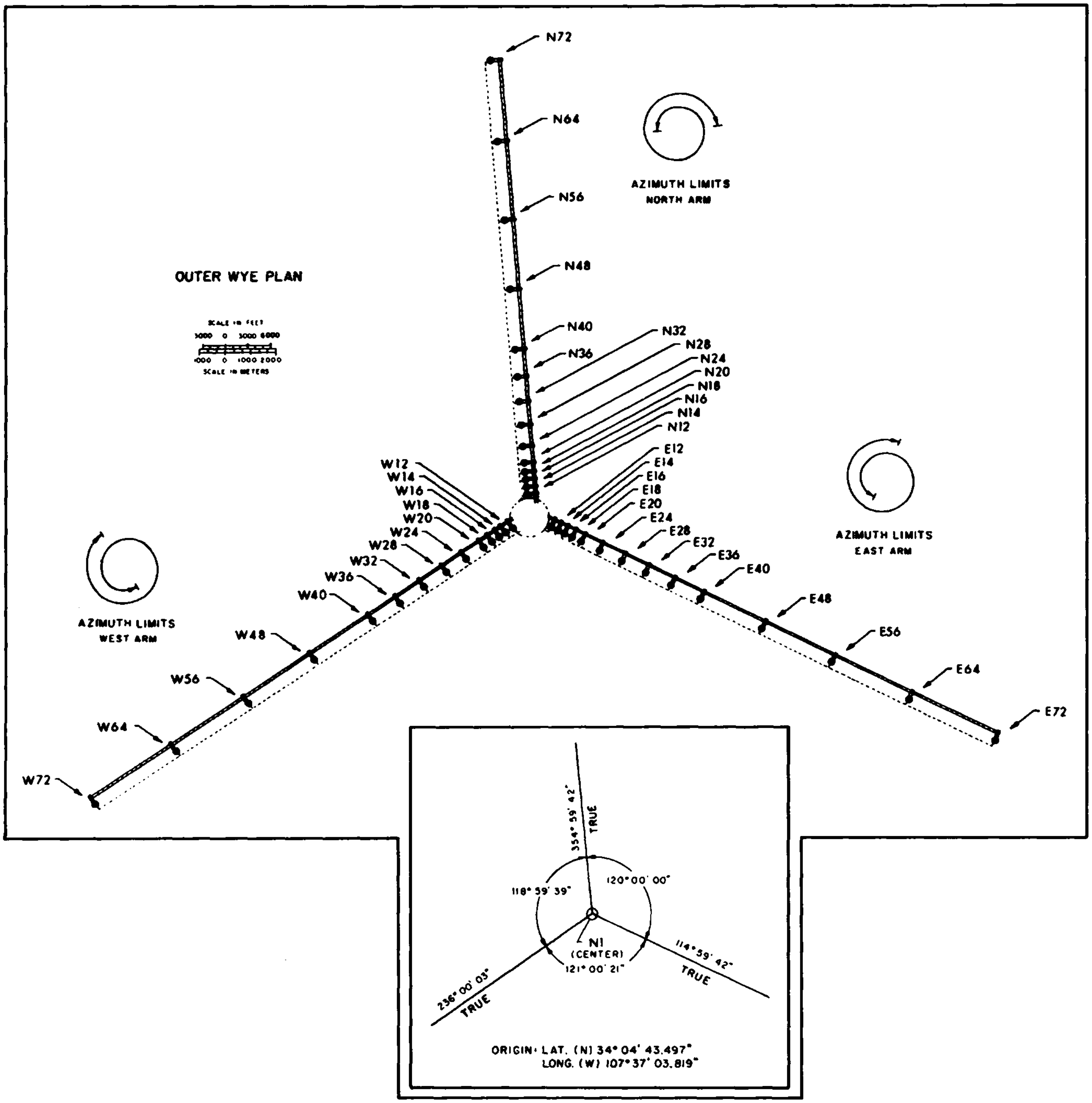


Figure I-5. The large-scale array configuration of VLA stations, showing connections to the railroad track and locations of the waveguide runs for each arm. Stations are identified, azimuth wrap limits for each arm are shown, and array location and orientation information are shown at the bottom.

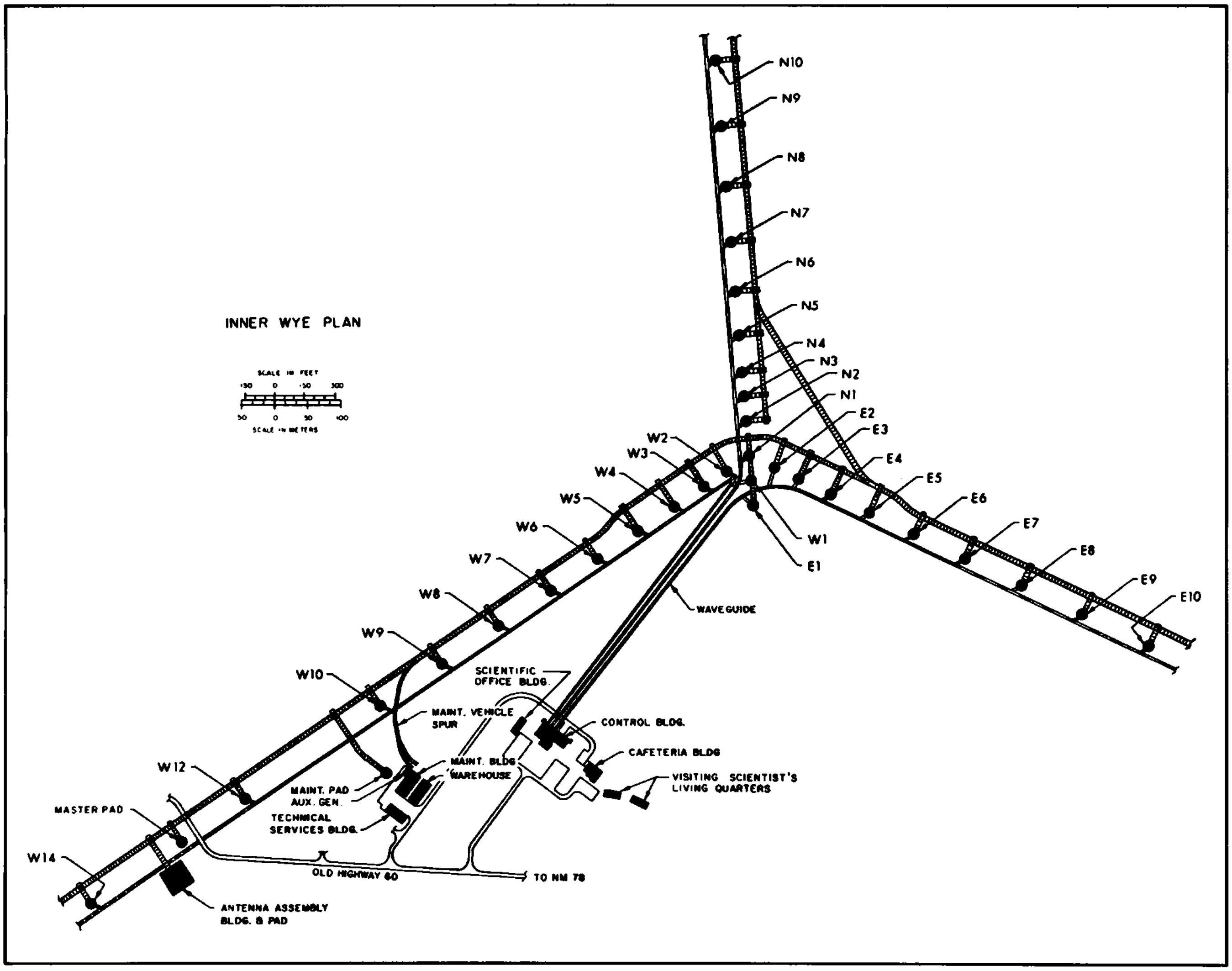


Figure I-6. The inner portions of the VLA are shown in detail, with locations of buildings, stations, roads, and railroad track. The waveguide runs for each arm are shown coming from the control building and going out to each arm.

4. Array Geometry

When the VLA is completed, there will be four standard configurations of antennas available. These are called A, B, C, and D configurations, with A being the largest. The locations of the stations for these configurations are shown in Figures I-5 and I-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 2m-th station on the next smaller configuration, allowing 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 I-3, I-4, and I-5 give the locations, and radial distances from the center, for the antenna stations on the southwest, southeast, and north arms. There are two types of station designations. Under one system, stations are designated A, B, C, or D for the configuration; N, E, or W for the north, southeast, or southwest arms; and m = 1,2,...,9 for the configuration station number on each arm. The other system, which is the standard for use in the future, denotes stations as Nn, En, or Wn for the north, southeast, and southwest arms so that

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

Under 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.

In Tables I-3, I-4, and I-5 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 antenna numbers ($k > j$ by convention) and $i = 1,2,3$ for x,y,z. The coordinates in these tables are only approximate since it will take regular operation on all 72 stations before accurate coordinates are available for them all.

Table I-3

Southwest Arm Stations					Lx(ns)	Ly(ns)	Lz(ns)	R(m)
W1				DW1	76.810	11.640	-108.410	38.984
W2			CW1	DW2	49.330	-124.060	-67.540	44.855
W3				DW3	96.580	-248.700	-137.120	89.928
W4		BW1	CW2	DW4	156.770	-407.490	-225.740	147.351
W5				DW5	228.800	-597.580	-331.800	216.088
W6			CW3	DW6	311.950	-817.030	-454.280	295.447
W7				DW7	405.680	-1064.350	-592.330	384.889
W8	AW1	BW2	CW4	DW8	509.520	-1338.460	-745.260	484.005
W9				DW9	623.180	-1638.180	-912.510	592.396
W10			CW5		747.160	-1962.880	-1093.010	709.807
W12		BW3	CW6		1021.200	-2683.780	-1494.700	970.497
W14			CW7		1328.320	-3496.370	-1948.690	1264.344
W16	AW2	BW4	CW8		1667.210	-4396.750	-2452.520	1589.914
W18			CW9		2040.540	-5381.490	-3002.040	1946.032
W20		BW5			2446.300	-6447.900	-3595.960	2331.660
W24	AW3	BW6			3353.670	-8816.190	-4910.890	3188.095
W28		BW7			4391.220	-11485.600	-6382.840	4153.424
W32	AW4	BW8			5470.640	-14443.160	-8061.210	5222.897
W36		BW9			6671.730	-17678.060	-9883.170	6392.704
W40	AW5				7989.060	-21181.090	-11844.730	7659.457
W48	AW6				10925.240	-28961.070	-16194.270	10472.842
W56	AW7				14207.400	-37730.150	-21115.180	13643.903
W64	AW8				17843.860	-47445.590	-26567.170	17157.201
W72	AW9				21804.110	-58072.110	-32542.140	20999.989

Table I-4

Southeast Arm Stations					Lx(ns)	Ly(ns)	Lz(ns)	R(m)
E1				DE1	151.290	23.190	-218.530	38.984
E2			CE1	DE2	37.800	135.510	-50.770	44.838
E3				DE3	73.400	271.800	-103.390	89.914
E4		BE1	CE2	DE4	118.750	445.380	-170.400	147.326
E5				DE5	172.950	653.180	-250.540	216.043
E6			CE3	DE6	235.640	893.070	-343.300	295.407
E7				DE7	305.180	1163.600	-448.420	384.878
E8	AE1	BE2	CE4	DE8	381.660	1463.190	-565.370	483.980
E9				DE9	465.710	1790.870	-692.940	592.367
E10			CE5		558.270	2145.740	-830.150	709.756
E12		BE3	CE6		765.390	2933.900	-1133.710	970.462
E14			CE7		997.100	3822.360	-1476.970	1264.331
E16	AE2	BE4	CE8		1257.430	4806.580	-1854.930	1589.893
E18			CE9		1547.890	5883.210	-2264.340	1946.006
E20		BE5			1868.100	7048.990	-2703.940	2331.633
E24	AE3	BE6			2552.250	9638.220	-3698.570	3188.088
E28		BE7			3330.780	12556.460	-4814.510	4153.379
E32	AE4	BE8			4179.910	15789.750	-6060.160	5222.876
E36		BE9			5118.120	19326.290	-7416.120	6392.680
E40	AE5				6126.630	23156.020	-8889.490	7659.448
E48	AE6				8324.380	31661.390	-12190.250	10472.766
E56	AE7				10813.640	41248.110	-15902.560	13643.796
E64	AE8				13535.770	51869.300	-20039.460	17156.990
E72	AE9				16205.520	63679.070	-24272.080	20999.981

Table I-5

North Arm Stations					Lx(ns)	Ly(ns)	Lz(ns)	R(m)
N1				DN1	2.350	.000	1.590	.851
N2			CN1	DN2	-100.220	-15.980	152.410	54.894
N3				DN3	-174.850	-27.630	262.290	94.865
N4		BN1	CN2	DN4	-249.580	-39.270	372.240	134.872
N5				DN5	-361.560	-56.730	537.040	194.832
N6			CN3	DN6	-495.220	-77.580	733.740	266.400
N7				DN7	-645.850	-101.050	955.440	347.061
N8	AN1	BN2	CN4	DN8	-812.750	-126.940	1201.020	436.414
N9				DN9	-955.350	-155.520	1469.740	527.585
N10			CN5		-1193.040	-186.220	1760.650	640.035
N12		BN3	CN6		-1632.130	-254.650	2406.750	875.124
N14			CN7		-2126.500	-331.810	3135.350	1140.100
N16	AN2	BN4	CN8		-2673.280	-417.250	3943.200	1433.665
N18			CN9		-3271.340	-510.630	4826.830	1754.765
N20		BN5			-3917.250	-611.790	5784.720	2102.444
N24	AN3	BN6			-5352.530	-836.590	7911.930	2874.697
N28		BN7			-6976.720	-1089.820	10305.200	3745.121
N32	AN4	BN8			-8769.960	-1370.420	12960.980	4709.484
N36		BN9			-10732.700	-1677.380	15864.930	5764.289
N40	AN5				-12858.090	-2009.740	19009.540	6906.507
N48	AN6				-17583.140	-2747.960	25990.630	9443.373
N56	AN7				-22919.060	-3580.000	33852.090	12302.688
N64	AN8				-28827.370	-4501.660	42564.540	15470.636
N72	AN9				-35283.290	-5509.950	52098.360	18935.662

A few modifications of the ideal station positions have been made. The north arm is scaled down by 19/21 to avoid a dry lake. The outermost stations on the southeast arm deviate slightly to the north to avoid a ravine. The D configuration station locations are slightly modified to avoid congestion near the array center by putting the n = 1 stations of the southeast and southwest arms on a short southern extension of the north arm. Station N24 is moved 100 meters north to be farther from Highway U.S. 60.

The position angles of the arms are:

north arm	354 degrees 59' 42"
southeast arm	114 degrees 59' 42"
southwest arm	236 degrees 00' 03" .

The geodetic coordinates of the center of the array are:

latitude	34 degrees 04' 43.497" north
longitude	107 degrees 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 $\pm$ 32 m.

During 1978 the most likely configuration available for astronomical programs will involve six antennas located on the southwest arm and four antennas on the inner portions of the southeast arm. Figure I-7 shows the location of the occupied stations for the configuration we will adopt as standard for use in 1978. This standard configuration is W48, W40, W32, W24, W16, and W8 on the southwest arm, with four other antennas at locations E4, E8, E12, and E16. The basic resolution for observations with this configuration is 1" at 6 cm; therefore, this array is capable of high quality, high resolution mapping of high declination sources.

The basic plan for array expansion is to extend track, stations, and waveguide out to W64 on the southwest arm, then to go to E64 on the southeast arm, followed by extension out to N64 on the north arm. Finally, the last four kilometers and the last station on each arm (W72, E72, N72) will be added.

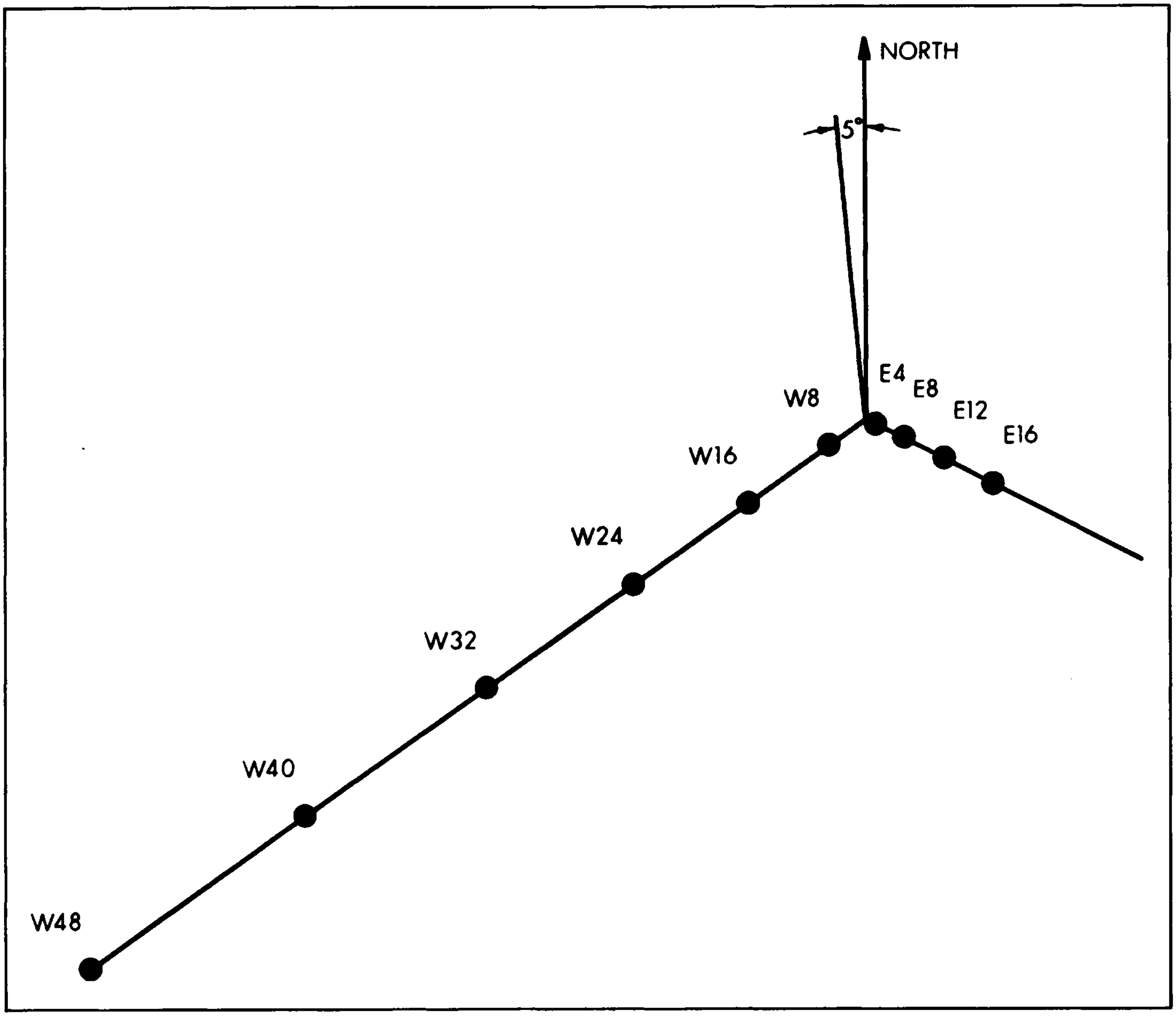


Figure I-7. The location of the 10 stations used for astronomical observing in September 1978.

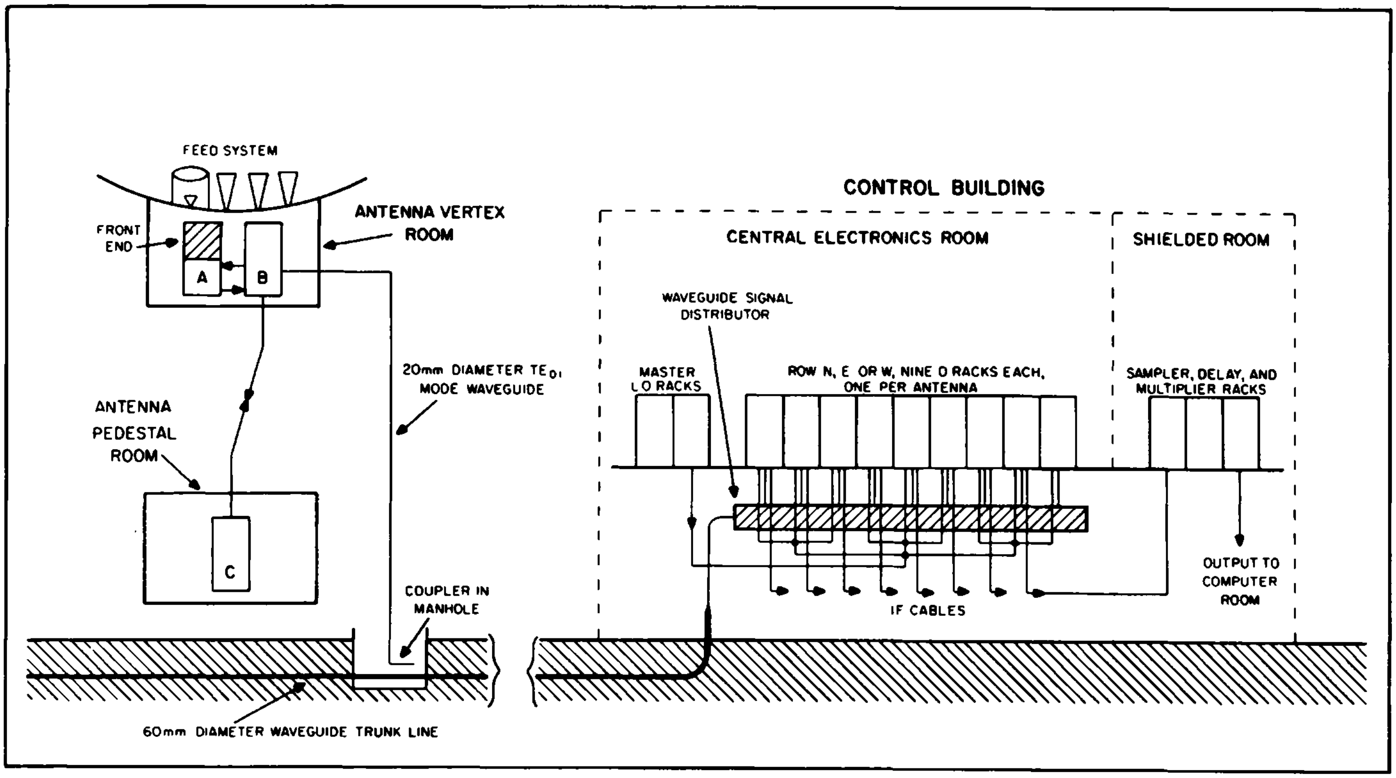


Figure I-8. Schematic diagram showing the major locations of VLA electronics equipment, including details of the waveguide communications system and the signal distribution system located under the racks in the control building.

5. Location of Major System Components

The antennas on each station of each arm are connected with the central control building via a waveguide communications system. 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 I-8 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 Rack A and Rack B are suspended from the central portion of the main reflector inside a temperature controlled vertex room. Rack C is the Antenna Control Unit (ACU) located in the antenna pedestal room at the base of the antenna. Each antenna communicates back and forth to the control building via a combination of 20 mm waveguide coming down each antenna and 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 a single Rack D for each antenna. Equipment in each Rack D communicates with the corresponding B Rack at the antennas through the waveguide system, and local oscillator, IF, control and monitor signals are transmitted back and forth. Each Rack D receives signals from the master LO racks and sends IF signals for each antenna by cable to the shielded room where the sampler and delay and multiplier racks are located. The resulting cross-correlated signals 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 sections.

CHAPTER II

THE THEORETICAL BASIS OF INTERFEROMETRY AND APERTURE SYNTHESIS

1. Introduction

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

The basic process upon which interferometry is based is the cross-correlation of signals from two antennas after correction for the delay in time of signal arrival at one antenna with respect to another. A pair of antennas operated in this manner is called an interferometer. With N antennas there are N(N-1)/2 possible interferometers; therefore, there will be 351 interferometers in the full 27-antenna VLA. Radio interferometric measurements are considerably more complicated than simply measuring 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 intensity of all sources in the beams of the antennas, but also information about their position 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 distribution of sources in the antenna beam. The essential characteristic of aperture synthesis in radio astronomy is using the measurement of a large number of different Fourier components of a radio source to reconstruct a picture or map of the spatial intensity distribution of a source. For N antennas there are N(N-1)/2 interferometric measurements of Fourier components being sampled at any instant. Because of the changing geometric relationship between the antenna pairs on the rotating earth and the radio source in the sky, at different times, in general, N(N-1)/2 different Fourier components are being measured. Because of 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 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. Since the purpose of Section II is to provide a thorough basis for understanding these subjects, we will begin by defining some fundamental concepts. We will then cover 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 C. H. Wright ("Galactic and Extra-galactic Radio Astronomy", ed. G. L. Verschuur and K. I. Kellermann, Spring-Verlag (New York), 1974, Chapter 10).

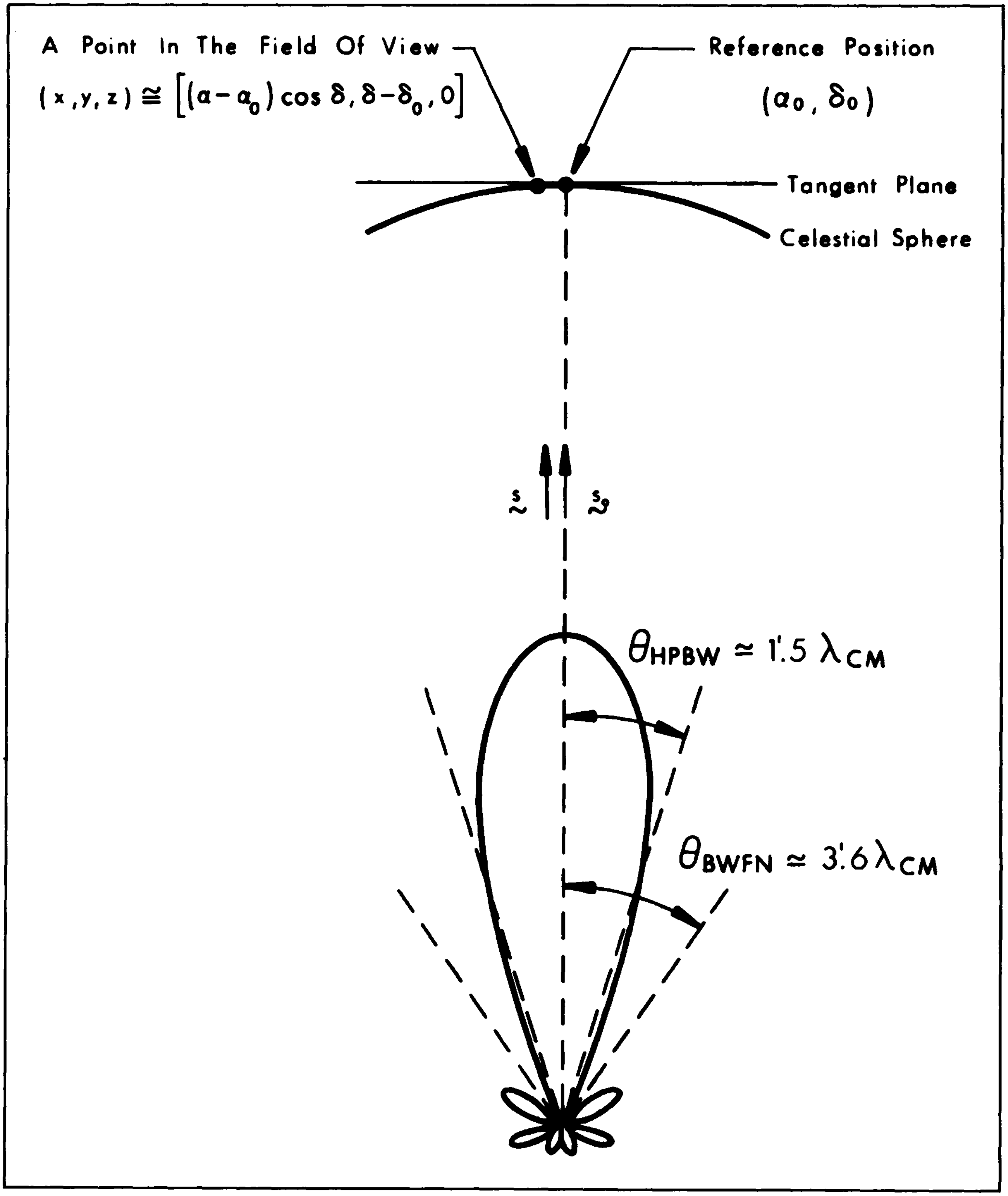


Figure II-1. A schematic diagram showing the relation between an antenna beam pattern, pointed at the reference position, and positions on the celestial sphere and its tangent plane.

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. We define the reference position as (α_o,δ_o), the position of a general point in the field of view as (α,δ), and frequently describe the location of points with respect to the reference position in terms of a vector displacement $(\alpha-\alpha_o,\delta-\delta_o) = (x,y,z)$. 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

$$\Theta_{HPBW} \cong 1\overset{'}{.}5 \; \lambda_{cm} \qquad \text{(II-1)}$$

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

$$\Theta_{BWFN} \cong 2.4\Theta_{HPBW} \cong 3\overset{'}{.}6 \; \lambda_{cm} \quad . \qquad \text{(II-2)}$$

A schematic representation of these angles with respect to the antenna beam pattern is shown in Figure II-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. We also show in

Figure II-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

$$\underset{\sim}{s} \cong ((\alpha-\alpha_o) \cos \delta_o, \delta-\delta_o, 0) \qquad \text{(II-3)}$$

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

$$H = LST - \alpha \qquad \text{(II-4)}$$

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^{o} 04' 43.497" north latitude

107^{o} 37' 03.819" west longitude

or a local zenith with a declination 34^{o} 04' 43.497" on a local meridian at $7^{h}\ 10^{m}\ 28\overset{s}{.}2546$. Local MST = GMT - $7^{h} \cong$ UT - 7^{h}.

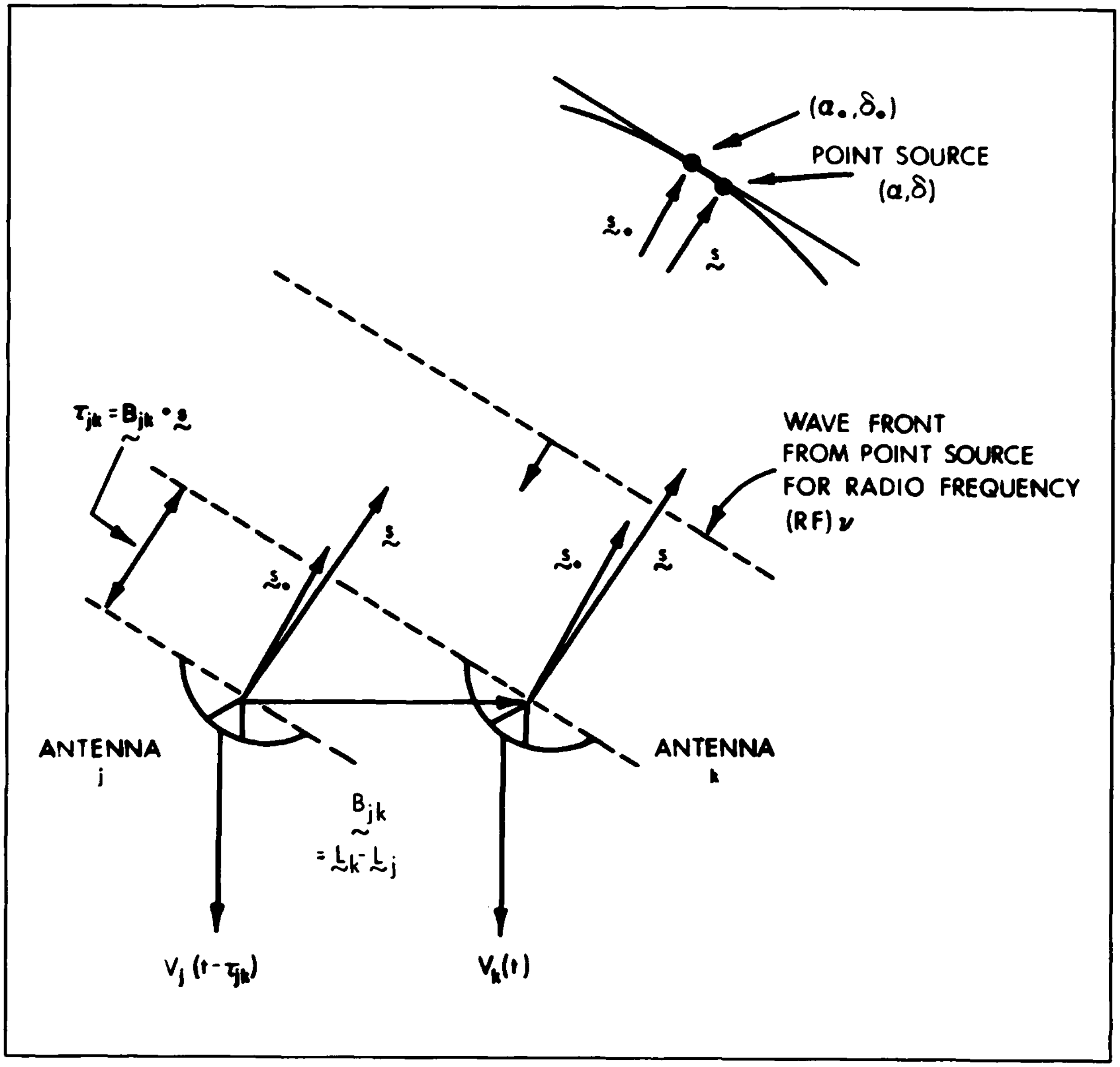


Figure II-2. The geometry of a single interferometer pair with respect to wavefronts arriving from a point (α,δ) on the celestial sphere.

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 ($\simeq((\alpha-\alpha_o)\cos\delta_o,\delta-\delta_o,0)$ on tangent plane)

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

ν_o, 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

$\underset{\sim}{B}_{jk} = \underset{\sim}{L}_k - \underset{\sim}{L}_j$ = baseline vector between the j-th and k-th antennas where $j < k$

In Figure II-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 II-2, a wavefront reaches the j-th antenna at a time

$$\tau_{jk} = \underset{\sim}{B}_{jk} \cdot \underset{\sim}{s} = (\underset{\sim}{L}_k - \underset{\sim}{L}_j) \cdot \underset{\sim}{s} \tag{II-5}$$

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 $\underset{\sim}{s}$ is given by $\omega \underset{\sim}{B}_{jk}(\underset{\sim}{s}-\underset{\sim}{s}_o)$ 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 II-16, taking the results on faith.

Let E be the electric field strength of the incoming wavefront schematicized in Figure II-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, are

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

and

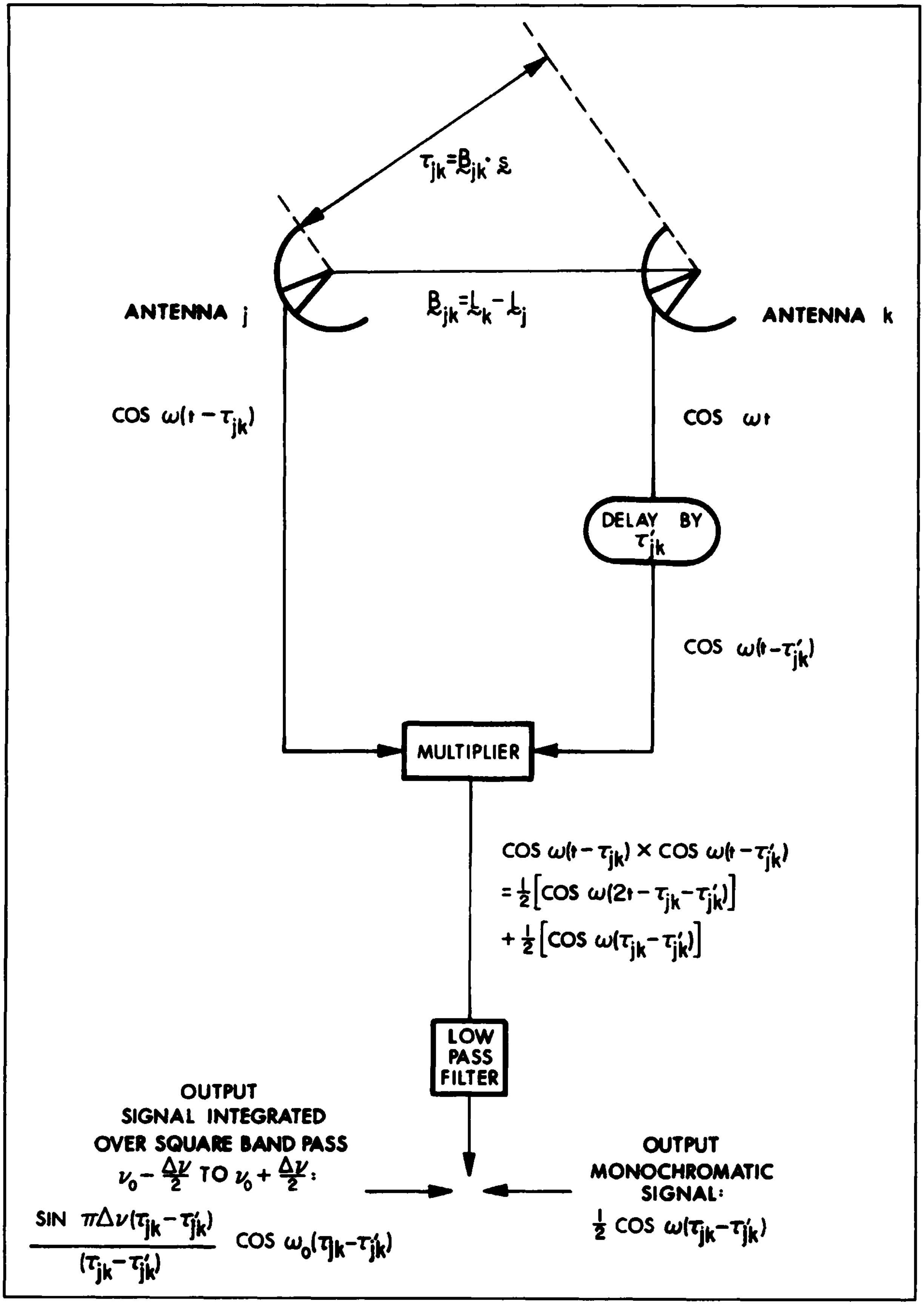


Figure II-3. A schematic diagram of the processing of pure RF signals from an interferometer pair.

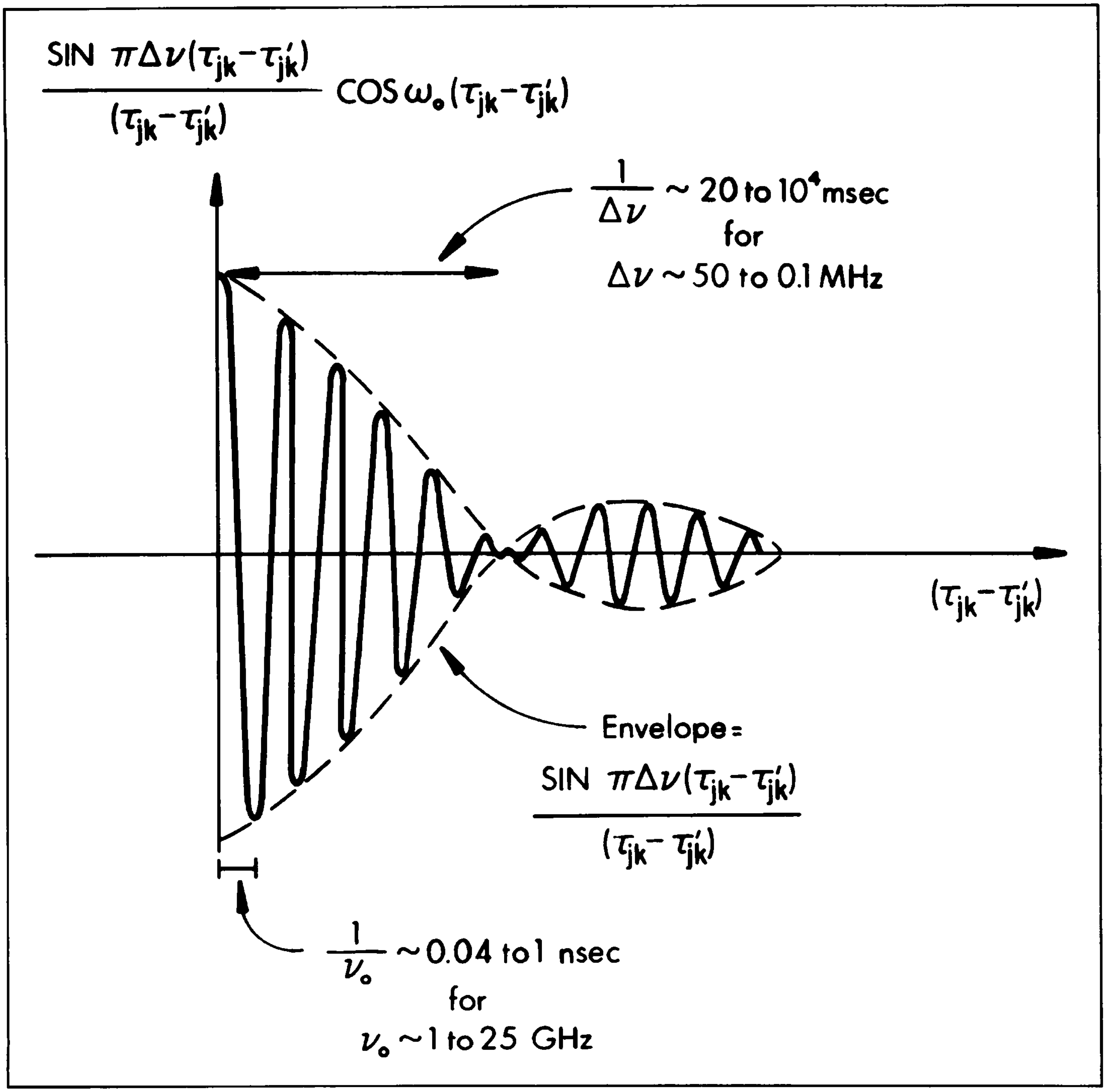


Figure II-4. The theoretical signal output from the system shown in Figure II-3.

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

where the factors of ½ 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 II-6 and II-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 II-3 where cross-correlation (multiplication) is performed after a simple delay compensation τ'_{jk}, where all frequencies are RF. The result after multiplication contains the sum of high and low frequency components, of which only the low frequencies are desirable. Therefore, a low pass filter suppresses the high frequencies and the output signal is proportional to $\cos \omega(\tau_{jk}-\tau'_{jk})$ for a single monochromatic component. However, the antenna electronics actually pass on a range of frequencies corresponding to a designated pass band. The actual output voltages are, therefore, obtained by integrating over the range $\nu_o - \Delta\nu/2$ to $\nu_o + \Delta\nu/2$ (assuming uniform signal in this range and 0 signal elsewhere) to obtain an output voltage from the low pass filter proportional to

$$\frac{1}{(\tau_{jk}-\tau'_{jk})} \sin \pi\Delta\nu(\tau_{jk}-\tau'_{jk}) \cos \omega_o(\tau_{jk}-\tau'_{jk}) \quad .$$

A schematic representation of this idealized output signal is shown in Figure II-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. The delay τ_{jk} can be as big as 120 msec for a 35 km baseline, and for 1% accuracy we need time errors in delay compensation of 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 RF LO signal, one can convert the signals to intermediate frequencies (IF) before delay and multiplication. The accuracy of timekeeping in delays then need be only of the order of $0.01/\Delta\nu$ which is 0.2 nanosec for $\Delta\nu \sim 50$ MHz. In actuality, the VLA system inserts a small delay in the RF path and a large delay in the IF path. A model of this system is shown in Figure II-5. The coarse delays, τ_j' and τ_k', in the IF signal path play the role of keeping the output signal on one of the large positive peaks of Figure II-4 if $\underset{\sim}{s} = \underset{\sim}{s}_o$, and the phase shifts $\phi_j(t)$ and $\phi_k(t)$ introduced into the LO signal before mixing do the fine tuning to keep the output signal at the very top of that large positive peak. In Figure II-5 we show RF phase shifting and delay in the IF signal paths for each antenna. This is representative of the fact that, since this is done with respect to an arbitrary position at the center of the array for all N antennas, the cross-correlated signals from each antenna pair will automatically have the correct delay compensation. This is the first instance of the dominantly antenna-based treatment of VLA signal processing that the reader will encounter in this and subsequent sections.

Figure II-5 does not attempt to illustrate the many amplification stages in the system and ignores a host of imperfections that may affect the signal phase, but it does treat the essential aspects of the way phase information is handled in the system for signals due to the wavefront from a point source seen as $\cos(\omega t-\tau_{jk})$ for the j-th antenna and $\cos \omega t$ for the k-th antenna. The conversion of these signals to IF frequencies is accomplished by mixing 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 fine 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 IF frequencies, the two signals are proportional to $\cos[(\omega-\omega_o)t-\omega\tau_{jk}-\phi_j(t)]$ and

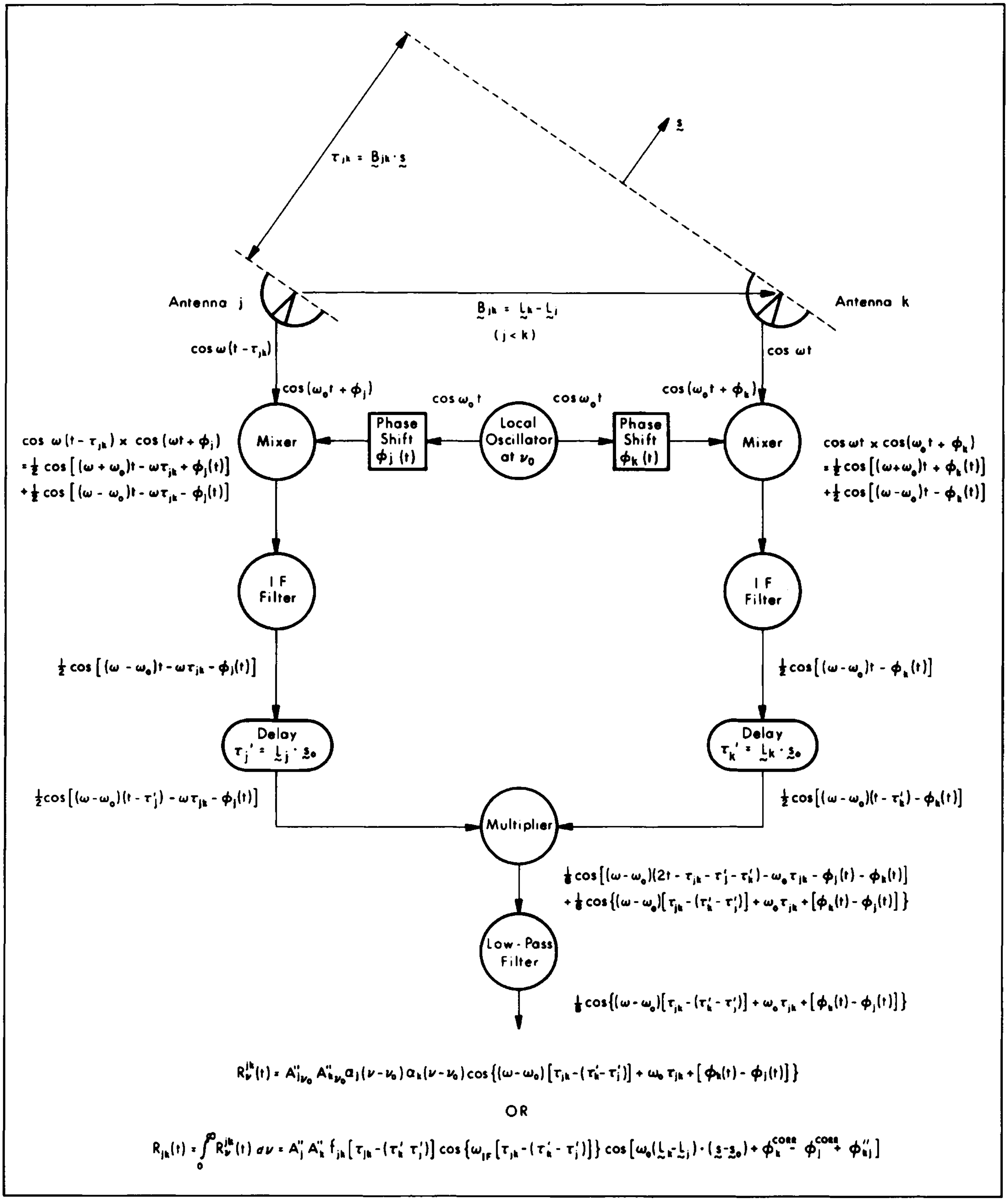


Figure II-5. A simplified schematic of the signal path for a VLA interferometer pair.

$\cos\,[(\omega-\omega_o)t-\phi_k(t)]$, which are then delayed by times $\tau_j' = \underset{\sim}{L}_j \cdot \underset{\sim}{s}_o$ and $\tau_k' = \underset{\sim}{L}_k \cdot \underset{\sim}{s}_o$. After multiplication and passage through a low pass filter, the IF signal response for frequency ν is proportional to

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

The instantaneous response for frequency ν can then be written as

$$R_\nu^{jk}(t) = \qquad \text{(II-8)}$$

$$A''_{j\nu_o} A''_{k\nu_o} \alpha_j(\nu-\nu_o)\alpha_k(\nu-\nu_o)\ \cos\left\{(\omega-\omega_o)[\tau_{jk}-(\tau_k'-\tau_j')] + \omega_o\tau_{jk} + [\phi_k(t)-\phi_j(t)]\right\}$$

where

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

and $\alpha_j(\nu-\nu_o)$ is the band pass function for the j-th antenna. The total signal response is obtained by integrating $R_\nu^{jk}(t)$ over all frequencies. Letting $\Delta\omega = \omega - \omega_o$ and $\Delta\tau = [\tau_{jk}-(\tau_k'-\tau_j')]$, the phase dependent factor can be written as

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

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

$$R_{jk}(t) = \qquad \text{(II-10)}$$

$$A_j''A_k''f_{jk}[\tau_{jk}-(\tau_k'-\tau_j')]\ \cos\left\{\omega_{IF}[\tau_j-(\tau_k'-\tau_j')]\right\}\ \cos\left\{[\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o) + \phi_k-\phi_j]\right\}$$

where

$$\omega_{IF} = \frac{\int(\omega-\omega_o)\alpha_j(\nu-\nu_o)\alpha_k(\nu-\nu_o)d(\nu-\nu_o)}{\int\alpha_j(\nu-\nu_o)\alpha_k(\nu-\nu_o)d(\nu-\nu_o)} \qquad \text{(II-11)}$$

is the effective IF angular frequency and

$$f_{jk}(\Delta\tau) = \int\alpha_j(\Delta\omega)\alpha_k(\Delta\omega)\ \exp\ (i\Delta\omega\Delta\tau)d(\Delta\omega) \qquad \text{(II-12)}$$

is the so-called fringe-washing function which is unity for identical, symmetrical band pass under conditions of good delay tracking. The symbol i represents the square root of -1. The factor $\cos\ \omega_{IF}\Delta\tau$ is also unity under conditions of good delay tracking ($\omega_{IF}\Delta\tau < 6^o$). Under these conditions, which should be valid for normal VLA operation, the output signal response is

$$R_{jk}(t) = A_j''A_k''\ \cos\left\{\omega_o\tau_{jk} + [\phi_k(t)-\phi_j(t)]\right\} \quad . \qquad \text{(II-13)}$$

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

$$\phi_j(t) = \omega_o\underset{\sim}{L}_j\cdot\underset{\sim}{s}_o - n(2\pi) + \phi_j^{corr}(t) \qquad \text{(II-14)}$$

where $\phi_j^{corr}(t)$ represents any phase corrections applied at this stage. Equation II-13 then becomes

$$R_{jk}(t) = A_j''A_k''\ \cos\left\{\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o) + [\phi_k^{corr}(t)-\phi_j^{corr}(t)]\right\}. \qquad \text{(II-15)}$$

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, in measuring the processing interferometer response output, it is most convenient to deal with the amplitude and phase of a complex representation of the response function; thus, Equation II-15 becomes

(II-16)

$$V''_{jk} = A''_{jk} e^{i\Phi''_{jk}} = A''_j A''_k \exp\left\{ i\omega_o (\underset{\sim}{L}_k - \underset{\sim}{L}_j)\cdot(\underset{\sim}{s} - \underset{\sim}{s}_o) + i[\phi_k^{corr} - \phi_j^{corr} + \phi_k^o - \phi_j^o] \right\}$$

where we now have system phase constants ϕ_j^o for the j-th antenna.

The measured A''_j and

$$\Phi''_{jk} = \Phi''_k - \Phi''_j \qquad \text{(II-17)}$$

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 plays such a major role in using the instrument, let us now adopt a notation to describe this process. Let the raw signal derived from the correlator output by the on-line computer system be described by double-primed quantities, such as

$$V''_{jkp} = A''_{jkp} \exp\,(i\Phi''_{jkp}) \qquad \text{(II-18)}$$

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.

As will be discussed in more detail later, the on-line, real time computer system can apply further corrections and calibration before sending the visibility data on to the off-line computer system. Let us denote data that have been subjected to on-line corrections and calibration by single-primed quantities, such as

$$V'_{jkp} = A'_{jkp} \exp\,(i\Phi'_{jkp}) \quad . \qquad \text{(II-19)}$$

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

$$V_{jkp} = A_{jkp} \exp\,(i\Phi_{jkp}) \quad . \qquad \text{(II-20)}$$

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.

The signal channels for the two orthogonal polarizations are denoted A and C. The full VLA will have duplicate orthogonal polarization channels denoted B and D. If we let R and L denote right-hand and left-hand circular polarization, respectively, then the A and B channels are R, and the C and D channels are L. We will adopt a special notation whereby, when the index p is attached to a single antenna quantity (like ϕ_{jp})

$$p = A,\ C,\ B,\ \text{or}\ D$$

whereas, when attached to a correlator-related variable (like V_{jkp})

$$p = \begin{matrix} AA,\ CC,\ AC,\ CA \\ \text{or} \\ BB,\ DD,\ BD,\ DB \end{matrix} \quad .$$

In the following we will mainly deal with the A and C polarizations, giving AA, CC, AC, and CA correlators. We will also give major emphasis to the standard circularly polarized system.

All the previous discussion in this section made no distinction between signals generated for AA, CC, AC, or CA correlators. Let us now discuss the special features of dealing with polarized signals. Let I, Q, U, and V_{circ} denote the Stokes parameters of source radiation. The variables I, Q, U, and V_{circ} are normally associated only with completely corrected and calibrated data. If a source, like the strong point source we are mainly discussing so far in this section, has a total intensity flux density of S_ν, a degree of linear polarization m, a circularly polarized flux density of V_{circ}, and a linear polarization position angle χ, then

$$
\begin{aligned}
I &= S_\nu = \tfrac{1}{2}(V_{jkRR} + V_{jkLL}) \\
P &= V_{jkLR} = Q + iU = mIe^{2i\chi} \\
P^* &= V_{jkRL} = Q - iU = mIe^{-2i\chi} \\
|P| &= (Q^2 + U^2)^{\frac{1}{2}} = mI \\
\chi &= \tfrac{1}{2}\tan^{-1}(U/Q)
\end{aligned}
\tag{II-21}
$$

and

$$V_{circ} = \tfrac{1}{2}(V_{jkLL} - V_{jkRR})$$

are a consistent set of equations relating Stokes parameters, some other variables frequently used to describe linear polarization, and the completely corrected and calibrated visibilities V_{jkLL}, V_{jkRR}, V_{jkLR}, and V_{jkRL}.

Let us now discuss the parameters of calibration of AA, CC, AC, and CA correlators. Let us denote the complex electric field of the radiation in the antenna beam as E_R and E_L for the circularly polarized system. One then has

$$
\begin{aligned}
I &= \frac{1}{2}(E_L E_L^* + E_R E_R^*) \\
V_{circ} &= \frac{1}{2}(E_L E_L^* - E_R E_R^*) \\
Q &= \frac{1}{2}(E_L E_R^* + E_R E_L^*) \\
U &= \frac{i}{2}(E_L E_R^* - E_R E_L^*)
\end{aligned}
\tag{II-22}
$$

or, equivalently,

$$E_L E_L^* = I + V_{circ} = V_{jkLL}$$

$$E_R E_R^* = I - V_{circ} = V_{jkRR} \qquad \text{(II-23)}$$

$$E_L E_R^* = Q - iU = V_{jkLR}$$

$$E_R E_L^* = Q + iU = V_{jkRL} \quad .$$

The asterisk (*) denotes complex conjugation. Now that we have all of these relationships between different ways of describing calibrated polarization data, let us 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

$$R_j = G_{jR} \cdot (E_R e^{-i\phi_p} + D_{jR} E_L e^{i\phi_p})$$

$$\text{(II-24)}$$

$$L_j = G_{jL} \cdot (E_L e^{i\phi_p} + D_{jL} E_R e^{-i\phi_p})$$

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 cross-talk between polarizations, and ϕ_p is the parallactic angle which can be obtained from

$$\phi_p = \qquad \text{(II-25)}$$

$$\tan^{-1}[\cos \lambda_{lat} \sin H/(\sin \lambda_{lat} \cos \delta - \cos \lambda_{lat} \sin \delta \cos H)]$$

where λ_{lat} is the VLA latitude. The parallactic angle is the angle between the local meridian and the elevation coordinate of the VLA alt-az antennas.

The correlator outputs are then

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

$$V''_{jkLL} = L_j L_k^* \qquad \text{(II-26)}$$

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

and

$$V''_{jkRL} = R_k L_j^* \quad .$$

For V''_{jkRR}, for example, we get

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

and for V''_{jkLR} we get

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

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 II-23,

$$V''_{jkRR} = G_{jR} \cdot G_{kR}^* \cdot V_{jkRR} \qquad \text{(II-27)}$$

$$V''_{jkLL} = G_{jL} \cdot G_{kL}^* \cdot V_{jkLL} \qquad \text{(II-28)}$$

$$V''_{jkLR} = G_{jL} \cdot G_{kR}^* \cdot (V_{jkLR} e^{2i\phi_p} + V_{jkLL} D_{kR}^* + V_{jkRR} D_{jL}) \qquad \text{(II-29)}$$

$$V''_{jkRL} = G_{jR} \cdot G^*_{kL} \cdot (V_{jkRL} e^{-2i\phi_p} + V_{jkRR} D^*_{kL} + V_{jkLL} D_{jR}) \quad . \qquad \text{(II-30)}$$

Equations (II-27) - (II-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_{circ} so that

$$\begin{aligned} V_{jkLL} &= I + V_{circ} \\ V_{jkRR} &= I - V_{circ} \\ V_{jkLR} &= Q - iU \\ V_{jkRL} &= Q + iU \end{aligned} \qquad \text{(II-31)}$$

and from measured V''_{jkp} one can solve Equations (II-27) - (II-30) for G_{jR}, G_{jL}, D_{jR}, and D_{jL}. Once these are known, we define

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

and (II-32)

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

and Equations (II-27) - (II-30) can be rearranged to give

$$V_{jkLL} = g_{jL}g_{kL}^{*}V''_{jkLL} \quad \text{(II-33)}$$

$$V_{jkRR} = g_{jR}g_{kR}^{*}V''_{jkRR} \quad \text{(II-34)}$$

$$V_{jkLR} = (g_{jL}\cdot g_{kR}^{*}V''_{jkLR} - D_{jL}V_{jkRR} - D_{kR}^{*}V_{jkLL})e^{-2i\phi_p} \quad \text{(II-35)}$$

$$V_{jkRL} = (g_{jR}\cdot g_{kL}^{*}V''_{jkRL} - D_{jR}V_{jkLL} - D_{kL}^{*}V_{jkRR})e^{2i\phi_p} \quad \text{(II-36)}$$

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 unprimed 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

$$V'_{jkLL} = g'_{jL}(g'_{kL})^{*}V''_{jkLL} \quad \text{(II-37)}$$

$$V'_{jkRR} = g'_{jR}(g'_{kR})^{*}V''_{jkRR} \quad \text{(II-38)}$$

$$V'_{jkLR} = [g'_{jL} \cdot (g'_{kR})^{*} V''_{jkLR} - D'_{jL} V''_{jkRR} - (D'_{kR})^{*} V'_{jkLL}] e^{-2i\phi_p} \qquad \text{(II-39)}$$

$$V'_{jkRL} = [g'_{jR} \cdot (g'_{kL})^{*} V''_{jkRL} - D'_{jR} V''_{jkLL} - (D'_{kL})^{*} V'_{jkRR}] e^{2i\phi_p} \qquad \text{(II-40)}$$

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

$$V_{jkLL} = g_{jL} g^{*}_{kL} V'_{jkLL} \qquad \text{(II-41)}$$

$$V_{jkRR} = g_{jR} g^{*}_{kR} V'_{jkRR} \qquad \text{(II-42)}$$

$$V_{jkLR} = (g_{jL} g^{*}_{kR} V'_{jkLR} - D_{jL} V_{jkRR} - D^{*}_{kR} V_{jkLL}) e^{-2i\phi_p} \qquad \text{(II-43)}$$

$$V_{jkRL} = (g_{jR} g^{*}_{kL} V'_{jkRL} - D_{jR} V_{jkLL} - D^{*}_{kL} V_{jkRR}) e^{2i\phi_p} \quad . \qquad \text{(II-44)}$$

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

$$V_{jkLL} = (I + V_{circ} + I_{noise} + V_{circ,noise}) \cdot \qquad \text{(II-45)}$$

$$\exp\,[i\omega_o (\underset{\sim}{L}_k - \underset{\sim}{L}_j) \cdot (\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}]$$

$$V_{jkRR} = (I - V_{circ} + I_{noise} - V_{circ,noise}) \cdot \qquad \text{(II-46)}$$

$$\exp\,[i\omega_o (\underset{\sim}{L}_k - \underset{\sim}{L}_j) \cdot (\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}]$$

$$V_{jkLR} = (Q - iU + Q_{noise} - iU_{noise}) \cdot \qquad \text{(II-47)}$$

$$\exp\,[i\omega_o(\underset{\sim}{L}_k - \underset{\sim}{L}_j)\cdot(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}]$$

$$V_{jkRL} = (Q + iU + Q_{noise} + iU_{noise}) \cdot \qquad \text{(II-48)}$$

$$\exp\,[i\omega_o(\underset{\sim}{L}_k - \underset{\sim}{L}_j)\cdot(\underset{\sim}{s} - \underset{\sim}{s}_o) + \phi_{noise}] \quad .$$

In Equations (II-45) to (II-48) 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_{circ}, which are relatively constant, are used in conjunction with Equations (II-27) - (II-32) 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 (II-33) - (II-36).

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 (= 25m)

ε_a = aperture efficiency

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

then the theoretical rms noise fluctuation in the amplitudes for a single telescope pair is

$$\sigma = \frac{4(2^{\frac{1}{2}})k_B T_{sys}}{\varepsilon_c \varepsilon_a D^2_{ant} \sqrt{\Delta\nu t}} \tag{II-49}$$

$$= \frac{2.2 \times 10^{-4}\ T_{sys}}{\varepsilon_a \sqrt{(\Delta\nu_{MHz}/50)(t_{sec}/10)}}\ \text{Jy}$$

where k_B is the Boltzmann constant and t is the length of observing time involved. Using Equation II-49 and the nominal values of T_{sys} and ε_a for each standard VLA frequency, one predicts the rms noise fluctuations listed in Table II-1 for a single ten second record.

Table II-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	$0.026\ (50/\Delta\nu_{MHz})^{1/2}$ Jy
6 cm	65%	60° K	$0.020\ (50/\Delta\nu_{MHz})^{1/2}$ Jy
2 cm	54%	300° K	$0.12\ (50/\Delta\nu_{MHz})^{1/2}$ Jy
1.3 cm	46%	400° K	$0.19\ (50/\Delta\nu_{MHz})^{1/2}$ Jy

For N antennas,

$$\sigma = \frac{2.2 \times 10^{-4}\, T_{sys}}{\varepsilon_a \sqrt{(\Delta\nu_{MHz}/50)(t_{sec}/10)(N\cdot(N-1)/2)}} \quad . \qquad \text{(II-50)}$$

Let us now discuss the probability distributions for both amplitudes and phases. Let

S = true amplitude due to a real signal

A = a measured amplitude

P(A)dA = probability a measured amplitude will be between A and A + dA

ϕ_{true} = true phase due to a real signal

ϕ = a measured phase

$P(\phi)d\phi$ = probability a measured phase will be between ϕ and $\phi + d\phi$.

Following the discussion by Vinokur (Ann. D'Ap., 28, 412, 1965), the probability distribution for a measured amplitude is given by

$$P(A) = \frac{A}{\sigma^2} I_o \left[\frac{AS}{\sigma^2} \right] \exp \left\{ - \frac{[S^2 + A^2]}{2\sigma^2} \right\} \tag{II-51}$$

where $I_o(x)$ is the modified Bessel function of the first kind, of order 0. This function is unity when the argument is zero, corresponding to $A_{true} = 0$, i.e., no real signal is present. In Figure II-6, we show plots of P(A) as a function of A/σ for several values of signal to noise: S/σ = 0, 1, 2, 3, 5, and 10.

The probability distribution of the phases, $P(\phi-\phi_{true})$ is plotted in Figure II-7 as a function of $(\phi-\phi_{true})$ for S/σ = 0, 1, 2, 3, and 5. We see that, in the absence of a real signal, all phases are, in principle, equally probable. As the signal-to-noise increases, the phase probability distribution has less and less deviation from the true phase, as seen from Figure II-7 and the following table:

S/σ	$(\phi-\phi_{true})_{P/P_{max}} = \frac{1}{2}$
1	$\pm 55^o$
2	$\pm 35^o$
3	$\pm 22^o$
5	$\pm 13^o$

For large values of $S/\sigma(\gtrsim 2)$,

$$(\phi-\phi_o)_{P/P_{max}=\frac{1}{2}} \cong \frac{\pm 65^o}{(S/\sigma)} \quad . \tag{II-52}$$

Examination of Figures II-6 and II-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.

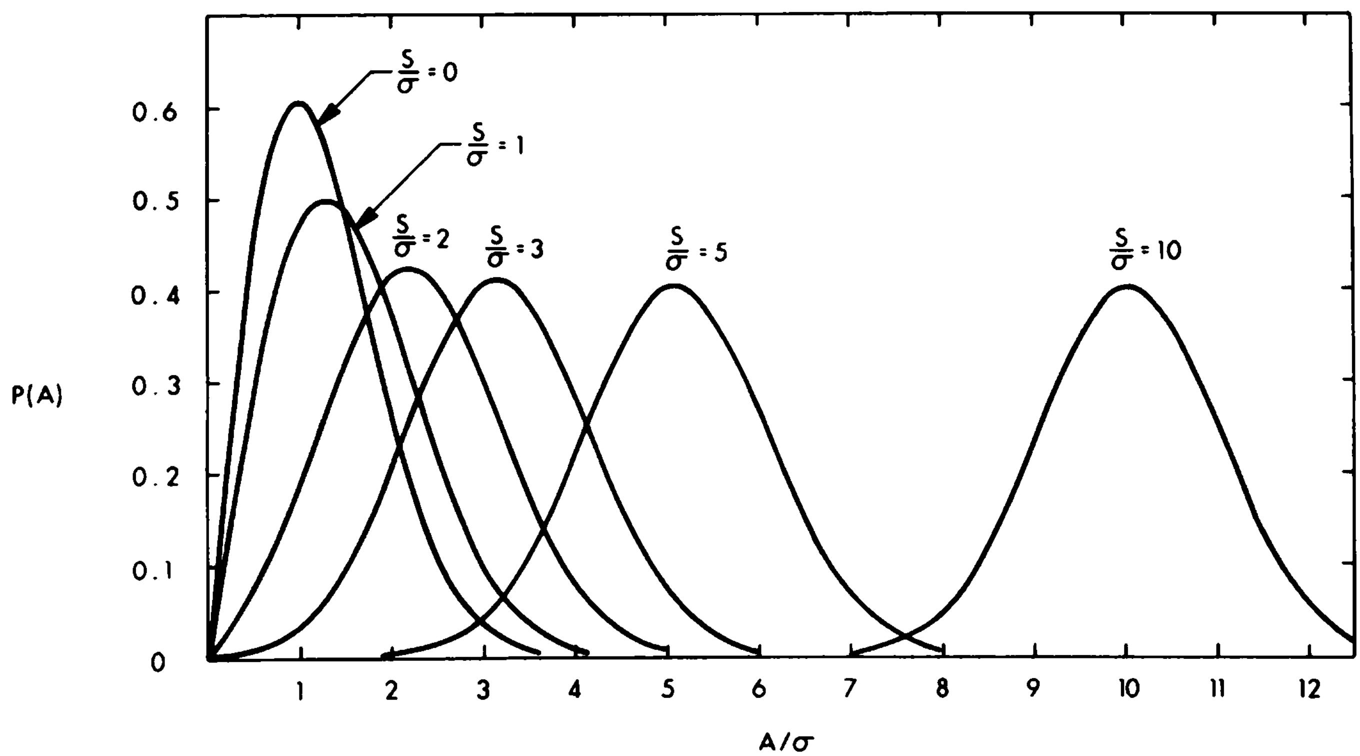


Figure II-6. The probability distribution of measured amplitudes is plotted as a function of apparent signal to noise for a number of values of true signal to noise.

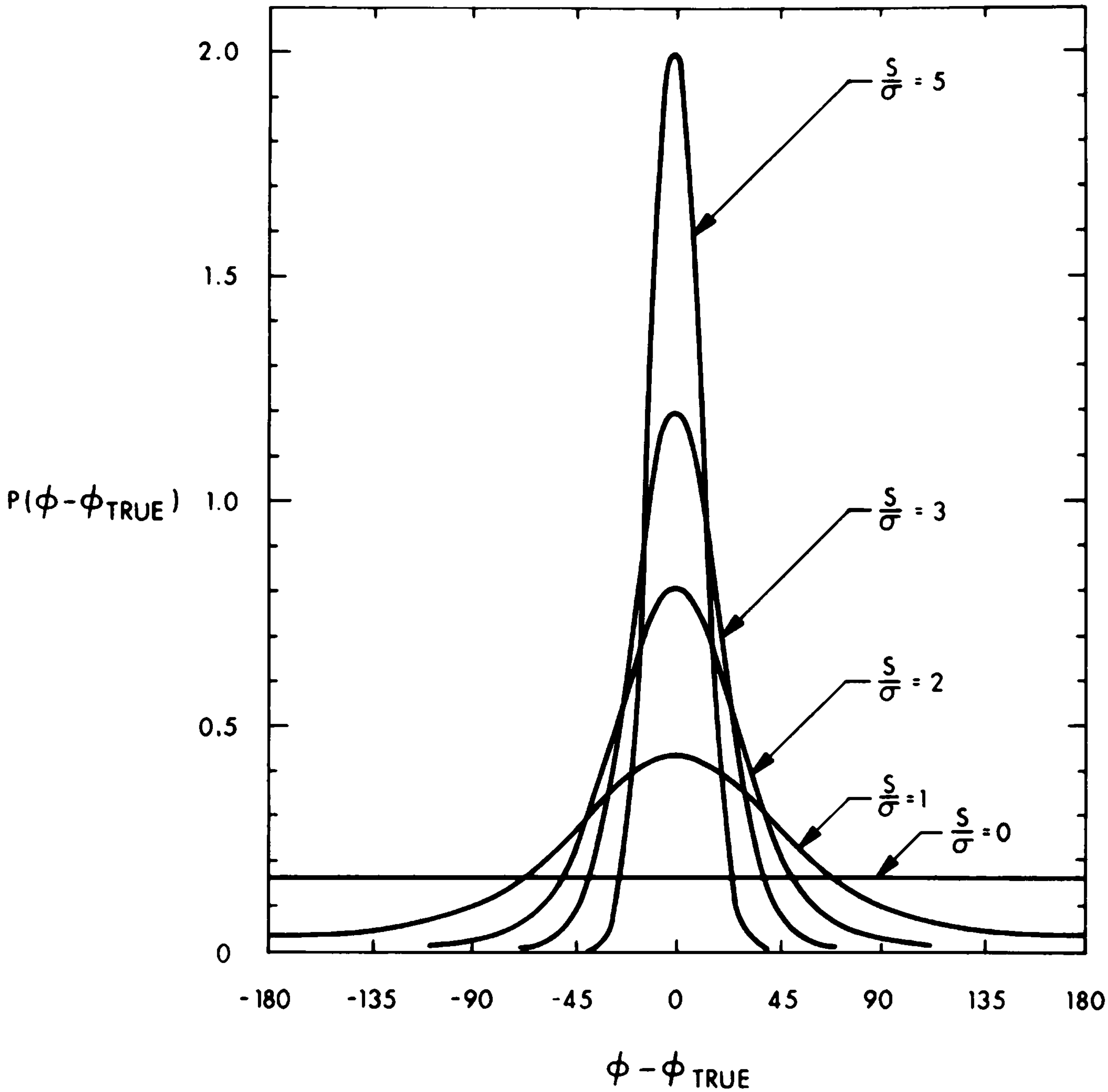


Figure II-7. The probability distribution of measured phases is plotted as a function of $(\phi-\phi_{true})$ for a number of values of true signal to noise.

6. Geometry and Coordinates

In the foregoing discussions in this section we have been able to avoid detailed discussions of geometry and coordinates. Let us now discuss these explicitly so further equations can be discussed in more 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 II-8 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 orientation of the x_e-y_e-z_e system with respect to the Y-geometry is shown in Figure II-8, where dots along each arm of the Y show the station positions for any one of the standard (A, B, C, or D) configurations. An example of station positions $\underset{\sim}{L}_j$ and $\underset{\sim}{L}_k$, with the resultant baseline vector 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 $< \alpha$ and $\phi = 360^{\circ} - H$ for LST $> \alpha$.

The sky-oriented coordinate system as shown in Figure II-8 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,

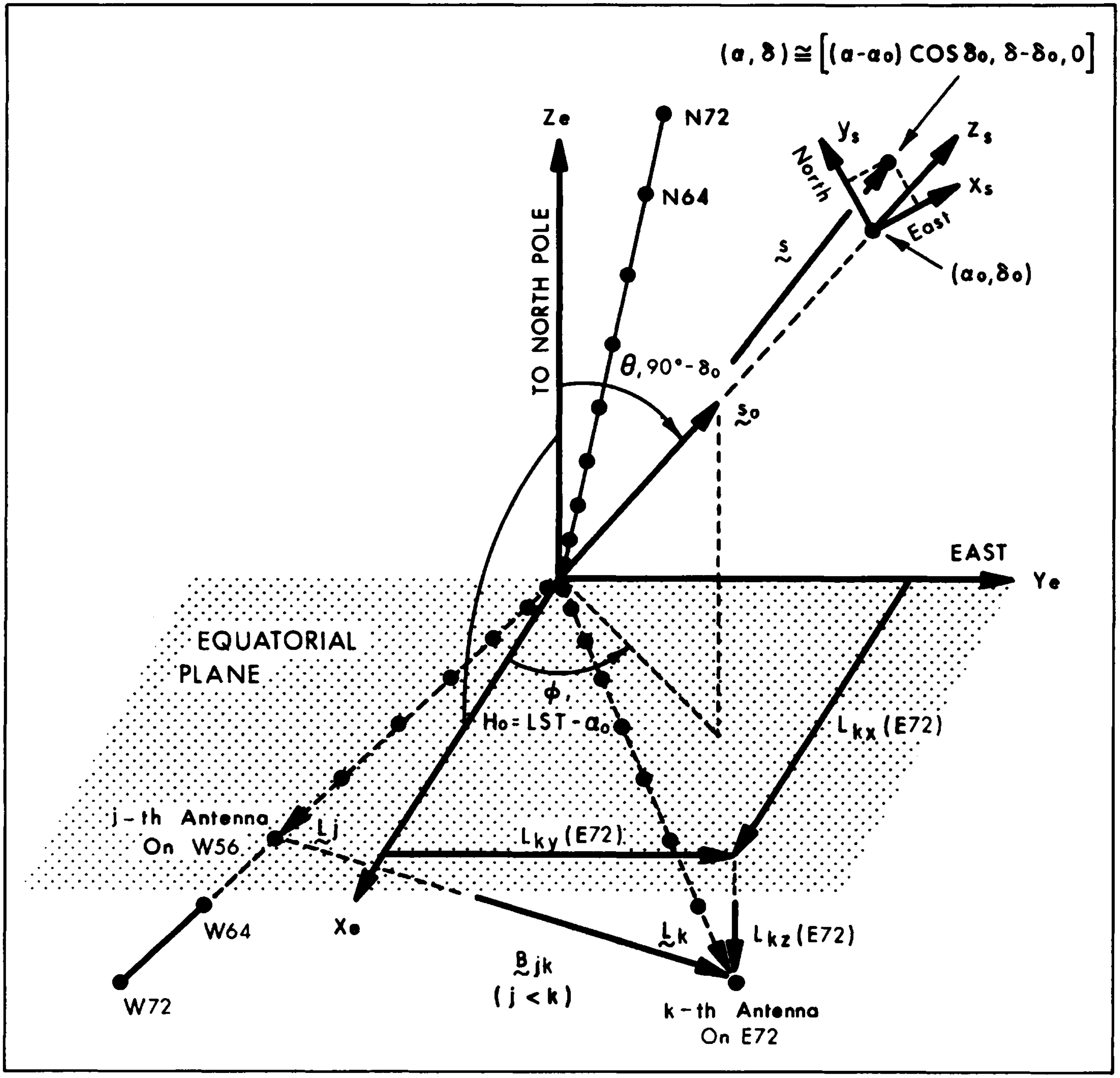


Figure II-8. The geometric relationships between antenna locations on the VLA wye and the earth- and sky-oriented coordinate systems.

$$\underset{\sim}{s} = \begin{bmatrix} \cos H \cos \delta \\ -\sin H \cos \delta \\ \sin \delta \end{bmatrix}_e \qquad \text{(II-53)}$$

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 $H_o = \mathrm{LST} - \alpha_o$. In the earth-oriented system, the station position of the j-th antenna, as shown in Figure II-8, is given by

$$\underset{\sim}{L}_j = (L_{jx}, L_{jy}, L_{jz})_e \quad . \qquad \text{(II-54)}$$

The transformation matrix to go from a vector in the earth-oriented system to the same vector described in the Cartesian sky-oriented system is

$$M_{\text{earth-sky}} = \begin{bmatrix} \sin H & \cos H & 0 \\ -\sin \delta \cos H & \sin \delta \sin H & \cos \delta \\ \cos \delta \cos H & -\cos \delta \sin H & \sin \delta \end{bmatrix} \qquad \text{(II-55)}$$

so that, for example,

$$\underset{\sim}{L}_j = \begin{pmatrix} u_j \\ v_j \\ w_j \end{pmatrix} = \begin{bmatrix} \sin H & \cos H & 0 \\ -\sin \delta \cos H & \sin \delta \sin H & \cos \delta \\ \cos \delta \cos H & -\cos \delta \sin H & \sin \delta \end{bmatrix} \begin{bmatrix} L_{jx} \\ L_{jy} \\ L_{jz} \end{bmatrix}_e \qquad \text{(II-56)}$$

Equation II-56 gives

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

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

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

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

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.

A position (x,y,z) in the sky-oriented system corresponding to a position (α,δ) on the celestial sphere is given by

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

and for the cases where the tangent plane approximation to the celestial sphere is valid,

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

Most of this discussion has occurred so we can now write explicit expressions for the vector product $(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o)$, i.e.,

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

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

$$= ux + vy + wz$$

where $u_{jk} = u_k-u_j$, $v_{jk} = v_k-v_j$, and $w_{jk} = w_k-w_j$; and 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 where the tangent plane approximation to the celestial sphere is valid, we have

$$(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o) \cong u_{jk}x + v_{jk}y = ux + vy \quad . \tag{II-63}$$

Because we will need to be careful about when we use Equation II-62 and when the approximate Equation II-63 is sufficient, let us evaluate the conditions under which the wz term can be neglected. From Equation II-60 it can be shown that

$$z = (1-x^2-y^2)^{\frac{1}{2}} \cong -\tfrac{1}{2}(x^2+y^2) \tag{II-64}$$

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

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

where $\Theta^2 = x^2 + y^2$. Letting $w = B/c$, and putting B in kilometers and Θ in arcminutes

$$\phi_z = \frac{53^\circ}{\lambda_{cm}} \left(\frac{B_{km}}{35}\right) \Theta^2_{arcmin} \tag{II-66}$$

where B_{km} will range up to 35 and Θ will typically range up to either Θ_{HPBW} (c.f. Equation II-1) or the delay beamwidth caused by use of finite band passes,

$$\Theta_{delay} \cong 1!2 \left(\frac{50}{\Delta\nu_{MHz}}\right) \left(\frac{35}{B_{km}}\right) \quad , \tag{II-67}$$

depending upon which is smaller. For the two cases

$$\Theta^{max} = \Theta_{HPBW} < \Theta_{delay}, \; \phi_z^{max} = 38^\circ \lambda_{cm} \left(\frac{B_{km}}{35}\right) \tag{II-68}$$

and

$$\Theta^{max} = \Theta_{delay} < \Theta_{HPBW}, \; \phi_z^{max} = \frac{18^\circ}{\lambda_{cm}} \left(\frac{35}{B_{km}}\right) \left(\frac{50}{\Delta\nu_{MHz}}\right) \tag{II-69}.$$

7. Visibility Function for a Point Source

Let I, Q, U, and V_{circ} 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 II-45 and II-48 with Equations II-56 and II-62, the four corrected, calibrated correlator visibilities for this point source can be written as

$$V_{jkLL} = (I + V_{circ}) \exp \left[i\omega_o(ux + vy + wz)\right] \tag{II-70}$$

$$V_{jkRR} = (I - V_{circ}) \exp \left[i\omega_o(ux + vy + wz)\right] \tag{II-71}$$

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

and

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

neglecting noise effects, where ϕ_p is the parallactic angle given by Equation II-25, $(\underset{\sim}{s}-\underset{\sim}{s}_o) = (x,y,z)$, 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 $V_{jkV_{circ}}$, then

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

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

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

and

$$V_{jkV_{circ}} = V_{circ} \exp \left[i\omega_o(ux + vy + wz)\right] \tag{II-77}$$

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 many cases where 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 (II-74) - (II-75) the functional forms of the others are the same. Equation II-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 II-37, 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 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 $d\alpha d\delta$. 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

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

therefore, the infinitesimal solid angle $d\alpha d\delta$ can be considered to make an infinitesimal contribution to the flux density of $I_\nu(\alpha,\delta)d\alpha d\delta$. If we further define $f_{ant}(\alpha-\alpha_o,\delta-\delta_o)$ to be the normalized antenna sensitivity pattern, the contribution of the solid angle $d\alpha d\delta$ to the visibility function is given by the following generalization of Equation II-74:

$$dV_{jkI}(\alpha,\delta) = f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)\ \exp\ [i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o)]d\alpha d\delta \tag{II-79}$$

where for convenience we now drop the frequency subscripts. Integrating Equation II-76 over the antenna beam, we get the integrated or total visibility

$$\boxed{V_{jkI} = \iint f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)\ \exp\ [i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o)]d\alpha d\delta} \quad . \tag{II-80}$$

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

Equation II-80 is the complex Fourier transform of the apparent intensity distribution $f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$. It is because of this that <u>we can describe any single complex visibility measurement as a single Fourier component of $f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$.</u> Because Equation II-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 $f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta)$ from VLA data by the Fourier inversion integral

$$f_{ant}(\alpha-\alpha_o,\delta-\delta_o)I(\alpha,\delta) = \iiint V_I \exp\left[-i\omega_o(\underset{\sim}{L}_k-\underset{\sim}{L}_j)\cdot(\underset{\sim}{s}-\underset{\sim}{s}_o)\right]dudvdw \quad . \qquad \text{(II-81)}$$

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

$$V_I(u,v,w) = \iint f_{ant}(x,y)I(x,y) \exp\left[i\omega_o(ux+vy+wz)\right]dxdy \qquad \text{(II-82)}$$

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

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

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

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

$$
\begin{aligned}
f_{ant}(x,y)I(x,y) = & \sum_{\substack{\text{measured} \\ u,v,w}} [V_I(u,v,w)e^{-i\omega_o(ux+vy+wz)} \\
& \quad + V_I^*(u,v,w)e^{i\omega_o(ux+vy+wz)}]\Delta u\Delta v\Delta w \\
& + \sum_{\substack{\text{unmeasured} \\ u,v,w}} [V_I(u,v,w)e^{-i\omega_o(ux+vy+wz)} \\
& \quad + V_I^*(u,v,w)e^{i\omega_o(ux+vy+wz)}]\Delta u\Delta v\Delta w \quad .
\end{aligned}
\tag{II-84}
$$

In Equation II-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 II-83 and II-84 to be real. We have also conceptually separated measured and unmeasured visibilities and assumed $z \cong -(\frac{1}{2})(x^2+y^2)$.

9. 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,

$$u = u_k - u_j = (L_{kx} - L_{jx}) \sin H + (L_{ky} - L_{jy}) \cos H \tag{II-85}$$

and

$$v = v_k - v_j = \sin \delta [-(L_{kx} - L_{jx}) \cos H + (L_{ky} - L_{jy}) \sin H$$

$$+ (L_{kz} - L_{jz}) \cos \delta] \quad , \tag{II-86}$$

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

$$\frac{u^2}{a^2} + \frac{(v - v_o)^2}{b^2} = 1 \tag{II-87}$$

which is the equation for an ellipse, where

$$a = \sqrt{(L_{kx} - L_{jx})^2 + (L_{ky} - L_{jy})^2} \quad , \tag{II-88}$$

$$b = a \sin \delta \quad , \tag{II-89}$$

and

$$v_o = (L_{kz} - L_{jz}) \cos \delta \quad . \tag{II-90}$$

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 $\delta = 80^o$, 60^o, 40^o, 20^o, 0^o, -20^o, and -40^o in Figure II-9. The ellipses shown in Figure II-9 are for continuous, elevation limit to elevation limit tracking for $\delta < 64^o$ and 24^h tracking for $\delta > 64^o$. 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 II-9.

Examination of Figure II-9, 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.

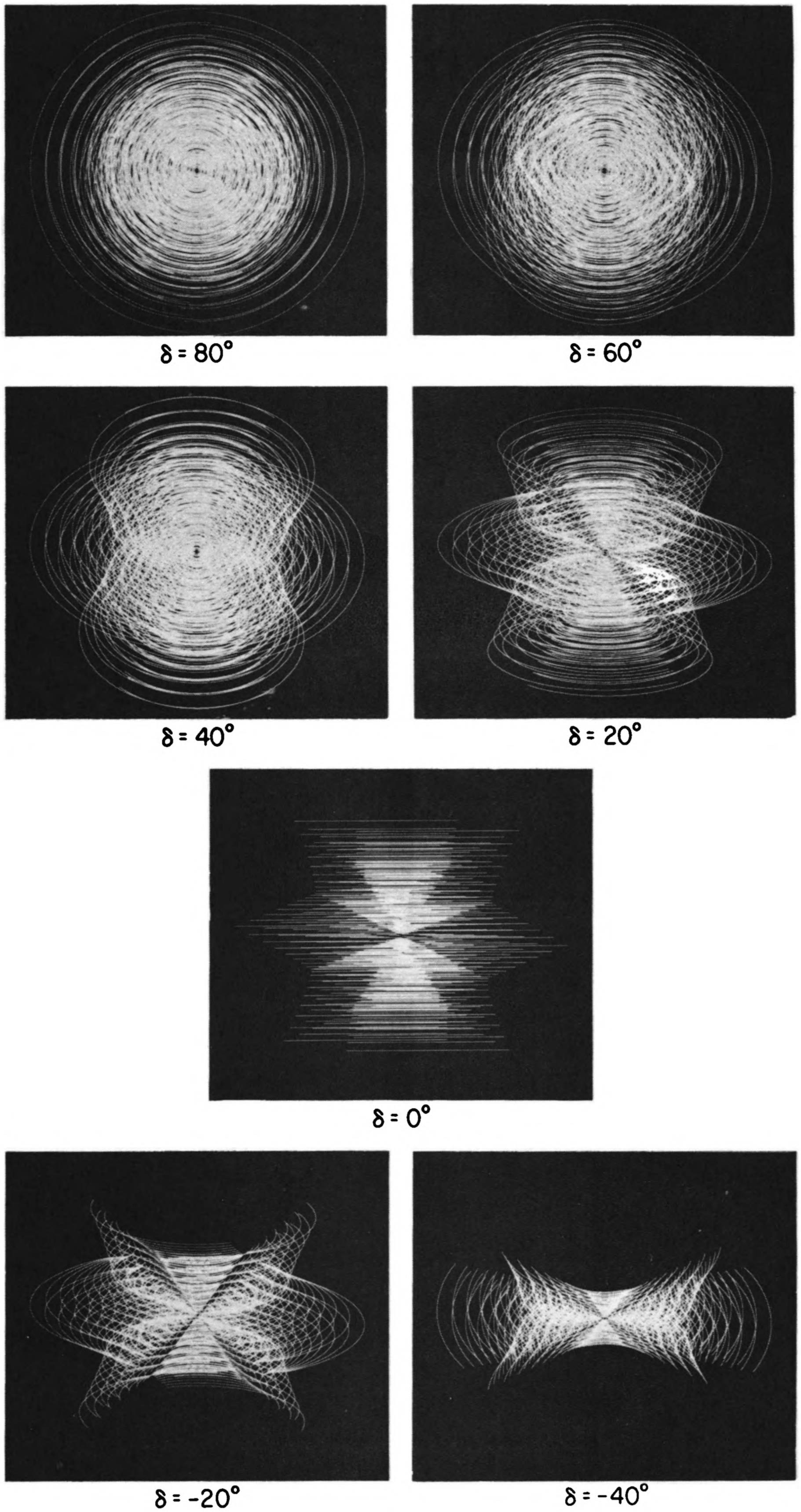


Figure II-9. The possible u-v plane coverage for the 27-antenna VLA for declinations of 80°, 60°, 40°, 20°, 0°, -20°, and -40°.

10. 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 II-84 dealing with nonmeasured visibilities and approximating f(x,y)I(x,y) by

$$f(x,y)I(x,y) \cong \frac{\sum\limits_{\substack{\text{measured}\\ u,v}} [V_I e^{-i\omega_o(ux+vy+wz)} + V_I^* e^{i\omega_o(ux+vy+zw)}]W(u,v)T(u,v)}{\sum\limits_{\substack{\text{measured}\\ u,v}} W(u,v)T(u,v)} \qquad \text{(II-91)}$$

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,

$$T(u,v) = \exp\ [-u/u_{taper})^2 - (v/v_{taper})^2] \qquad \text{(II-92)}$$

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

Radio image reconstruction using Equation II-91 has some advantages, but is computationally expensive. In general, it is used only for mapping very small regions where reduction of aliasing and exact computation of the radiation distribution on the celestial sphere is desirable.

11. Point Source Images for the Full VLA

We know the visibility function for a point source from Equation II-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

$$f(x,y)I(x,y) \cong \frac{\sum\limits_{\substack{\text{measured}\\u,v,w}} 2S_\nu \cos\left[\omega_0(ux+vy+wz)\right]W(u,v)T(u,v)}{\sum\limits_{\substack{\text{measured}\\u,v,w}} W(u,v)T(u,v)} \tag{II-93}$$

which is obtained from Equation II-91 for a point source at the reference position.

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 $\delta = 60^\circ$, 30°, 0°, and -30°, are then shown in Figure II-10. The central beams in Figure II-10 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 II-11 shows an instantaneous u-v plane distribution and synthesized beam for a source at $\delta = 30^\circ$, H = 0. The principal sidelobe level in this map, made with uniform weighting, is 27%. More extensive observing

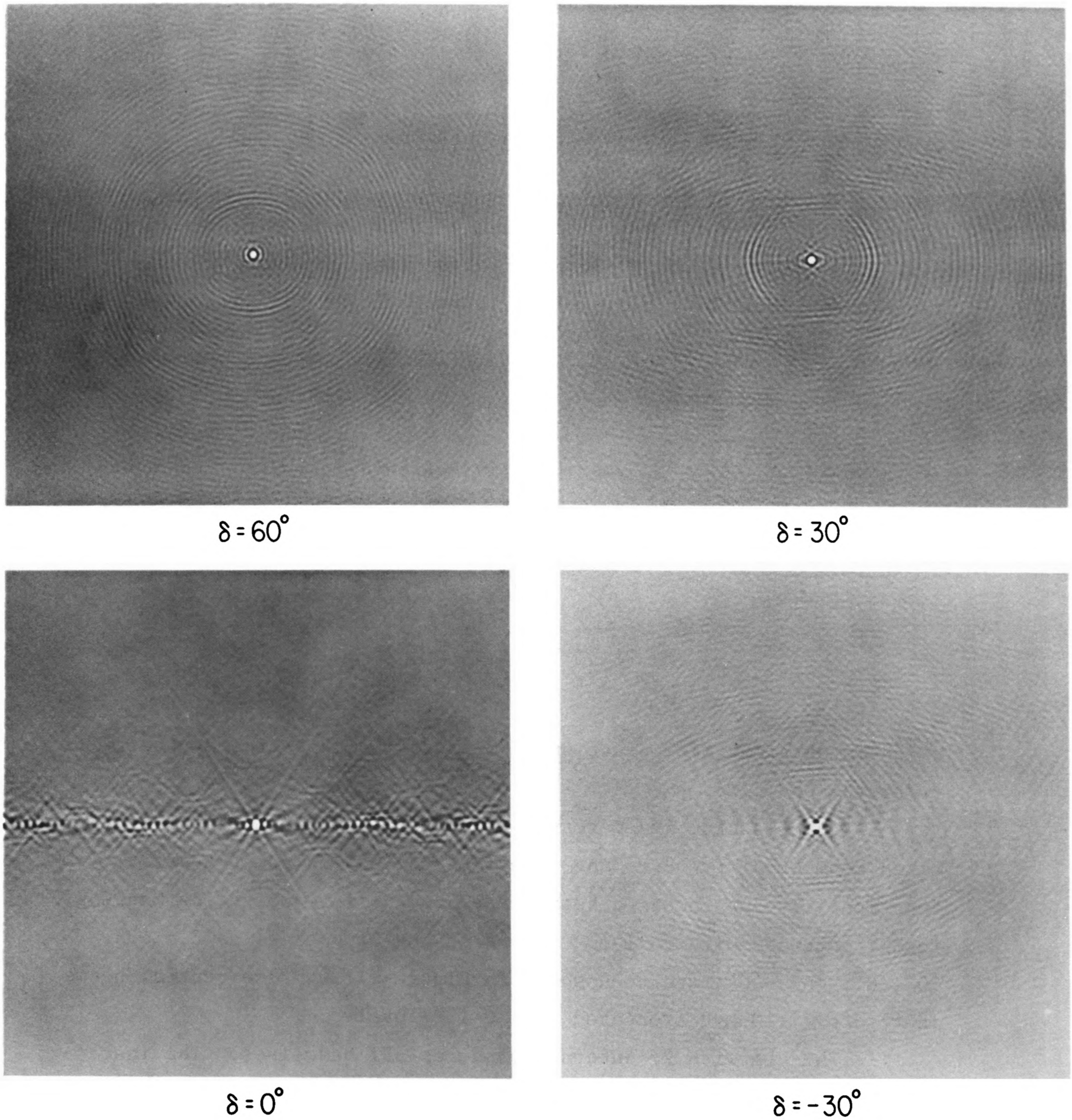


Figure II-10. The synthesized beams for full tracking coverage of the 27-antenna VLA for a number of declinations. The main beam has been truncated to the 90% level to allow sidelobe patterns to be more visible.

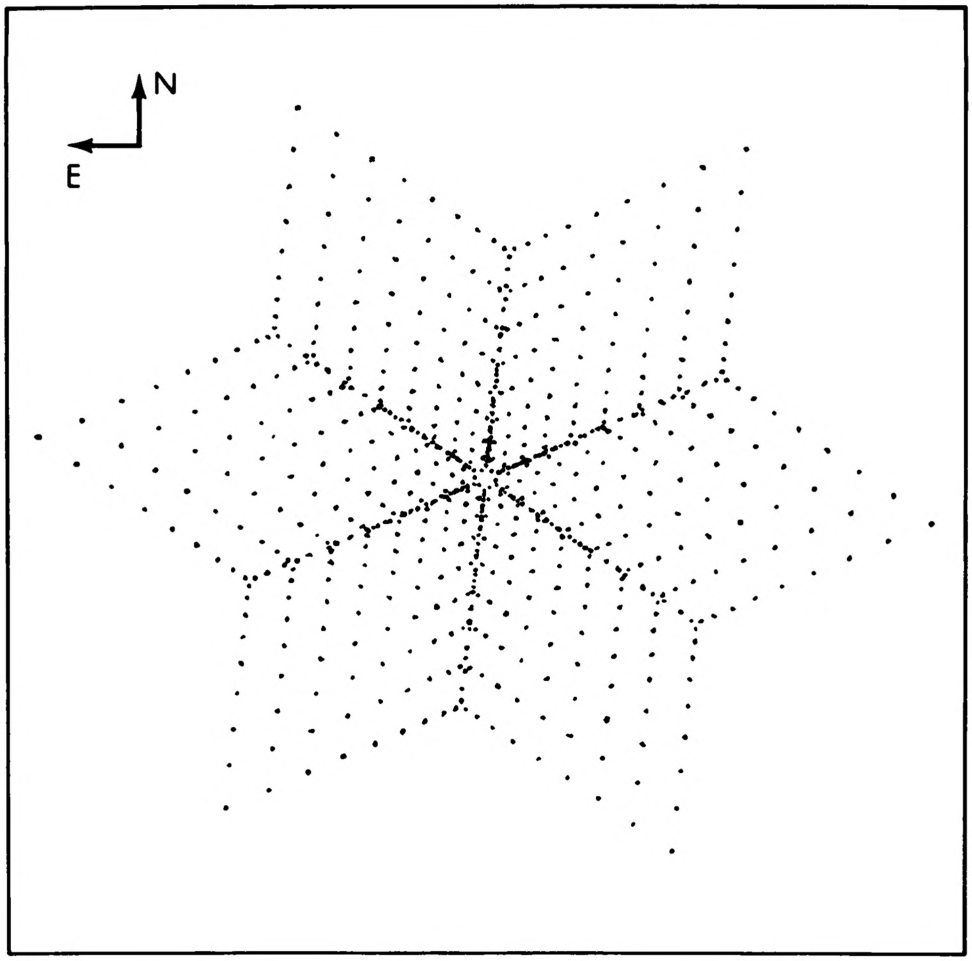
of sources at this declination will result in improved beam shape and lower sidelobes. For example, Table II-2 shows the decrease of maximum sidelobe level in the inner one-fourth and outer three-fourths of the beam as data on a source at $\delta = 30^{o}$ increases.

Table II-2

Sidelobe Levels for $\delta = 30^{o}$ 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 II-12 shows the change in beam shape for the $\delta = 30^{o}$ buildup map, showing the map with fifteen minutes, one hour, two hours, six hours, and twelve hours of integration time.



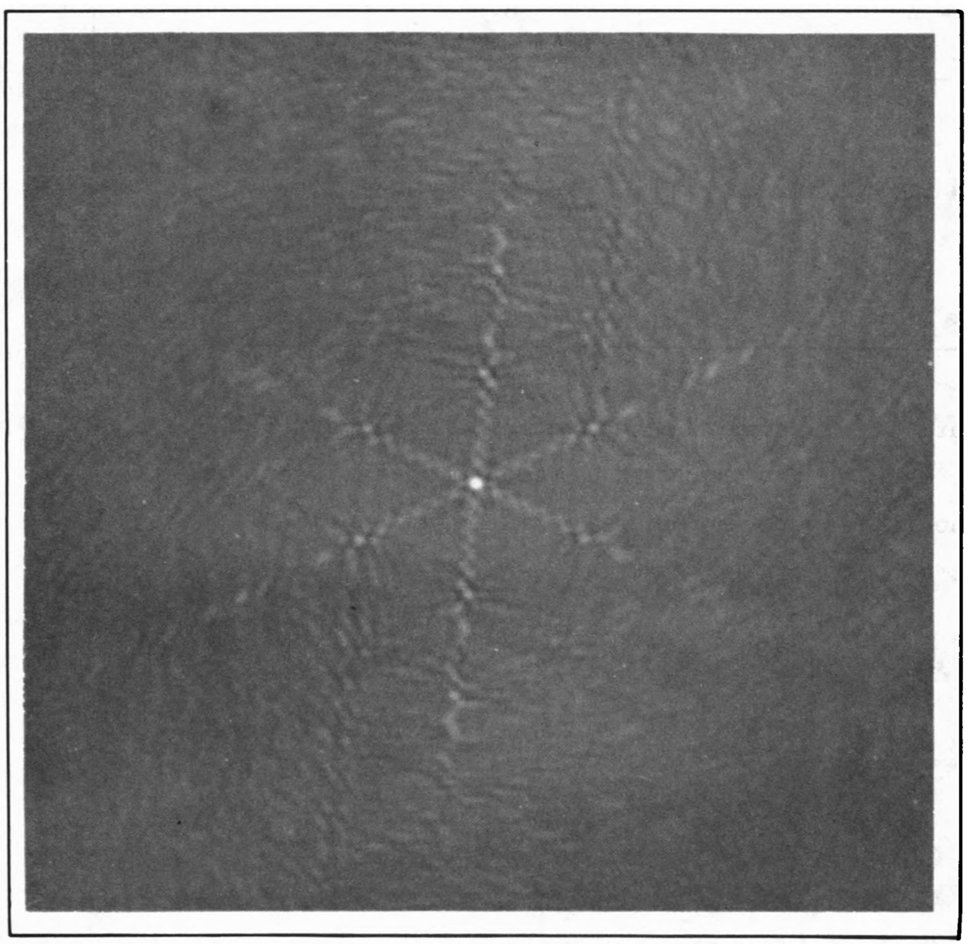


Figure II-11. The u-v plane coverage and synthesized beam for an instantaneous sampling of data for a source at $\delta = 30^{o}$ and $H = 0$ for a 27-antenna VLA.

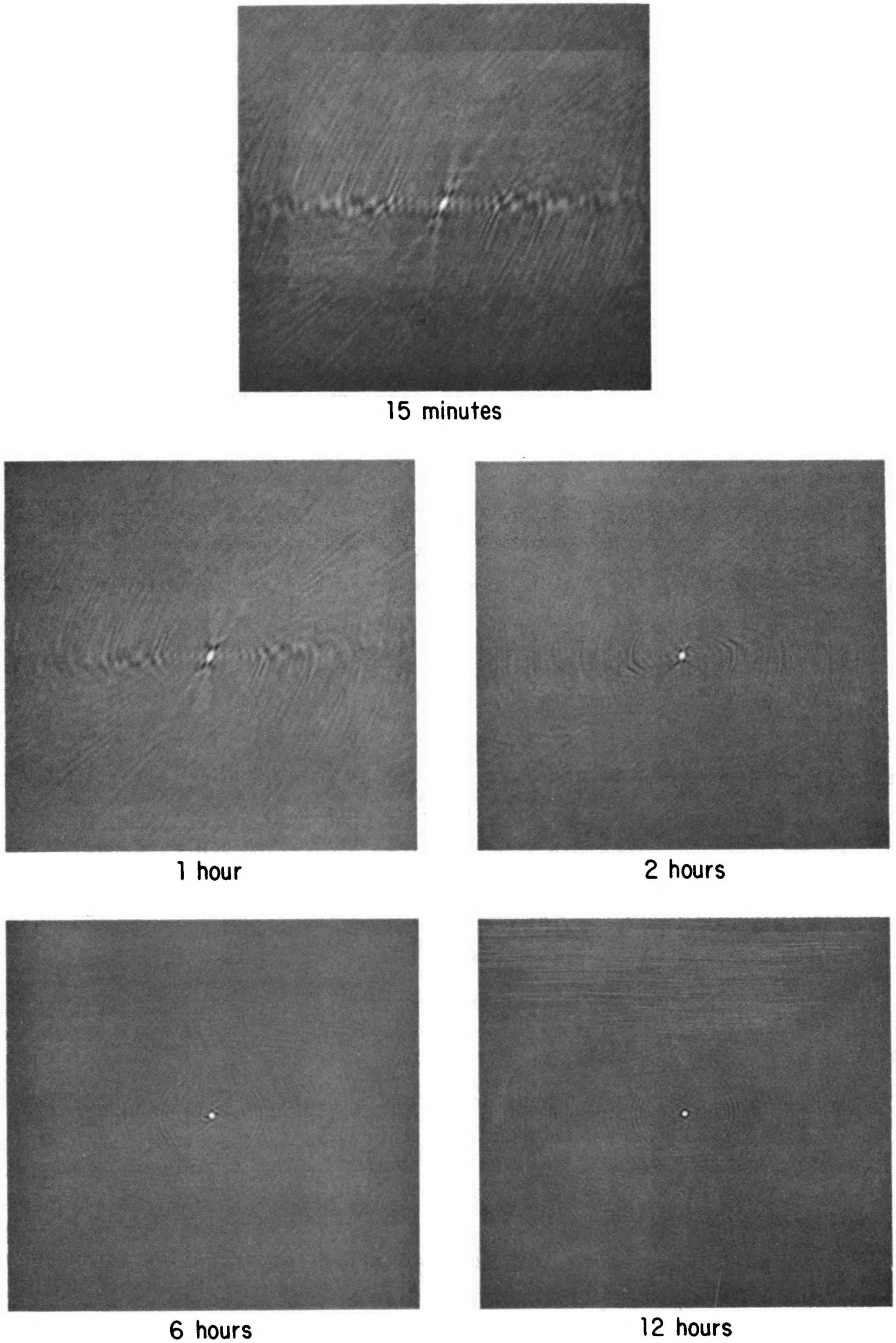


Figure II-12. The changing synthesized beam patterns for a buildup map made from data continuously added to maps of a source at $\delta = 30^{o}$, observed from $H = -6^{h}$ to $H = +6^{h}$ with a 27-antenna VLA.

12. 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 $N_x \cdot N_y \cdot N_{uv}$ 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,

$$V_{true}(u,v) = \overline{I_{true}(x,y)} \tag{II-94}$$

and

$$I_{true}(x,y) = \overline{V_{true}(u,v)} \quad . \tag{II-95}$$

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

$$V(u,v) = V_{true}(u,v) \cdot W(u,v) \quad , \tag{II-96}$$

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

$$W(u,v) = \sum_{i=1}^{N_{uv}} W_i T_i{}^2 \delta(u-u_i, v-v_i) \quad . \qquad \text{(II-97)}$$

In Equation II-97 the weight W_i and taper T_i are those for the i-th of the N_{uv} measured (u_i, v_i) in a real observing situation.

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

$$V_{grid} = III(u,v) \cdot \left\{ C(u,v) * (V_{true} \cdot W) \right\} \qquad \text{(II-98)}$$

where * indicates convolution, C(u,v) is a convolution function, and

$$III(u,v) = \sum_{\ell=1}^{N_x} \sum_{m=1}^{N_y} \delta(u,u_\ell)\delta(v-v_m) \qquad \text{(II-99)}$$

is a rectangular sampling function which has nonzero values only on the grid points $(u_\ell u_m)$ of a rectangular array of size N_x x N_y, where both N_x and N_y are powers of two.

The radio image or map is obtained from the Fourier transform of V_{grid}, so from Equations II-94 and II-99 we get

$$I(x,y) = \overline{III} * \left\{ \overline{C} \cdot (I_{true} * \overline{W}) \right\} \qquad \text{(II-100)}$$

after judicious use of the convolution theorem for Fourier transforms

$$\overline{A*B} = \overline{A} \cdot \overline{B} \qquad \text{(II-101)}$$

or its close relative

$$\overline{A \cdot B} = \overline{A} * \overline{B} \quad . \qquad \text{(II-102)}$$

The point spread function or synthesized beam corresponding to II-100 is

$$I_{beam}(x,y) = \overline{III} * \left\{ \overline{C} \cdot \overline{W} \right\} \qquad \text{(II-103)}$$

taking $I_{true}(x,y) = {}^2\delta(x=0,y=0)$.

The function $\overline{W}$ 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 effect of convolution with $\overline{III}$ is to introduce aliasing. Aliasing is an effect whereby the entire apparent radio sky, when divided into rectangular grids of the size being mapped, appears with all such grids superimposed in the radio image or map being computed. 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 $\overline{C}(x_a,y_a)/\overline{C}(x_m,y_m)$ 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; however, the computing time is 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, and the result is 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 is not very well attenuated when box convolution is used.

13. 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

$$\Theta_{HPBW} = 1.24\ (\lambda/B)\ \text{radians} \quad . \qquad \text{(II-104)}$$

Let us denote the number of points per synthesized beam by N_{pts} and the size of a radio map by $N_x \times N_y$. The number of points in a map can then be derived from N_{pts} times the ratio of Θ_{HPBW} for a VLA antenna (Equation II-1) and the Θ_{HPBW} for a synthesized aperture of size B_{km} (Equation II-104), e.g.,

$$N_x = 36\ N_{pts} B_{km} \quad . \qquad \text{(II-105)}$$

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 II-105 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 II-3 gives the map sizes for N_{pts} = 2 and 4 for cases where the aperture diameter is taken as the arm length of each configuration.

Table II-3

Map Sizes for Different Configurations

Configuration	B_{km}	N_x or N_y	
		N_{pts} = 2	N_{pts} = 4
A	21	1510	3024
B	6.4	460	920
C	1.95	140	280
D	0.60	43	86

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 the dimensions of arm lengths by taking N_x or N_y equal to 4096, 1024, 512, and 128 for the A, B, C, and D configurations. 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.

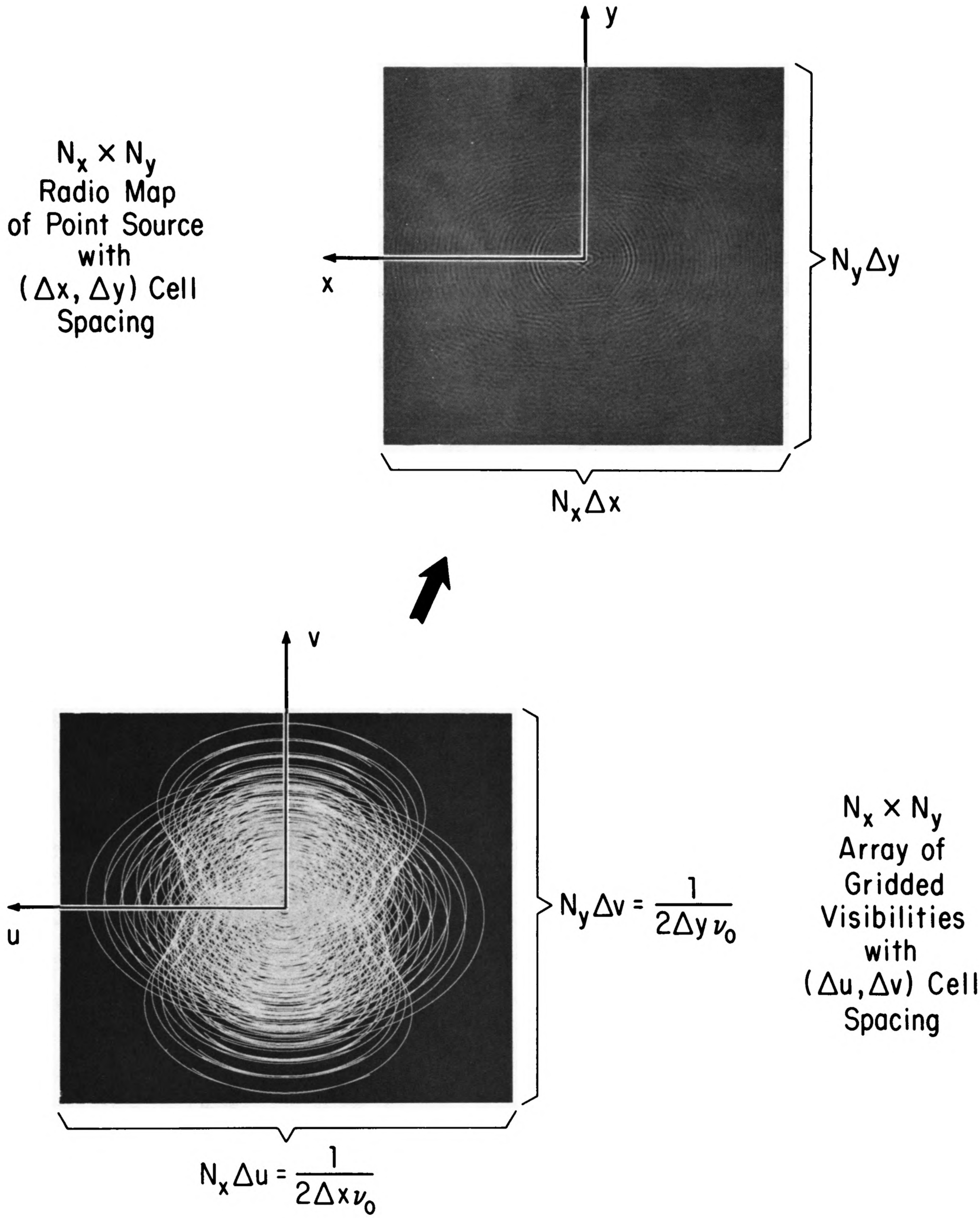


Figure II-13. The relation between a gridded u-v plane, for the 27-antenna VLA observing a source at $\delta = 40^{\circ}$, and the corresponding point source image map.

14. 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, i.e.,

$$\Delta u = \frac{1}{2 N_x \Delta x \nu_o} \tag{II-106}$$

and

$$\Delta v = \frac{1}{2 N_y \Delta y \nu_o} \tag{II-107}$$

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 $\delta = 40^o$ and the corresponding radio map of a point source is shown in Figure II-13.

If we select B_{km} to be the size of the u-v plane aperture we grid for mapping, then $N_x \Delta uc = 10^5\ B_{km}$, and Equations II-102 and II-103 can be used to obtain

$$\Delta x = \Delta y = 1''\!.03\ \lambda_{cm}/B_{km} \tag{II-108}$$

for the map cell size.

CHAPTER III

THE VLA ELECTRONICS SYSTEM

1. Introduction

The VLA electronics system was conceptually designed by S. Weinreb in 1972-1973. This design was further developed by members of the VLA Electronics Division. The objective is 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 usually called the 20 cm, 6 cm, 2 cm, and 1.3 cm bands, respectively. The same four bands are sometimes designated by the letters L, C, U (for Ku), and K, respectively. Three principal functions are performed in the VLA electronics system: (1) production and delivery of correlator visibility data every 312 ms for four polarizations and four frequency bands from all N(N-1)/2 pairs of N antennas; (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 III-1. 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 determine which of the four positions of the rotatable, asymmetric subreflector is to be used to select the desired feed and frequency band. Radio frequency (RF) signals from each feed are sent

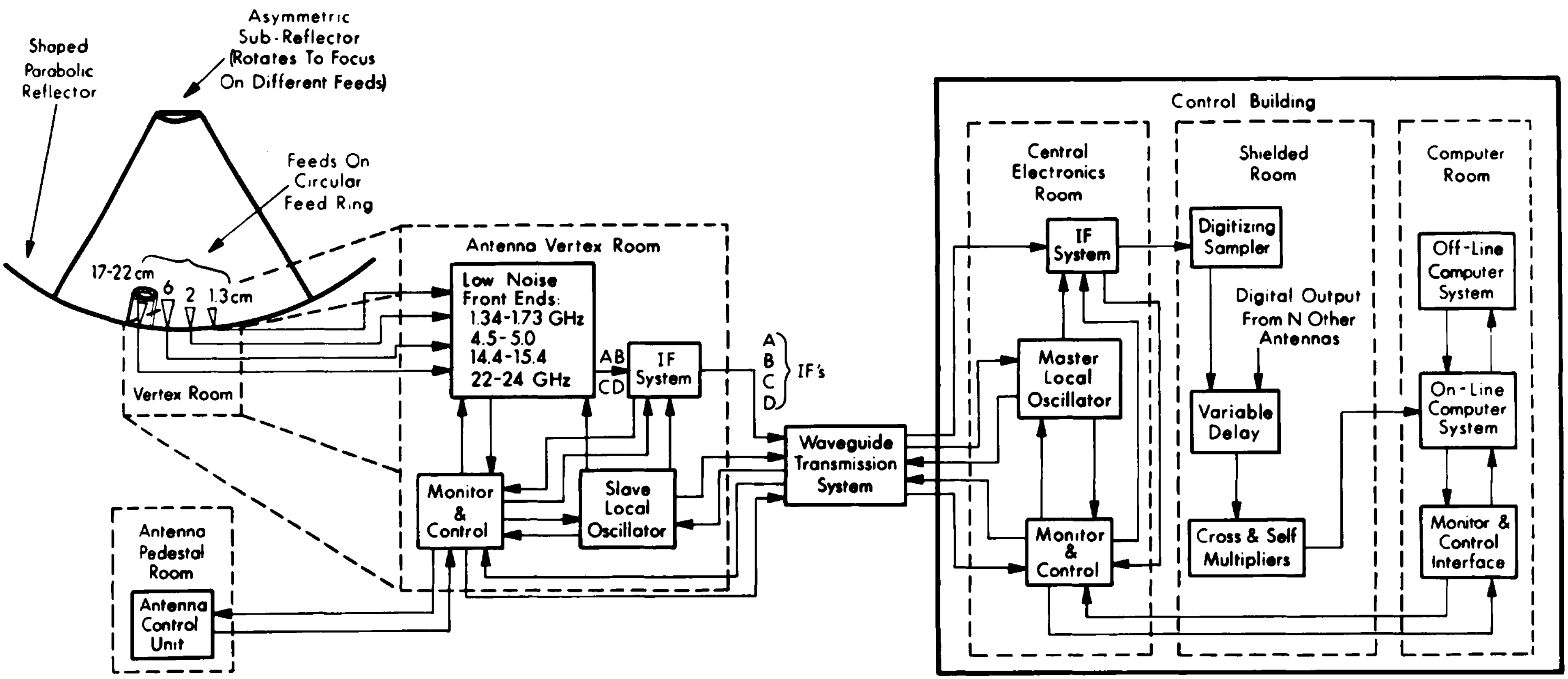


Figure III-1. A simplified schematic diagram showing the major components of the VLA electronics system and their location and relation to other systems.

via waveguide to the antenna vertex room where they are fed into low noise front ends. The parameters of these front ends, together with other parameters of the four bands, are given in Table III-1.

Table III-1

Parameters of the Four VLA Frequency Bands

VLA Bands	Wavelength	Radio Astronomy Band	System Temperature (T_{sys})	Antenna Efficiency (ε_a)
1.34- 1.73GHz	17 -22 cm	1.400- 1.427GHz	60° K	50%
4.5 - 5.0 GHz	6.0 - 6.7 cm	4.99 - 5.00 GHz	60° K	65%
14.4 -15.4 GHz	1.95- 2.08cm	15.35 -15.40 GHz	300° K	54%
22.0 -24.0 GHz	1.25- 1.36cm	23.6 -24.0 GHz	400° K	46%

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 sent from the control building, both controls the antenna and its electronics and monitors their 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 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 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 are carried by a single 60 mm waveguide line for each arm of the array. Data are communicated through the waveguide transmission system with a basic 52 ms cycle. During this 52 ms cycle there is 1 ms when control and timing data is 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 each antenna propagate in the waveguide in the so-called TE_{01} mode with the 1 to 2 GHz signals from each of the up to nine antennas multiplexed with a waveguide carrier frequency, $\nu_{carrier}$, that is different for each antenna and which ranges from 26.410 GHz to 50.410 GHz.

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 III-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 system in 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 III-1 is frequently called the serial line controller and the entire monitor and control system is frequently 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 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. As far as the antennas are concerned, the master LO system sends timing signals to each antenna slave LO; and when the same timing signals are sent back from each antenna, this provides the control building what it needs to keep tight loop control of all frequencies and timing. By comparing the phase of the timing signals sent with their phases when received from each antenna, one also obtains a measurement of the round trip phase (ϕ_{RT}) variations in the signal paths.

After passing through the control building IF system, the four channels of data from each antenna are sent on to the shielded room. The data from four channels for N antennas are sampled and digitized before undergoing variable amounts of delay that change the data from each antenna to a common time system so that all signals due to a source at the reference position in the sky seem to arrive at all antennas at exactly the same time. After delay compensation, the 4N digital signals are cross- and self-multiplied to obtain 4N(N-1) cross-correlator 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 on to the on-line computer system where each cross-multiplier output is divided by the mean of the outputs of the appropriate self-multipliers as the 196 samples per correlator are effectively vector-summed into producing a single 10 second visibility measurement. The system thus produces duplicate measurements of visibilities for four correlator polarizations for N(N-1)/2 antenna pairs in the on-line computer system, ready for whatever corrections and calibrations are applied on-line before being passed on to the off-line computer system for additional editing correction and calibration before visibility analysis, map making, and map display and analysis.

Figures III-2 through III-4 show three of the major locations of VLA electronics hardware. Figure III-2 shows the inside of the antenna vertex room as seen from the entrance door. In Figure III-2 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 portions of the waveguide plumbing 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 III-3 is a photograph of the central electronics room in the control building. The racks in the foreground contain the master local oscillator system and the monitor and control interface (serial line controller). In the center of the room are rows of D Racks. Each D Rack receives/sends signals for a particular antenna from/to the waveguide communications system. The D Rack, therefore, contains an IF combiner/divider, monitor and control modules, the electronics room IF system, 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 shown in Figure III-4 carry out sampling, delay, and multiplication before the correlator outputs for N(N-1)/2 pairs are sent every 312.5 ms 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 conceptual level of detail.

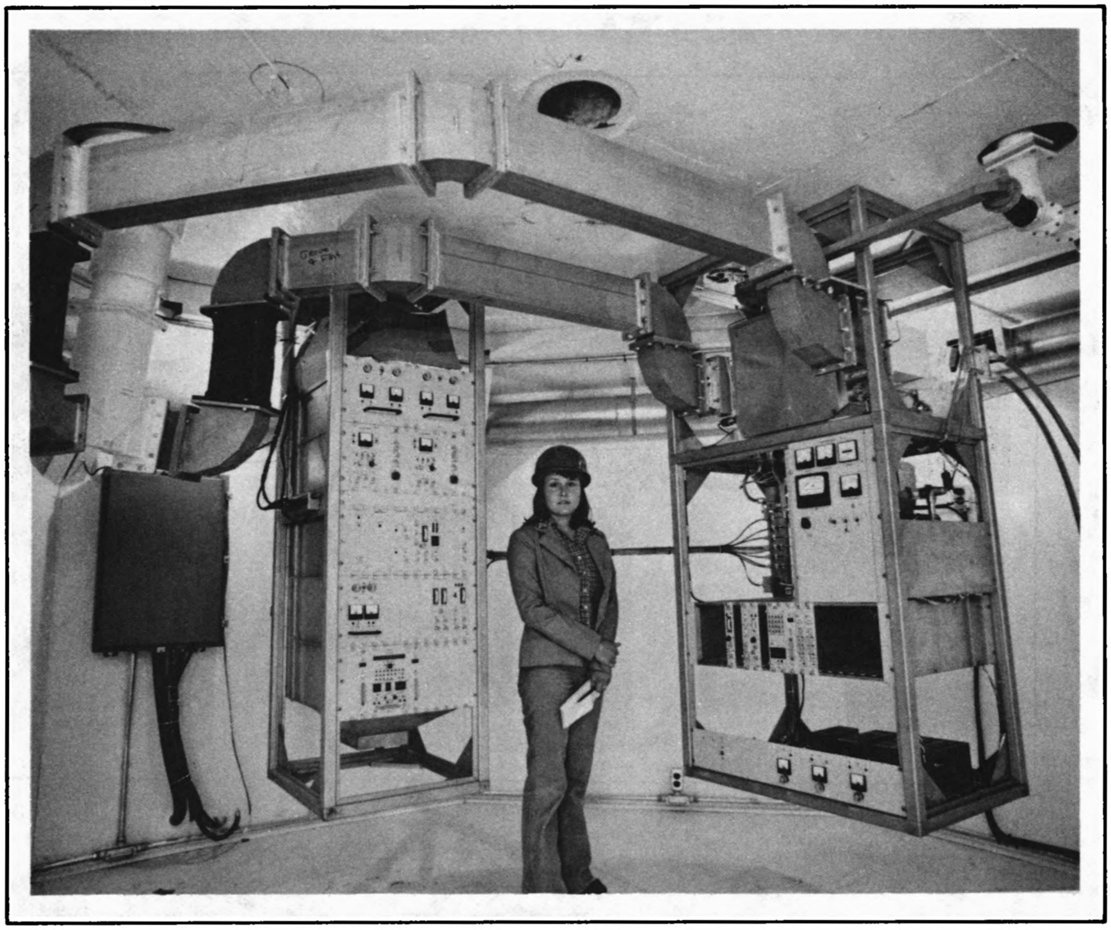


Figure III-2. A photograph of the inside of a VLA vertex room located under the Cassegrain focus of the parabolic antenna surface.

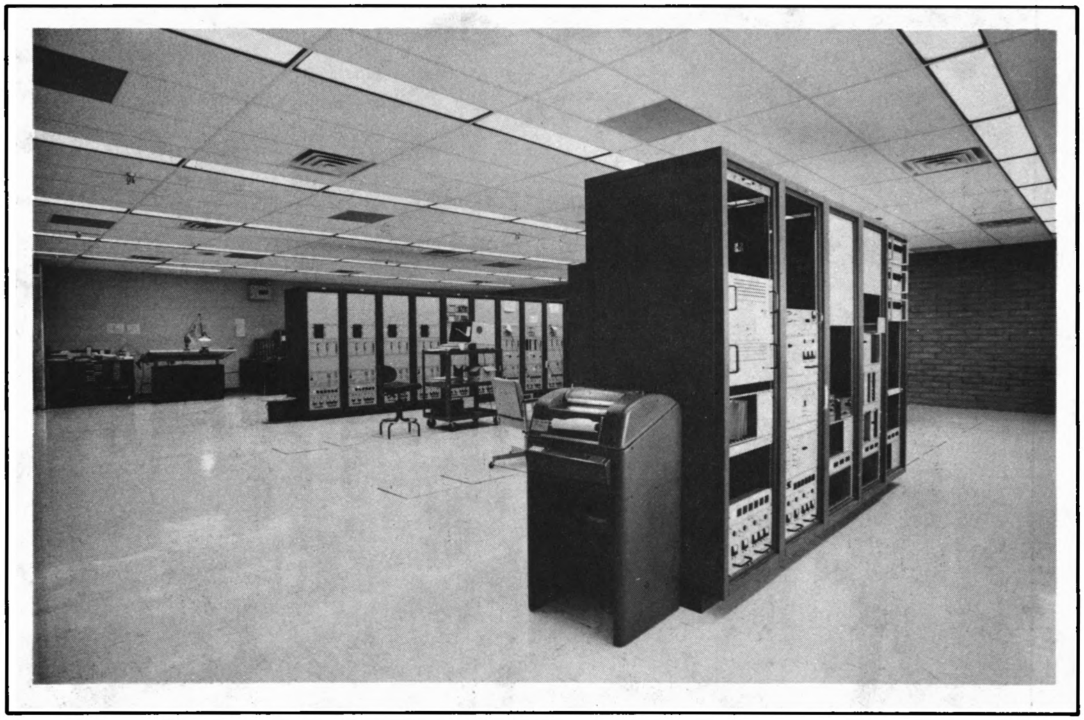


Figure III-3. A photograph of the central electronics room taken in July 1978.

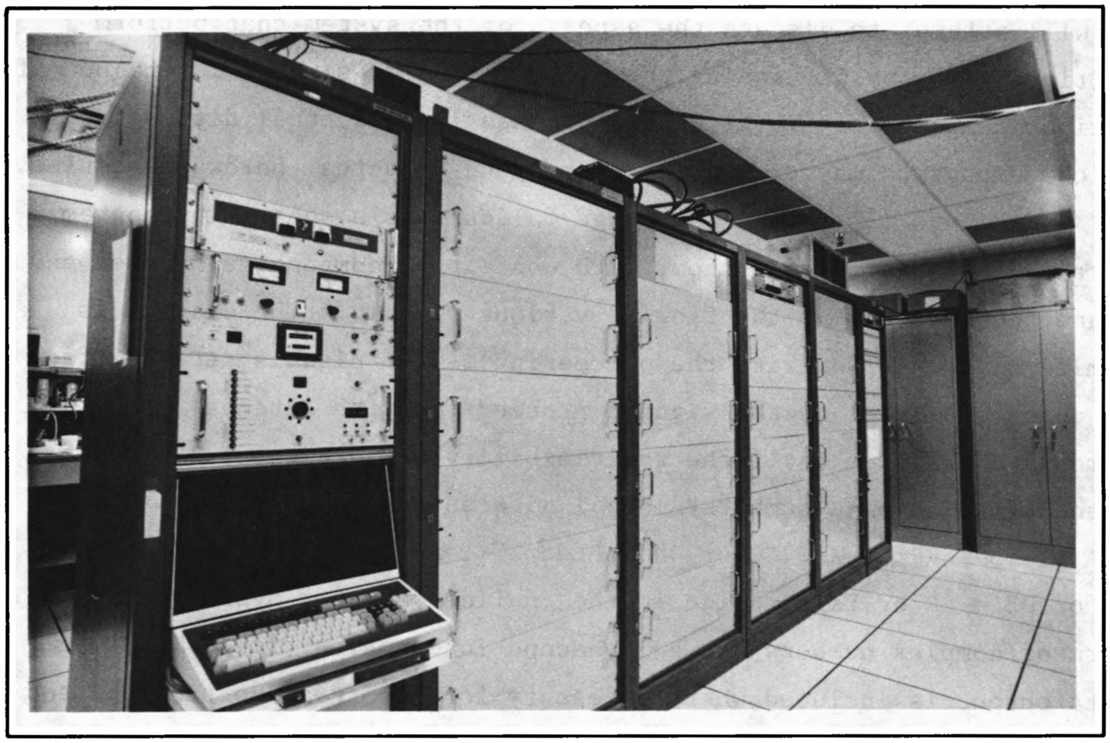


Figure III-4. A photograph of the racks in the shielded room with samplers and delay and multiplier hardware.

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 III-5, the four page foldout, is a schematic 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 necessary 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 III-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 polarization feeds. The 20 cm feed providing signals for the 1.34-1.73 GHz frequency range is a dielectric lens surrounded by waveguide elements illuminated by a horn feed. 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 feed for the 14.4-15.4 GHz range and the 1.3 cm feed for the 22-24 GHz range are multi-mode horns. After each feed, the RF signal passes through a polarization transducer or 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. Polarization transducers are changed from one type to another by physically replacing one type with another. The standard mode of operation is with 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 routed to the CD front end. Before reaching the front ends a calibration signal from 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 farther 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 proportions as the input RF signal needing calibration. The injected CAL signal has a known strength which normally contributes roughly 3% to the RF noise in the signal at the point of injection.

The combined RF and CAL signal then proceeds 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 two stage, cooled, parametric amplifier designed for amplification of 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 for amplification. The 6 cm parametric amplifier is pumped by a module outside the Dewar and sends its amplified output to a GaAs, field effect, transistor amplifier outside the Dewar. This F.E.T. amplifier provides a third stage of amplification to the 4.5-5.0 GHz RF signals.

When the RF signals originate from the 20 cm, 2 cm, or 1.3 cm feeds, they undergo a frequency conversion before being fed into the 4.5-5.0 GHz paramp. Signals in the 1.34-1.75 GHz range pass through a parametric upconverter that takes a 3.2 GHz LO signal and converts the input RF signal to a 4.54-4.93 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 are mixed with a tunable 17-20 GHz LO signal and the resulting lower sideband signal at 4.5-5.0 GHz is fed into the 6 cm paramp with the appropriate position of the coaxial switch. Finally, if the RF signals are in the 1.3 cm band, the 22-24 GHz signals are mixed with the tunable 17-20 GHz LO signal and the resulting upper sideband 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 frequently called the "band-select" switch.

After the signals leave the 6 cm paramp, subsequent frequency conversions and amplifications operate at the same frequencies, irrespective of the original RF observing frequency. The RF outputs from the nominally identical AB and CD systems in Figure III-5 are fed into a transfer switch. Depending upon the setting of the transfer switch, the AB and CD signals 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 where 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. The electronics system used in 1978 will not have the B and D IF channels implemented, and this fact is reflected in Figure III-5 by showing dashed lines for unimplemented or nonfunctioning components.

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 IF signals. The phase shift applied to the LO signal before mixing applies the equivalent of fine delay adjustment as discussed in Chapter II, 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 II, Section 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 also discussed in the same section of Chapter II.

The antenna IF system hardware in 1978 contains a mixture of an "old" design and a "new" design. In the old design, the output of the RF to IF frequency converter is at central frequencies of 1325, 1425, 1575, and 1675 MHz for A, B, C, and D channels, respectively. In the new design, all channels convert to the same IF frequency of 1025 MHz. For both designs, the IF channels after the frequency converter are then limited to bandwidths of BW = 50, 25, or 12.5 MHz. In the old design the filtered IF's are directly fed into an automatic level control (ALC) loop which sees to it that a constant power level is maintained for IF signals fed into the combiner. In the new design a 300, 400, 550, or 650 MHz LO signal is fed into a frequency offset module which 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 the ALC loop. The ν/BW notation is used here and later to denote central frequency and bandwidth of an IF signal.

There are differences in the functioning of the ALC in the old and new antenna IF systems; however, for both designs, the IF signal is measured by both a square law detector and a synchronous detector.

An inset plot in the lower central part of Figure III-5 shows the signal being measured by these two 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 (CAL) of the CAL signal that was originally injected before the front ends with a 26 ms periodicity (9.6 Hz rate). The gain of the system between the point of noise injection before the front end and the point of measurement in the ALC loop is given by

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

where the constant in Equation III-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 III-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. Basically, 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 of Figure III-2 show the frequency spectrum of the data in the send (upper center of Figure III-5) and receive (lower center of Figure III-5) cycles. Each antenna on each arm has a waveguide channel with a carrier frequency ($\nu_{carrier}$) listed in Table III-2 and in the lower central portion of Figure III-5. The send/receive spectrum covers frequencies from (1.0 GHz + $\nu_{carrier}$) to (2.0 GHz + $\nu_{carrier}$).

Table III-2

Waveguide Channels and Carrier Frequencies

Waveguide Channel	Carrier Frequency ($\nu_{carrier}$)
1	26.410 GHz
2	28.790
3	31.210
4	33.590
5	36.010
6	38.390
7	40.810
8	43.910
9	45.610
10 (spare)	47.990
11 (spare)	50.410 GHz

As shown in the lower central inset in Figure III-5, control data is sent to antennas in the form of sidebands to 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 and 5 MHz signals are derived from these signals to control the slave LO system. The upper central inset showing the spectrum of data sent down the waveguide from 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 (or less) passbands centered at (1325 MHz + $\nu_{carrier}$), (1425 MHz + $\nu_{carrier}$), (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 where the 600 MHz phase is measured and sent to the master LO system, and 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 IF signals are then mixed with tunable IF frequencies in the ranges 1260-1350 MHz, 1360-1450 MHz, 1510-1600 MHz, and 1610-1700 MHz, respectively, for the A, B, C, and D IF channels.

The resulting lower IF frequencies are between 0.2 and 50 MHz. These IF signals are then passed through final IF filtering where the available filter parameters are listed in Table III-3.

Table III-3

Final IF Filter Parameters for the 1978 and Eventual Systems

System	Bandwidth ($\Delta\nu$)	Center Frequency (ν_{IF})	Filter Type
1978	50 MHz	25 MHz	Low Pass
	12	40	Band Pass
	1.5	40	Band Pass
Eventual	50	25	Low Pass
	25	12.5	Low Pass
	12.5	6.3	Low Pass
	6.0	3.2	Low Pass
	3.0	1.65	Low Pass
	1.35	0.88	Low Pass
	0.58	0.50	Low Pass
	0.391	0.586	Hybrid
	0.195	0.29	Band Pass
	0.098 MHz	0.29 MHz	Hybrid

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 that the IF signal is fed into. These are 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 but coarse delays, plus the fine delays applied inside the samplers, constitute the total antenna delay compensation discussed in Section 2 of Chapter II. This and the phase shifting done in the antenna IF system constitute the major phase and time compensations discussed in the same section.

After delay compensation there are 4N digital inputs (A, B, C, and D channels for N antennas) to the cross- and self-multipliers. These produce 4N(N-1) cross-multiplications (AA, CC, AC, CA, BB, DD, BD, and DB for N(N-1)/2 antenna pairs) and 4N self-multiplications which are sent on to integrators, which accumulate data for every 52 ms. These are sent on to a controller which can integrate for up to 312 ms, but which mainly sends the appropriate accumulations on to the correlator data computers (CORA, CORBIN) of the on-line computer system. In these computers the cross-multiplier outputs are divided by the mean of the appropriate self-multiplier outputs as part of the process of turning the 192 52 ms measurements into a single, 10 second integration time measurement for each antenna-IF pair. This process generates

$$\underbrace{4}_{\text{Polarizations}} \times \underbrace{2}_{\substack{\text{Duplicate}\\ \text{AB,CD}\\ \text{Systems}}} \times \underbrace{N(N-1)/2}_{\substack{\text{Antenna}\\ \text{Pairs}}} = 4N(N-1)$$

measurements of V''_{jkp} every ten seconds. For N = 27, this is 2808 complex numbers and 5616 real numbers every ten seconds. Accumulated for twelve hours to make a map of an extended source, this makes 12.13×10^6 complex visibility measurements which can be reduced to 3.03×10^6 complex numbers before computing a map in a single Stokes parameter.

3. Technical Descriptions of VLA Electronics

A series of VLA Technical Reports are available, which provide more technically oriented descriptions of the VLA electronics system and its component modules. The VLA Technical Report Number 29, "An Introduction to the VLA Electronic System", provides an overview of the system, and other technical reports document individual modules of the system. The reader who wishes to obtain more technical information about the VLA Electronics System is referred to this series of Technical Reports.

CHAPTER IV

ARRAY CONTROL AND DATA ACQUISITION

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 tasks of the on-line computer system. The on-line computer system will be discussed in more detail in Section 3; however, let us briefly mention its major components so we can survey the overall problem of array control and data acquisition.

The on-line computer system has five 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; the second part is another MODCOMP minicomputer called MONTY, which runs the array communication services that handle the monitor data coming back from antennas and electronics and send out the control data or commands, originating from BOSS, which control the antennas and electronics; the third part is a MODCOMP called SPECTRA, which manages the correlator hardware; the fourth part is a Floating Point Systems array processor, which, for line data, will convert from cross-correlation function to cross-spectral function; and the fifth part consists of two MODCOMP minicomputers called CORA and CORBIN, which handle the correlator data sent from the correlator system every 312.5 ms. 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 in the hands of the on-line

Figure IV-1. A photograph of the array control room, with an operator and an observer in the foreground amongst on-line and off-line communication terminals. On-line computer system Modcomps are visible through the windows on the right.

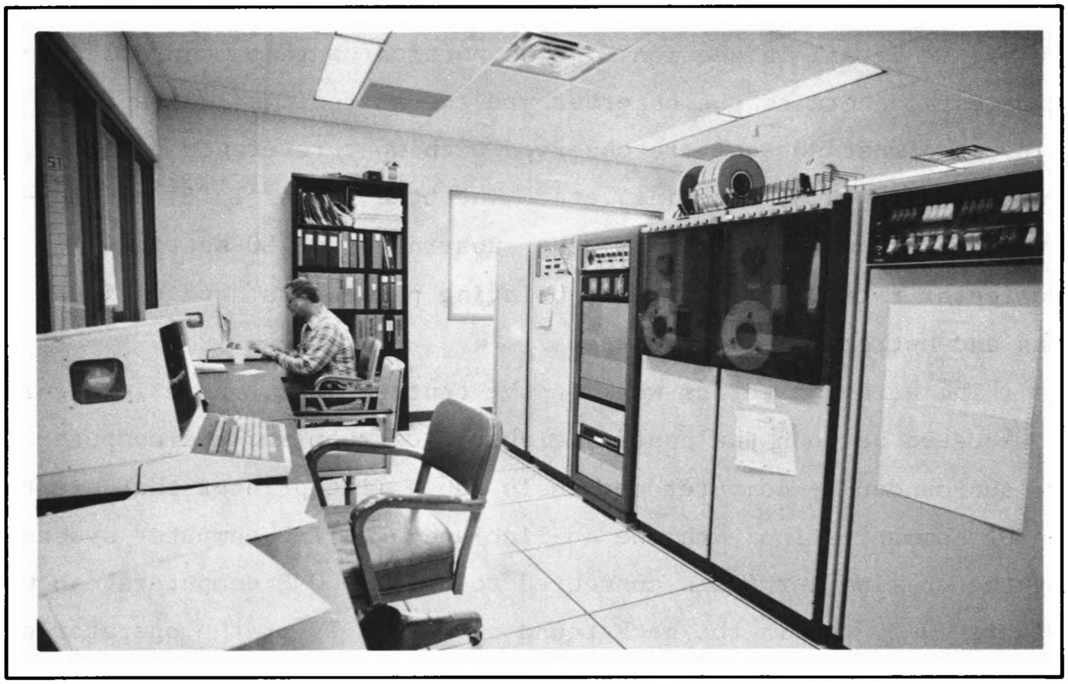


Figure IV-2. A photograph with portions of the Modcomp minicomputers of the on-line computer system located on the right. Terminals for communication with this system are seen on the left.

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 detail in Section 2. The portion of these control files of greatest concern to the observer are the source list files that specify when what sources are observed with what reference position, frequency, bandwidth, labeling, etc. The other control files determine which antennas will run in what subarrays, the LO settings, subreflector rotation parameters, pointing parameters, and various timing and astrometric parameters.

The array operators work in the control room, shown in Figure IV-1, located between the central electronics room and the computer room, surrounded by computer terminals and a line printer that are the means of communication with the on-line and off-line computer systems. Using the on-line terminals connected to the MODCOMP computers, shown in Figure IV-2, and in the background of Figure IV-1, the operator can request a range of data displays that describe the status of any part of the antenna and electronic systems, or list correlator, pointing, etc. data. The design of the system is based upon 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 for all 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 judgments. The same data allows an on-line program to assign flags which are judgments of data quality for each piece of correlator data.

Figure IV-3 is a schematic diagram illustrating the major features of the array control and data acquisition system. In the upper central portion of Figure IV-3 the terminals and line printer

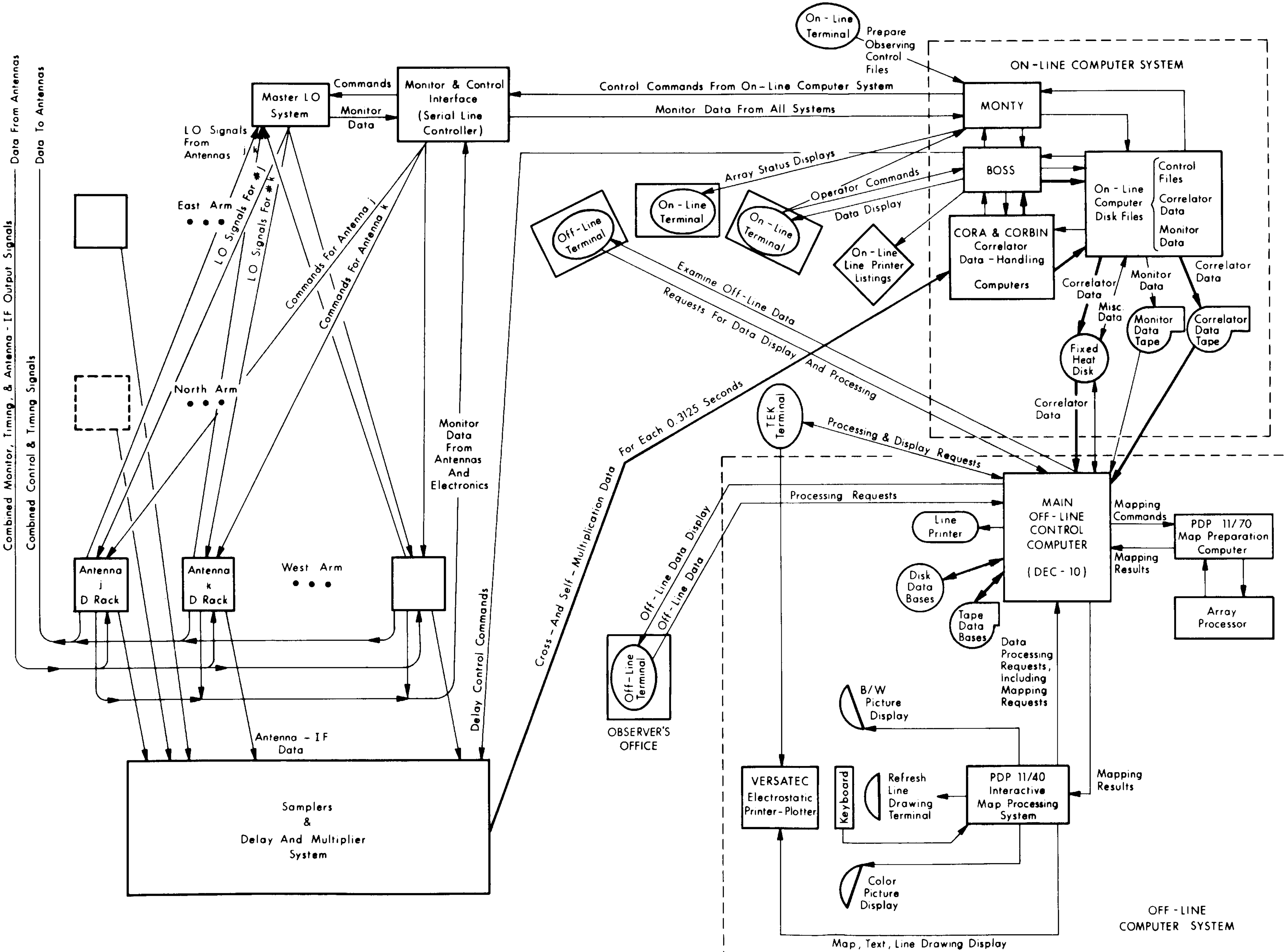

On - Line Terminal
Prepare Observing Control Files
ON-LINE COMPUTER SYSTEM
MONTY
BOSS
Control Commands From On-Line Computer System
Monitor Data From All Systems
Master LO System
Commands
Monitor Data
Monitor & Control Interface (Serial Line Controller)
LO Signals From Antennas j k
Data From Antennas
Data To Antennas
Combined Monitor, Timing, & Antenna - IF Output Signals
Combined Control & Timing Signals
East Arm
LO Signals For # j
LO Signals For # k
Commands For Antenna j
Commands For Antenna k
North Arm
West Arm
Antenna j D Rack
Antenna k D Rack
Monitor Data From Antennas And Electronics
Delay Control Commands
Antenna - IF Data
Samplers & Delay And Multiplier System
Cross - And Self - Multiplication Data For Each 0.3125 Seconds
Array Status Displays
On - Line Terminal
Operator Commands
Data Display
On - Line Terminal
On - Line Line Printer Listings
Off - Line Terminal
Examine Off - Line Data
Requests For Data Display And Processing
On - Line Computer Disk Files
Control Files
Correlator Data
Monitor Data
CORA & CORBIN Correlator Data - Handling Computers
Correlator Data
Misc. Data
Monitor Data
Correlator Data
Fixed Heat Disk
Monitor Data Tape
Correlator Data Tape
Correlator Data
TEK Terminal
Processing & Display Requests
Processing Requests
Off - Line Data Display
Off - Line Data
Off - Line Terminal
OBSERVER'S OFFICE
MAIN OFF - LINE CONTROL COMPUTER (DEC - 10)
Line Printer
Disk Data Bases
Tape Data Bases
Mapping Commands
Mapping Results
PDP 11/70 Map Preparation Computer
Array Processor
Data Processing Requests, Including Mapping Requests
B/W Picture Display
Refresh Line Drawing Terminal
Keyboard
VERSATEC Electrostatic Printer - Plotter
PDP 11/40 Interactive Map Processing System
Mapping Results
Color Picture Display
Map, Text, Line Drawing Display
OFF - LINE COMPUTER SYSTEM

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

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. On-line system disk files that control the array and provide temporary storage for monitor and correlator data are illustrated. MONTY is shown in the critical role of receiving monitor 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. MONTY also sends delay control commands to the sampler and delay systems in the shielded room. The left side of Figure IV-3 shows the major data paths to and from the waveguide transmission system together with the appropriate data paths between systems in the central 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 through the appropriate D rack, the antenna-IF data are sent to the shielded room where the samplers and delay and multiplier system produce cross- and self-correlator 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 to the correlator handling computers which normalize 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 written on magnetic tape by the on-line computers every ten seconds and on the fixed head disk where the off-line computer system reads it for processing into the DEC-10 visibility data base. Monitor data is accumulated on disk by a monitor data logging program that selects monitor data points for varying time intervals for periodic logging on MODCOMP disks and later transfer to a monitor data tape.

The major components of the off-line computer system are shown schematically in the lower right-hand portion of Figure IV-3. Because correlator data is stored in the DEC-10 data base in nearly real time, the operator and the observers can monitor the output of the array in almost as close to real time as they wish. When the system is operating reasonably well, a goal to be achieved by the time the array is in full operation, and which is often closely approached in regular operation in 1978, the observer can, if it is desirable, calibrate and make maps in the off-line computer system within an hour or so after data are taken. Many observers will wait until all data on a source is available before mapping and will typically monitor visibilities for calibrators and program sources while observing is going on.

The control of source observations is philosophically oriented toward specifying the 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 specification supplied by the observers in a source list control file. The resultant data in the off-line system are then organized according to sequential scans and this is what the user deals with in off-line data processing.

2. System Control Files

(a) Role of the Control Files

A series of files containing control information is 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 superseding control file commands. The operator can also control the sequencing of observations specified in a source list file, skipping to an object late in the list, extending the time on the current source, or even skipping back to a previous one.

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

1. ARRAY control file - Information applicable to the whole array, mainly time parameters.

2. SUBn control files - Files for n = 1, 2, ..., 5 subarrays, contains names of controlling source list files for each subarray plus parameters of LO and receiver settings that determine frequencies of operation. Contains names of files with controlling information for IFs and subreflectors.

3. ANTENNAS control file - Contains information about antenna locations, the subarray number for each antenna, delay constants, axis intersection defect parameters, and pointing parameters.

4. IF control files - Gain calibration and antenna efficiency parameters for each antenna.

5. ROT control files - Subreflector rotation and front end parameters.

6. Source list files - Sequential list of source request cards with:

   a. Source Name
   b. Source Qualifier
   c. LST stop time or duration of scan
   d. Right ascension and declination
   e. Epoch of position
   f. Observing band for scan
   g. Observing mode
   h. Calibrator code if a calibrator
   i. Gain code
   j. Bandwidth selection

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

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

Although most observers will never deal with anything but source list files, some will do so and everyone should be aware of the parameters controlling the observing. For this reason, let us now go through a boring but useful discussion of the contents of these files. Subsections 2b through 2f describe the control files the user will generally not be modifying, hence these sections can be skipped during a casual reading of this chapter; however, subsection 2g describes the very important source list files that every observer will need to deal with.

(b) 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 the previous value of 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 conventional 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 Time Service Announcements Series 7.

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. Tentative assignments are as follows: columns 1-4 specify the controlling subarray for each quadrant of the correlator - 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 deicers are off and has a T when they are turned on during the winter months; and column 12 is blank if refraction corrections are to be based upon measurements of the weather station, but contains a T if estimated values of refraction are to be used based upon a model.

(c) Subarray Files SUBn = SUB1, SUB2, ..., SUB5

Since the VLA can function in up to five 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

FILE1 FILE2 FILE3 FILE4

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 - optional specification of LO frequencies, synthesizer settings, and the names of files with alternative IF parameters, front end parameters, and subreflector rotation parameters.

(3) External LO frequencies card - 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. On this card, 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. 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 contain the AB first side LO frequency in GHz and in F7.1 format. Columns 14-20 contain the CD side first LO frequency in GHz and in F7.1 format. Columns 26-30 and 36-40 are the 2-4 GHz synthesizer frequencies in MHz and I5 format for the A-C and B-D IF pairs, respectively. Until the B and D IFs are installed, the C LO is supplied by the B-D synthesizer. Until the new IF conversion scheme is installed in all antennas (in late 1978 it is only in antennas 3 and 5), columns 21-25 and 31-35 are used for the first LO settings for the old IF conversion scheme. Columns 41-50 and 51-60 are the (roughly 150 MHz) synthesizer frequency setting in MHz and F10.4 format for the AC and CD channels. Columns 61-70 contain the left-adjusted name of the file containing IF gain calibration parameters. These files are arbitrarily called IF files. Columns 71-80 contain the left-adjusted name of the file containing front end and subreflector parameters. These files are arbitrarily called ROT files because of the subreflector rotation parameters.

The SUBn files always should contain LO and frequency card images for the standard band combinations. Thus, for example, the following is a minimum SUBn file without alias cards:

FILE1 FILE2 FILE3 FILE4

CCLO			3510	3710	3260	3710	100.0	200.0	SYSCIF	SYSCROT
LLL000	-3.2	-3.2	3310	3660	3060	3660	100.0	200.0	SYSLIF	SYSLROT
UULO	19.6	19.6	3510	3660	3260	3660	100.0	200.0	SYSUIF	SYSUROT
KKLO	17.6	17.6	3510	3660	3260	3660	100.0	200.0	SYSKIF	SYSKROT

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 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.

An additional LO frequency card to be used in the spectral line system is optionally supplied with one card for each band. Tentative formats are as follows. Columns 1-2 should contain the band codes for the AC and BD systems. Columns 3-4 must contain the letters 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, 1, 2, etc.). Column 10 contains an L if it is a line observation card and a C if it is a continuum card. Column 11 indicates which velocity system is to be used, with T for topocentric, H for heliocentric, and L for the local standard or rest. Column 12 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. Columns 14-16 contain the correlator mode code. Columns 21-24 contain the code for the line transition of interest, e.g., H_2O for water. Columns 41-50 contain an external LO frequency in MHz.

(d) ANTENNAS File

The ANTENNAS file contains major information about each antenna. There are three different types of card images in the ANTENNAS file and there must be one of each type of card for every antenna in the system. The ANTENNAS file is modified only by the array operators or other VLA staff.

The first type of card in 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, 21-25, 26-30, and 31-35 contain, respectively, the A, B, C, and D channel delay lines in I5 format. Column 40 contains a T if elevations greater than 90 degrees are forbidden, and is blank if they are allowed. Column 42 contains an integer specifying the subarray number of the antenna. 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 50, a T means the new design IF conversion scheme (F7/F8) is installed in the antenna. In column 51, a T means the round trip phase correction is to be turned off. In column 53, a T means new design IF filter control modules (T6) are used in the antenna.

The second type of card contains the antenna station positions, a delay constant, and the axis intersection defect parameter. On this 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, Lx, Ly, and Lz for the station positions in nanoseconds and F15.4 format. Columns 46-60 contain a delay constant in nanoseconds and F15.4 format. Columns 61-70 contain the axis intersection defect parameter in units of nanoseconds with F10.4 format.

The third type of card in the ANTENNAS file contains the pointing parameters for each antenna. This card image is in free format with the following information in order: the antenna physical ID number; the arm reference azimuth in degrees; the tilt N-S component, A1; the tilt E-W component, A2; the coefficient of a COS(AZ) term, A3; the coefficient of a SIN(AZ) term, A4; the axis perpendicularity error, A5; the collimation error, A6; the azimuth encoder offset, A7; the elevation tilt N-S component, E1; the elevation tilt E-W component, E2; the coefficient of a COS(EL) term, E3; the coefficient of a SIN(EL) 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 of the 600 MHz round trip phase detector. This parameter is used to resolve ambiguities about which lobe of the 600 MHz standing wave is correct.

The following is an example of the three types of card images in the ANTENNAS file, corresponding to antenna #1 located on station W8.

```
  1    1  DW8    2   -2    1   -1    T    1

 1   509.561    -1338.424       -745.203      -1547.0

1,-60  +6.00,-1.00,0.,0.,0.,-0.90,41.90  -0.00,-1.00,0.,0.,-1.15    -0.09
```

(e) The ROT files with Front End and Subreflector Parameters

The front end and subreflector files contain various subreflector and front end parameters. These are usually referred to as ROT files because they contain subreflector rotation parameters. The choice of which ROT files are operative for a particular subarray is made by putting the ROT file name in columns 71-80, left-adjusted, in the SUBn file for subarray n.

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 collimation 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

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

where ELEV 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 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 choice 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 front end auxiliary switch can be turned on or off by placing a T or a blank in columns 57-60. A T placed in column 63 means the on-line T_{sys} correction will be applied to the data; a blank means it will not. The 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. Finally, columns 67-70 should have a T if the frequency converter alternate input switches are to be turned on, and should be blank if they are to be off; in late 1978 nothing is yet connected to the alternate inputs.

(f) 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 names 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 F14.4 format. Columns 16-20 contain the IF peculiar phase in degrees in F5.1 format. Columns 21-25 contain the zenith efficiency parameter E0 in format F5.4. Columns 26-30 contain the E1 parameter for surface accuracy deterioration with elevation. Columns 31-35 contain the E2 parameter for surface accuracy deterioration with elevation. Columns 36-40 contain the E3 parameter of atmospheric absorption. The latter two parameters are in format F5.4 and the net efficiency is calculated from E = E0 + (SIN(ELEV)-1)E1 + (COS(ELEV))E2 - (CSC(ELEV)-1)E3. Columns 41-45 contain the noise tube temperature in degrees in format F5.3. Finally, a T in column 50 means this IF is out of operation and should be ignored, whereas a blank means the IF is good.

(g) Source List Files

The previously discussed array control files determine parameters of antennas and electronics function in each subarray. Under most normal circumstances the observer uses standard systems files for these. However, the observer has dominant control over the major parameters of the observing process by preparing source list files. The determination of which source list files control observing in the n-th subarray is accomplished by putting the source list file name in the first card image of the SUBn file. This is always done by the array operator once he 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. A special program called OBSERV, which will be described in Chapter V, is 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.

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 a specified time interval. This time interval can be specified either in terms of duration or Local Sidereal Time (LST). There is a one-to-one correspondence between the "scan" discussed elsewhere in this documentation 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 source having a numerical qualifier of zero. A blank in column 14 means time is specified in terms of LST, and a dollar sign ($) means time is specified in terms of a duration. Durations begin at the completion of the previous observation. No allowance is made for antenna move 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, 26-27, and 29-36, respectively. Column 38 contains plus (+) or a blank for positive declinations and minus (-) for negative declinations. Columns 39-50 then 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. In column 51 a blank 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 2 cm, and KK for 1.3 cm under standard conditions of operation. If alias cards were 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 with IF x = A, B, C, or D, Ix meaning interferometer pointing mode with IF x = A, B, C, or D, TF meaning a mode for the testing of the front ends, and D for delay center determination mode. Column 61 is blank if the source is not a calibrator, but with an A it is a nonvariable unresolved strong calibrator; with a B it is a nonvariable unresolved weak calibrator; with a C it is an unresolved strong calibrator; with a D it is an unresolved weak calibrator; with an E it is a nonvariable strong calibrator; and with an F it is a non-variable weak calibrator. Column 63 contains a gain code which has values between 0 and 8. Gain codes are chosen depending upon the strength of the source such that, calling GC the gain code, for L and C bands the flux of the source is between 2^{GC} and $2(2^{GC+1})$ Janskys, while for U and K bands the flux of the source is between $3(2^{GC})$ and $6(2^{GC+1})$ Janskys. One sets GC = 8 if the correlated flux expected from the source is more than 256 Jy for L or C band, or more than 768 Jy for U or K band. Columns 65-68 contain the bandwidth codes for the A, B, C, and D IFs, with 0 for 50 MHz, 2 for 12 MHz, and D for 1.5 MHz being allowable choices for the 1978 continuum system. Finally, columns 69-80 will contain the feature velocity for future spectral line mode observations.

A succession of source cards with specified durations or different LST stop times results in 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 minutes of time in the first part of each scan, since these changes are initiated only when a duration is exhausted or an LST stop time is reached.

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 moving source option card, used for the Sun, planets, comets, etc.; (5) a local oscillators 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 allows the observer to instruct the system to continue 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.

The optional antenna wrap card 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 wrap card. Columns 5-60 contain antenna ID number, elevation, and azimuth specification. Column 71 contains an arm identification parameter, W, E, or N for specific arms, and A for the entire array. Column 72 contains an elevation "plunge" specification, where U means go to elevations > 90 degrees if possible, D means use elevations < 90 degrees, and a blank means you don't care. Column 73 contains an azimuth wrap specification parameter, where R means use clockwise rotation if two azimuths differing by 360 degrees are possible, L means use counterclockwise rotation, and a blank means you don't care. You may specify each arm separately, using columns 74-76 and 77-79.

The optional moving source card 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 F10.3. Columns 21-30 contain the rate of change of source declination in seconds of arc per day in a format of F10.3. 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 date of observation. Finally, columns 41-50 contain the 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 ephemeris, 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 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 codes discussed previously in connection with the LO and receiver setting specification card images in the SUBn files. 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 thinks of this optional card image in terms of allowing the observer to change from a "standard" set of LO frequencies and synthesizer settings on a scan by scan basis.

Finally, the optional spectral line LO card 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
SUN         0$ 0 15 00  7 39 51.2561   21 27 27.819D    CC     7 2222
//PM         226.675  -561.262  0 10   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 the previous example of a source list file, the first scan, where the source qualifier is 1, is a calibrator observation with the normal situation of paramps on. The subsequent observations are for observations with the paramps turned off by appropriate changes in the IF file SUNCIF and the ROT file OFFCROT. One then alternates a calibrator observation with a solar observation. Only for the solar observations, of course, is it 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 and PM cards are not present.

3. The MODCOMP Computer System

(a) Major Tasks Running in the On-line System

The MODCOMP minicomputers of the on-line system perform a number of major tasks that control the observing and data acquisition. The CPU called BOSS carries out most of the observing management tasks and arranges the observing for different telescopes in different arrays based upon the control files. Amongst the management tasks of BOSS are the tasks performed every ten seconds, as we will discuss in more detail, including the writing of visibility data on magnetic tape and fixed head disk.

The minicomputer that directly controls the array and electronics through the routines that service the monitor and control interface is MONTY. MONTY generates commands based upon instructions given by BOSS and sends them to the digital communication system at the proper times. MONTY also receives data from the monitor and control interface and translates each data point and data address into a particular place in core memory, so that each point monitored in the electronics is represented by a voltage stored in core. MONTY can also make use of this data to generate the sampling of the monitor data requested by the monitor data logging program. Most importantly, MONTY uses the monitor data together with previously supplied tolerance limits to allow the CHK program to flag data with quality factors ranging from zero (for good) to four (for bad). All of the flags associated with a single ten second record for a particular correlator are combined by a logical OR to generate a flag level for each piece of data.

The handling of correlator data coming from the delay and multiplier system in the shield room every 312.5 ms is the task of the minicomputers CORA and CORBIN. All 312.5 ms samples of cross-multiplication and self-multiplication data are first normalized by dividing the cross-multiplier outputs by the mean of the appropriate self-multiplier outputs, then the 32 of these generated in ten seconds are vector averaged into real and imaginary visibilities for ten seconds of integration time. In 1978, CORBIN normally has time available for use for program development and source list preparation so it is also used for these purposes.

Amongst the programs running in the on-line system, there are three major ones. The programs called NEW, G10, and GEORGE perform critical tasks in the on-line system.

The program NEW is called upon every time there is a change of the control information in the source list file. NEW uses the information in the source list file to set LO frequencies and front end control switches, precess source coordinates, and look up phase and gain setting appropriate to specific bands and antennas. NEW typically requires 20 seconds or so to run, mostly while it waits for disk accesses and for completion of command transmission to antennas.

The program called G10 carries out major tasks that must be performed every ten seconds. This includes calculating the initial values and rates of change for phase, delays, and pointing commands. G10 also takes data reduced in CORA or CORBIN and writes it both on disk and on magnetic tape every ten seconds.

The program called GEORGE carries out tasks that are performed every 52 1/12 ms, which is one complete waveguide transmit/receive cycle. GEORGE takes the initial values and rates of change calculated every ten seconds by G10 and makes up the actual commands sent to the antennas. GEORGE also sends either an elevation or azimuth pointing command for each cycle so a complete position update is obtained every 0.1 seconds. A new phase, phase rate, and phase reversal command is sent to each antenna every 1.25 seconds. GEORGE also generates the delays and phase reversal commands sent to the delay and multiplier system every 52 ms.

(b) On-line Computations

(1) Ephemeris Calculations

The on-line system computes corrections for precession, nutation, aberration, and gravitational light bending. General precession is implemented by the formula given in the Explanatory Supplement to the American Ephemeris. It is presumed that the epoch given is in Besselian years. Nutation is calculated from the table of constants given in the Explanatory Supplement. Aberration is calculated for the Ephemeris by numerical differentiation of the position of the Sun; however, since this procedure is impractical for an on-line program, the program instead takes a sufficient number of terms from Newcomb's Tables of the Sun and calculates the velocity by summing algebraic derivatives (Atkinson, R. d'E., Astron. J., 77, 518, 1972). The precession is applied based upon the different modes of position input in the source list files. Coordinates may be entered in 1950.0 coordinates, coordinates of date, or coordinates of any integer Besselian year. For the case of objects in the solar system that move a significant amount in ten seconds, the position supplied on the source card is an initial position for a specific time, and the position is updated every 52 ms based upon supplementary information about the time of the supplied position and the rate of change of right ascension and declination at that time. The program does not currently calculate barycentric parallax corrections.

Eventually, ephemeris calculations will be based upon the constants adopted by the IAU General Assembly of 1976. It is planned to utilize these constants for equator and equinox 2000 positions only.

Calculation of the nutation follows the prescription of VLA Computer Memorandum 105 and is equivalent to the description of the Explanatory Supplement with the smaller terms removed for computational convenience.

(2) Time Calculations

The sidereal time is calculated from UT1 by the formulae in the Explanatory Supplement to the Ephemeris, with an assumed longitude of the array center of 107° 37' 03.800". Derivation of UT1 is a complex process. To avoid difficulties with the leap second, the fundamental time of the VLA is International Atomic Time (IAT). IAT is a continuous time incremented at the rate of one second per SI second. One of the tasks of the array operations group is to take each new copy of the US Naval Observatory, Series 7, and insert into the computer new values for the count of leap seconds, if necessary, and the formula given for the linear approximation for UT1-UTC. When the program NEW is run, it applies this formula for the estimation of UT1. These extrapolations frequently differ from post facto evaluations of time by as much as 10 ms. This means that observers interested in astrometry, proper motions, or combination of maps at different epochs may need to apply further corrections to the phase, based upon differences between the extrapolated time that was used and the "real" time. No correction is applied for the forced nutation of the earth. This can result in an error of up to 1 ms until the correction is implemented when the other recommendations of the IAU General Assembly of 1976 are incorporated.

(3) Antenna Location Corrections

The positions of antennas are taken from input card images in the ANTENNAS control file. These are in units of nanoseconds in a right-handed, topocentric coordinate system, with the z-axis pointing to the North Celestial Pole, the x-axis pointing to the intersection of the local meridian and the celestial equator, and the y-axis pointing east. In addition, the card images in the ANTENNAS file provide for entering a correction term arising from the fact that the azimuth and elevation axes of the telescopes do not precisely intersect. This axis intersection defect is quite small for most antennas.

The antenna locations as read are corrected for the effect of Earth tides by the formulae of VLA Computer Memorandum 105. They are not corrected for the forced nutation term. Better versions of these corrections are planned for future implementation.

(4) Refraction Calculation

The program called NEW also makes some elementary refraction calculations used in three different corrections. The first is a correction of the pointing position for antennas. Each antenna must be pointed to higher elevations than it would in the absence of an atmosphere by an angle (N-1)*tan z radians, where N is the index of refraction and z is the zenith angle. The third order term, proportional to the cube of tan z, can be important at elevations between 7 and 10 degrees, but it is not taken into account in 1978.

The second correction involving refraction is a phase correction for the differential atmosphere between antennas. This phase correction is proportional to (N-1)*h*sec z, where h is the height of the antenna above a common reference point.

The third is a correction for the sphericity of the Earth's atmosphere. This term is approximated by a model whereby it arises entirely from the effect that the source is higher in elevation at one antenna than at another. Making the further assumption that the gross contribution of the atmosphere to the phase path is proportional to the zenith phase path times sec z, and expanding the Taylor series, this gives rise to an additional term proportional to the geometric delay times the zenith phase path divided by the radius of the Earth. The zenith phase path is estimated by assuming a scale height of 2 km for the water vapor distribution. The dry air contribution is simply determined by the pressure, with no assumption about the scale height.

The coefficients for refractivity and atmospheric contribution to the phase path are calculated by NEW, and the actual application of the corrections of these terms, dependent on sec z, is done every ten seconds by G10. Ordinarily, the refraction is calculated from the temperature, dew point, and barometric pressure measured at a central weather station. In order to take into account the possible breakdown of the weather station, provision is made to optionally use weather values based upon a model. The model assumes a mean temperature of 8 degrees C, a sinusoidal, seasonal variation with amplitude 12 C, with a maximum about August 1, and a sinusoidal daily variation with amplitude 12 C, and a maximum at about 1300 MST. Dew point is taken to be 10 C less than ambient temperature, corresponding to about 35% relative humidity, and barometric pressure 750 mBars.

(5) Phase Command Calculations

The phase shift or lobe rotation applied for each antenna and IF in the antenna IF system requires information about the phase and rate of change of the phase. The G10 program takes the information provided by NEW and computes starting values of phase and phase rate of change for each fringe rotator. It does this by taking the sidereal time at IAT midnight produced by NEW and the rate of change of sidereal time and then calculating the sidereal time (LST) for the beginning of the next ten second interval. G10 then takes the reference position, referenced to IAT midnight, and applies the correction for the motion of the source, either as specified by the observer or as due to changes in nutation and aberration since midnight. Next, a correction for retarded baseline is applied. Having developed the reference position in the rectangular topocentric coordinate system in which the antenna positions are expressed, G10 then calculates, for each antenna, the geometric delay of wavefronts coming from the reference position and arriving at the antenna. This is further modified by the above mentioned refraction corrections. All of the above phase shifts then combine to constitute the starting phase for the next ten second interval. The phase rate, u*cos dec, is calculated and modified for the rate induced by the motion of the source. The second derivative of the phase is also calculated. These numbers are, at this point, converted from delay (time) units to units of wavelengths by multiplication by the LO frequencies for each IF chain.

Every 1.25 seconds the starting phase and phase rate for the next 1.25 second interval is calculated using the phase, phase rate, and second derivative of phase calculated every ten seconds by G10 and just discussed. A "peculiar phase" taken from the IF control files, with a different value for each synthesizer, is then added. When the later feature is properly implemented for a phase stable system, the result will be that the output phases from the on-line computer system will be calibrated to first order. The phase is further corrected according to the measured 600 MHz round trip phase for the antenna. These phases and rates are then formulated into commands to the fringe rotators and are dispatched to the appropriate antenna-IF system. Also sent every 1.25 seconds is a set of 24 phase reversal commands. These are 24 bits from Walsh functions of length 32, with a different Walsh function going to each antenna. Each one bit reversal command applies to one 52 ms waveguide cycle. Because of the orthogonality of the Walsh functions, any DC offsets in the system, whether they are due to self interference or digitizer offsets, will be canceled out on integration times of multiples of 32 waveguide cycles: 1-2/3 seconds. This also suppresses other instrumental effects, which vary on time scales much greater than three seconds.

Finally, using the starting delay and delay rate, GEORGE calculates, every 52 ms, the geometric delay for each antenna, adds to it a "peculiar delay" for each IF obtained from the IF control files, and sends the resulting delay and delay rate to the delay and multiplier system to be applied to each antenna-IF signal path.

(6) Pointing Command Calculations

The azimuth and elevation of the source as seen from the center of the array are calculated every ten seconds, including refraction corrections. The telescope stations are leveled so that all the azimuth axes are parallel to the vertical at the center of the array; at the ends of the arms the telescope will be tilted about 12 minutes of arc with respect to the local vertical. The antenna pointing corrections are then applied to each antenna. Provision for twelve pointing parameters for each antenna are allowed, and these pointing parameters are taken from the ANTENNAS control file: N-S tilt for elevation; E-W tilt for elevation; elevation encoder first harmonic term amplitude and phase; elevation collimation error; N-S tilt for azimuth; E-W tilt for azimuth; azimuth encoder first harmonic amplitude and phase; axis perpendicularity error; azimuth collimation error; and antenna base rotation.

In practice, the pointing is not improved by the addition of pointing parameters beyond tilt, collimation errors, and azimuth rotation. The collimation errors can be different for each observing band.

(c) Observing Modes

Standard interferometer observations are made by leaving the mode columns of the observation request card of the source list file blank. For special purposes four other modes are implemented, mainly for the use of VLA staff.

For delay mode, column 60 is blank on the observation request card while column 59 contains a D. For interferometer pointing mode, columns 59-60 contain IA. In delay mode, the delay is modified by specific amounts and, in interferometer pointing mode, the antennas are pointed at four antenna half-power points. In both of these special modes, some parameter is stepped through a cycle; the position in the cycle is called the submode. In both modes the odd submode data is invalid because the parameter is in the process of changing, e.g., in IA mode the antenna is in motion. The significance of the even submode data is given in Table V-1.

Table IV-1

Observing Submode Parameters

Pointing or IA Mode		Delay or D Mode	
Submode	Parameter	Submode	Parameter
2	On source	2	+ 14 ns
4	+ El half-power	4	- 14 ns
6	- El half-power	6	- 7 ns
8	+ Az half-power	8	On delay
A	- Az half-power	A	+ 7 ns

There is also a PA mode for single dish pointing, which is seldom used, and a TF mode for testing front end parameters. Eventually, other modes will be added for the support of line observing and other options.

(d) Correlator Data Processing

Because of the central importance of the visibility data, let us now describe the processing the data for each correlator receives.

The controller of the multiplier system has an internal memory which accumulates data for 0.3125 seconds before being dumped to the on-line computer system (CORA/CORBIN). The computer system decides which correlators it wishes to receive data from; in particular, it asks only for correlators involving antennas it knows about and which are in the same subarray. When this information is sent to CORA/CORBIN, it is accumulated for ten seconds and an rms computed from the 32 input data points. In ten seconds there are one billion attempted correlations at a 100 MHz clock rate, which can be expressed with 31 bits, including sign. The seven least significant bits are discarded, leaving 24 bits to express the remaining range of correlation. In practice, sixteen bits are usually more than sufficient range for any one source, and a gain code must be provided to tell which eight bits are to be discarded. The gain code on the observation request card is used for this. This gain code corresponds to the number of bits to be discarded from the right end of the 24 bit code. If too small a gain code is requested, then significant data may extend into the discarded bits on the left, with the result that CORA/CORBIN will generate overflow complaints. If too large a gain code is requested, you may generate truncation errors larger than thermal noise and gain uncertainty. With gain code 0, the thermal noise is about 100 times the least significant bit; therefore, gain codes up to 3 or 4 may be used without fear of being unduly affected by truncation noise. There may be a few sources and a few configurations in which the 16 bit dynamic range does not suffice. This should not be a problem for extragalactic objects or point sources, but it may be a problem on galactic HII regions, or on the galactic center source. It is definitely a problem for observation of strong, active regions on the Sun where the stronger flares and the fluxes in long spacings have more than 16 bit dynamic range.

CORA/CORBIN will apply gain corrections to convert the output correlations to units of Janskys if the appropriate gain factors are present in the IF control files. The correlator data, along with other data about the observations, are written on a disk file and on a magnetic tape for permanent storage or transport. The data written on a disk file are accessible to the FILLER program running in the DEC-10 so data are normally transferred to DEC-10 disk storage in nearly real time.

A separate disk file, later copied on to a monitor data tape, is written, containing selected portions of the information collected by the monitor system. These are mostly voltages measured at various test points throughout the system. These data are the basis for the on-line flagging of data to indicate quality, and may also be used for off-line editing and calibration.

CHAPTER V

PREPARATION FOR OBSERVING AND THE OBSERVING PROCESS

1. VLA Capabilities in Late 1978

(a) Antennas and Configurations

During 1978 and 1979 the dominant goal at the VLA will still be to get the entire 27-antenna instrument working before 1981. This will have some effect on the astronomical observing. Under normal circumstances, when an antenna system requires some work or involvement in testing, this will sometimes have priority over astronomical observing. The observer will generally be consulted, however, about optimum times for "taking" out a particular antenna. The result of this policy is that, although up to fifteen antennas are functioning at the end of 1978, the normal "best" likely to be available is twelve and ten is a reasonable average to expect. This is mainly for 6 cm, the dominant system wavelength. There should be almost as many antennas at 20 cm, but probably a few less at 2 and 1.3 cm.

As 1979 progresses, it is likely that more antennas will be available on average. However, for the purpose of discussion in this chapter, we will make the conservative assumption that ten antennas are functioning for astronomical observing. We will also assume that the most likely configuration has six antennas on the southwest arm out to 10 km and four antennas on the southwest arm out to 1.6 km:

E4	E8	E12	E16	W8	W16	W24	W32	W40	W48
0.15	0.48	0.97	1.5	0.48	1.5	3.2	5.2	7.7	10.6 km

where the distance corresponds to radial distance from the center of the array. With such a large number of antennas at various locations on the wye, it is impossible to keep separations and orientations clearly in mind. The closest one can come is by associating antennas with radial distances along arms.

Because the major orientation of baselines is along the southwest arm, it is useful to be aware of the u-v plane characteristics of antennas on the southwest arm. Figure V-1 shows the u-v coverage for a single antenna pair on the southwest arm. Examination of Figure V-1 shows a couple of characteristics useful in planning scheduling. For high declination sources you get nearly all of the possible u-v coverage for a ten-antenna situation by observing only positive hour angles. For very low declination sources the opposite is true, because most of the coverage in the u-v plane is obtained when the source is just rising in the east.

Figure V-2 shows the elevation limit to elevation limit u-v plane coverage possible for a number of declinations with the 10 antenna configuration we are considering. Sources above 64 degrees are circumpolar and can be observed for 24 hours, achieving excellent u-v plane coverage. However, for more southerly declination there is lack of sampling of spatial frequencies with NW-SE orientations. The synthesized beams corresponding to the u-v coverage in Figure V-2 are shown in Figure V-3. The point source images in Figure V-3 were made with uniform weighting and no tapering; therefore, they represent the worst case for sidelobes.

The maximum and minimum sidelobe levels of a synthesized beam are major indicators of image quality. These levels for the 10-antenna observing situations corresponding to Figures V-2 and V-3 are listed in Table V-1.

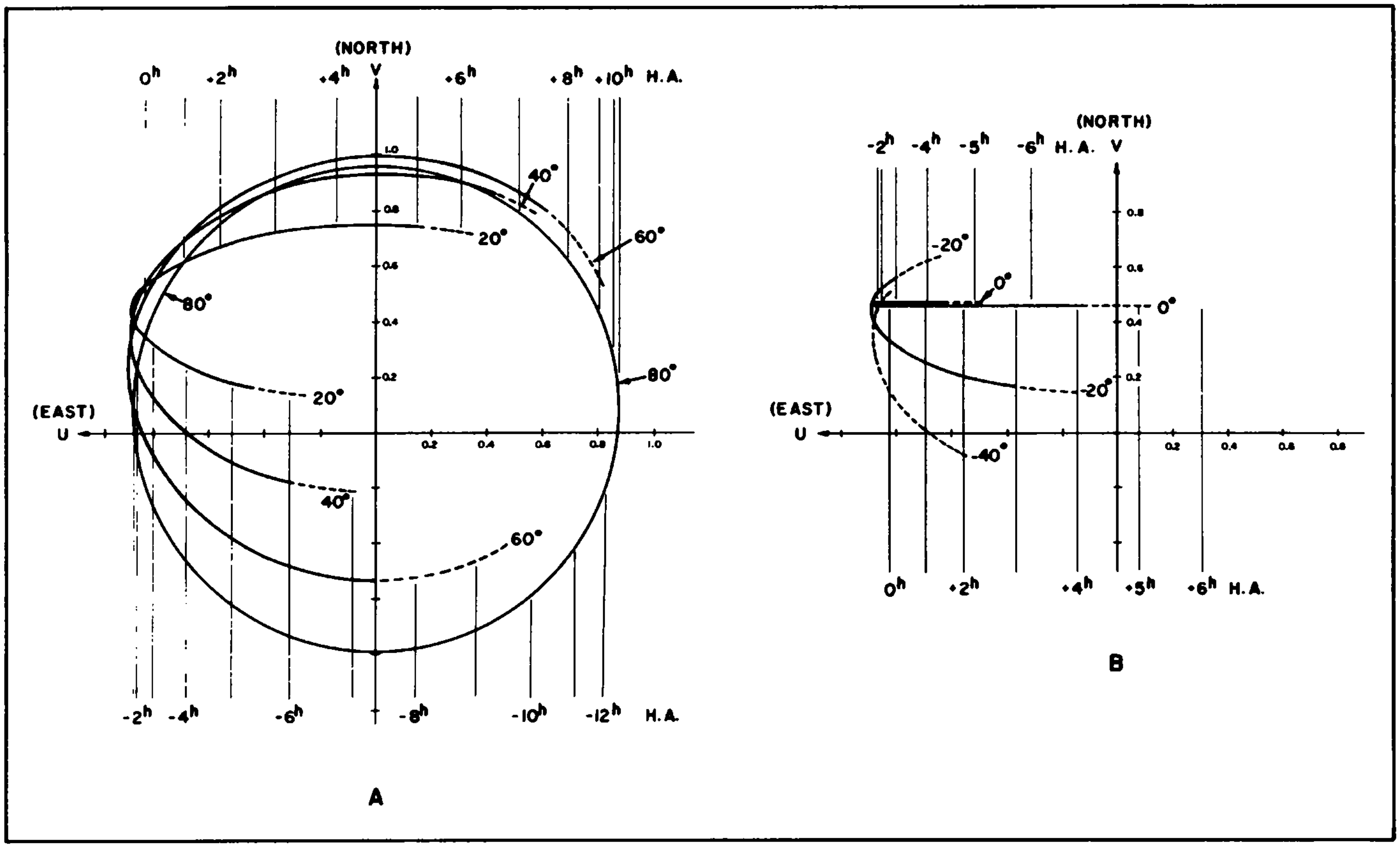


Figure V-1. The u-v tracks for antennas located on the SW arm of the VLA. Curves dashed for elevations between 20° and 10°.

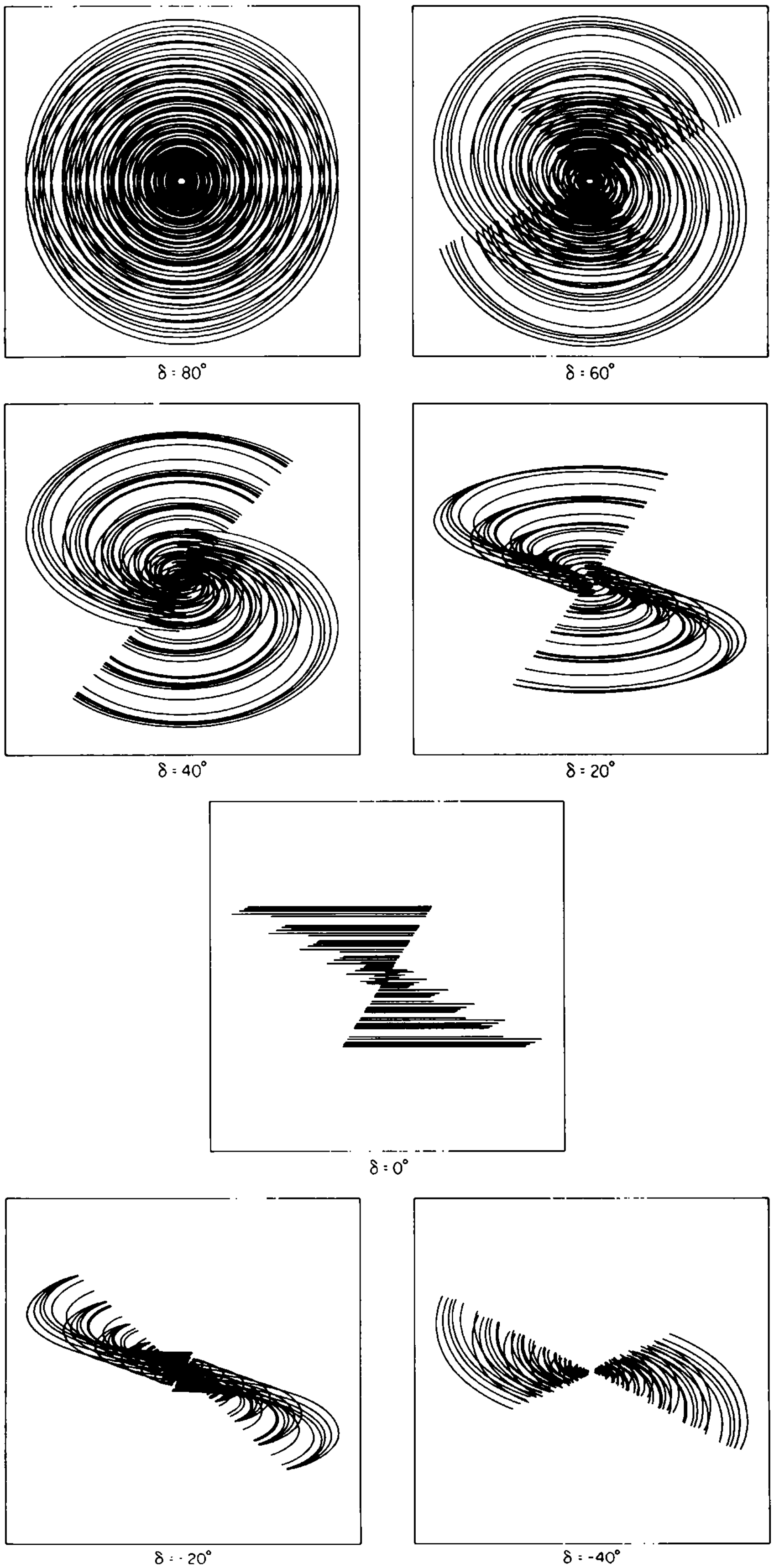


Figure V-2. The possible u-v plane coverage of a 10-antenna VLA with antennas on stations E16, E12, E8, E4, W8, W16, W24, W32, W40, and W48.

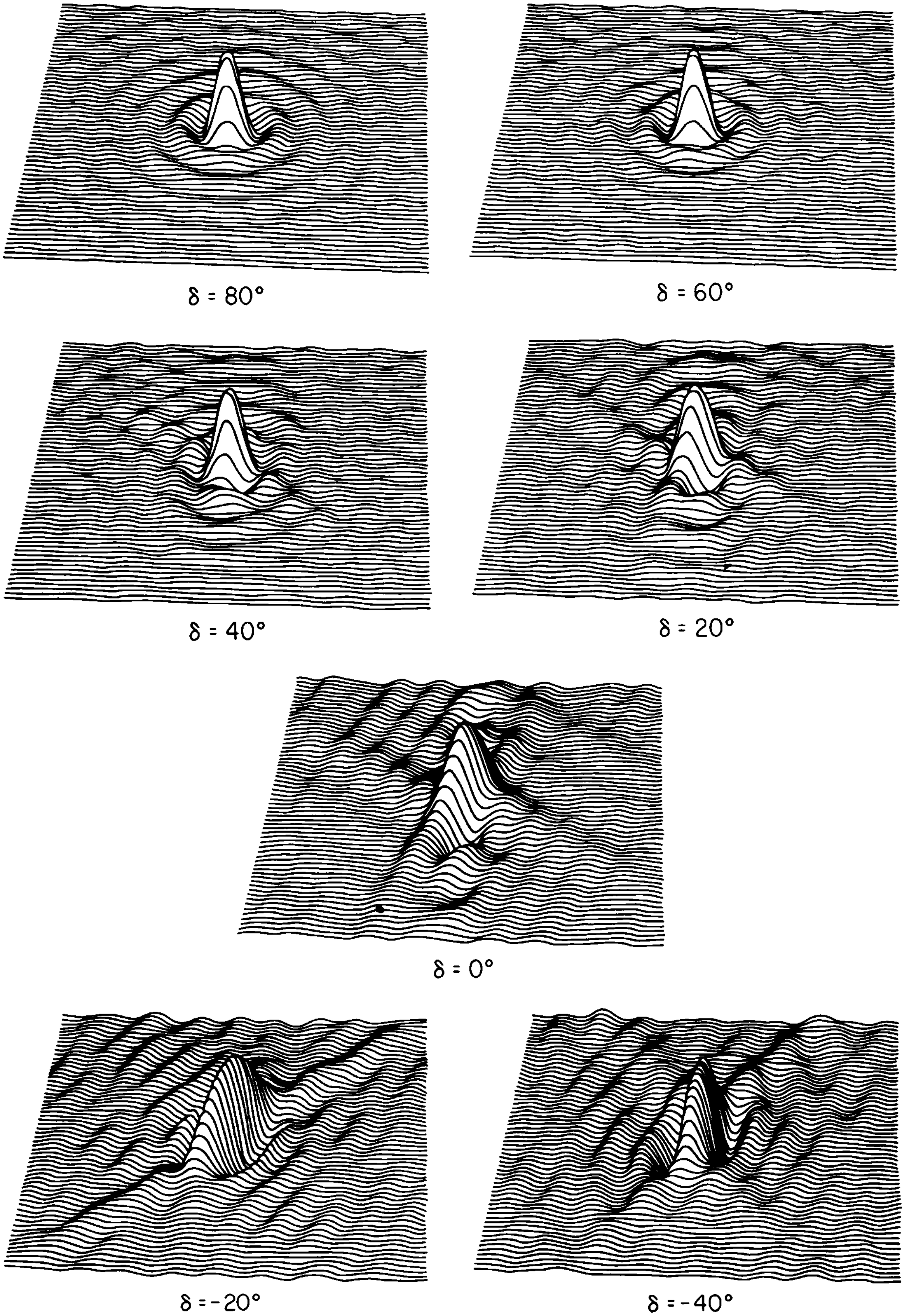


Figure V-3. The synthesized beams corresponding to the u-v coverage shown in Figure V-2.

Table V-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

(b) Sensitivity, Resolution, and Confusion

In addition to the question of the u-v coverage obtained for VLA observing in late 1978 and 1979, it is necessary to be aware of the sensitivity, resolution, and confusion limitations of the observations. Table V-2 summarizes the approximate parameters of these limitations for the standard 10-antenna observing situation we are considering.

Table V-2

Sensitivity, Resolution, and Confusion Limits of a 10-Antenna VLA

Frequency	1.34-1.73	4.5-5.0	14.4-15.4	22.0-24.0	GHz
Wavelength	18-21	6.0	2.0	1.3	cm
Band	L	C	U	K	
RMS Sensitivity in 10 minutes	1.3	1.0	10	13	mJy
RMS Sensitivity in 12 hours	0.15	0.12	2.5?	5?	mJy
Synthesized Beam Size (HPBW)	3.0"	1.0"	0.4"	0.2"	
Antenna Beam Size (HPBW)	30'	9'	3.7'	2'	
Field of View with 50 MHz Bandwidth	3'	3'	2'	1'	
Confusion in Antenna Beam	100	2	∿ 0.2	∿ 0.05	mJy
Confusion in 50 MHz BW Field of View	.8	0.2	∿ 0.1	∿ 0.02	mJy

As seen from Table V-2, the sensitivity of the VLA is excellent. A bandwidth of 50 MHz was assumed for the sensitivity calculations in Table V-2, so scaling with the square root of the bandwidth should be applied for other situations. The resolution of the 10-antenna configuration that we are considering is at the 1" level for 6 cm. However, until more antennas are available with shorter spacings, high quality mapping of sources will be limited to small sources. Sources with Fourier components larger than 2', 45", 15", and 10" at 20, 6, 2, and 1.3 cm, respectively, will be missing major fractions of the flux unless spacings of 50 to 400 m can be included in the observations. This fact, together with the significant confusion limits for the full antenna beam at 20 and 6 cm, means that there will tend to be a good match between capabilities and optimum conditions if the VLA bandwidth is chosen to be 50 MHz.

(c) Polarization

With care it should be possible to measure and map small, linearly polarized sources to the 1% level at 6 cm in late 1978. Because of special instrumental problems concerning polarization, however, the user should discuss the limitations of these observations with the VLA staff before submitting proposals requiring very accurate polarization measurements, or polarization measurements at other bands.

2. Planning for VLA Observing

(a) Before Observing

(1) The VLA "Friend" Program

Each visitor program scheduled for VLA observing is assigned a VLA staff member who functions as a "friend" before, during, and after observing. 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 that optimum use of the array to accomplish the purposes of the user's observing proposal can be made. Calibration techniques should be discussed. Lists of information about flux, position, and polarization calibrators should be obtained. In addition to the user obtaining current status information, it is important that the "friend" be thoroughly conversant with the planned program so that advice and direction can be optimized.

(2) 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) a thought-out 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 good to have planning done in advance, it is best to delay generation of the final observing program until arrival at the VLA site.

(3) Arrival at the Site

Observers should arrive at the VLA site at least one or two days before the observing begins. Since you cannot count on your "friend" 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 at least a week after the observing run for editing, calibration, and mapping of the data. Experience so far 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.

(4) 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 getting fed are well in hand. This is to avoid finding yourself after 4:30 p.m. with room and food problems and no one to help you straighten them out.

Next, observers should locate their "friend". At this point a rediscussion 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 usually prove valuable. Although your VLA "friend" should be your main source of information, outside of documentation, other input is often very helpful.

Next, the 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 to optimize results based upon reality. In the detailed plan the sequence of calibration should be established and the times of observation of all sources, whether in durations or LST 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 and hour angle coverage.

(b) Calibration

Until the VLA is completed and in normal operation, it is wise to overcalibrate. At least 15% 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 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 table of calibrator information available at the site in the observers offices. 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, should be determined by boot-strapping from observations of good flux density calibrators. Tables of information about these are also available in observers offices.

If more than one frequency is being used, it is recommended that all observations involve the basic sequence CALIBRATOR - SOURCE - CALIBRATOR for each band. 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 rain or thunderstorm weather observations at 2 and 1.3 cm may not even be possible.

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

(c) Lists of Phase and Amplitude Calibrators

Once you have arrived at the VLA site, you can obtain information about phase and amplitude calibrators once you learn how to use the DEC-10 computer from a terminal to print out text files or execute the EXPLAIN command that exists in all standard programs. Typing

```
print phical.aid[1,4]
```

and

```
print ampcal.aid[1,4]
```

to the DEC-10 will result in tables of phase and amplitude calibrator information being printed out on the line printer. This information will correspond to that in the VLA calibrator book in the observers offices. The use of the EXPLAIN command in standard programs will give you listing of various types of calibrator information under the following names:

PHICAL AMPCAL LCUKJY LCALJY CCALJY UCALJY KCALJY

The use of PHICAL and AMPCAL will give general information about phase and amplitude calibration. LCUKJY gives information about calibrators that are point sources at all VLA frequencies. The remaining names are associated with lists of calibrators that are good for specific bands.

(d) Planning Source Scheduling

(1) Subarray Operation

The VLA can operate with antennas in up to five subarrays, with each 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 sensitivity 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. You achieve 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 goes with the square of the number of antennas, one rapidly loses sensitivity with too much division into subarrays. Under most circumstances, the user will be much better off using only one subarray, but alternating observations of different types.

(2) Detailed Source Scheduling

Once the basic questions of calibration procedures, subarrays, and typical integration times for sources and calibrators are settled, more detailed source scheduling can proceed.

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 V-2. 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, if short spacings are included in the array, 12 or 1.5 MHz bandwidth should be used. 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 affect the field of view. For observations at 20 cm, where interference may appear in the 50 MHz bandwidth but not in the 12 or 1.5 MHz bandwidth, it may be desirable to choose the narrower band which is interference free.

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. From this, one checks that the source is above elevation limits. In addition, based upon right ascension and declination, one checks on time lost due to antenna moves. The antennas slew at 20 degrees a minute in elevation and 40 degrees a minute in azimuth. Some care should be taken in scheduling sources which require the antennas to move near the zenith. Also, when moving across azimuths of 150 or 330 degrees, the antennas may have to rotate 360 degrees to avoid cable wrapping. 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. The elevation limits of the telescopes are 8 degrees and 125 degrees (i.e., the telescopes can tip 35 degrees beyond the zenith).

Figure V-4 is a plot showing the correspondence between Altitude-Azimuth and Hour Angle-Declination. Figure V-5 shows the hours angle limits as a function of declination for 8, 10, and 20 degrees elevation limits. The 10 degree limit is useful for scheduling if you want to schedule it close without excessive danger of encountering limits, and the 20 degree limit is useful when you want to avoid large air masses with concomitant correction problems.

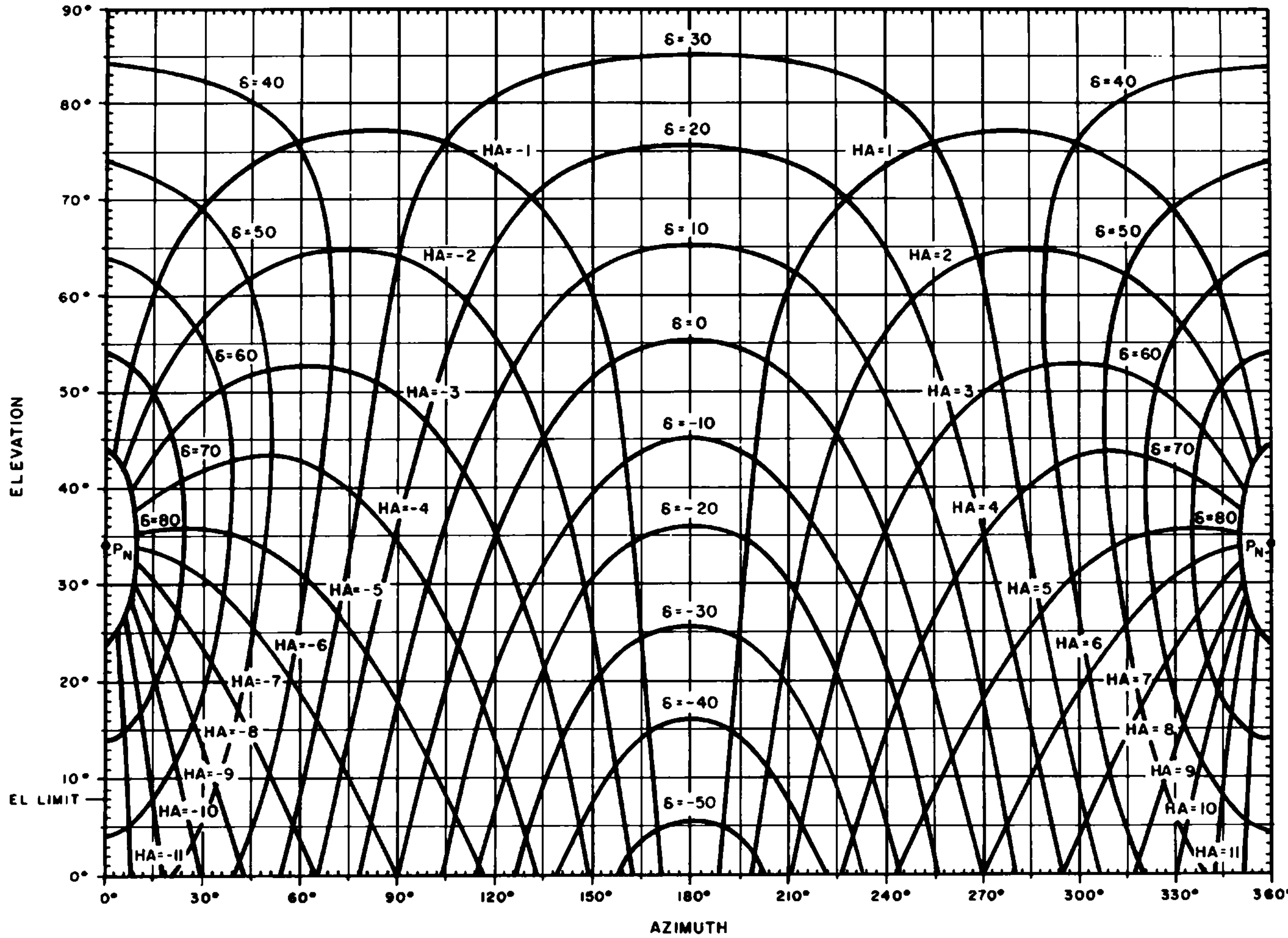


Figure V-4. Chart for conversion from Alt-Az coordinates to (H,δ) coordinates.

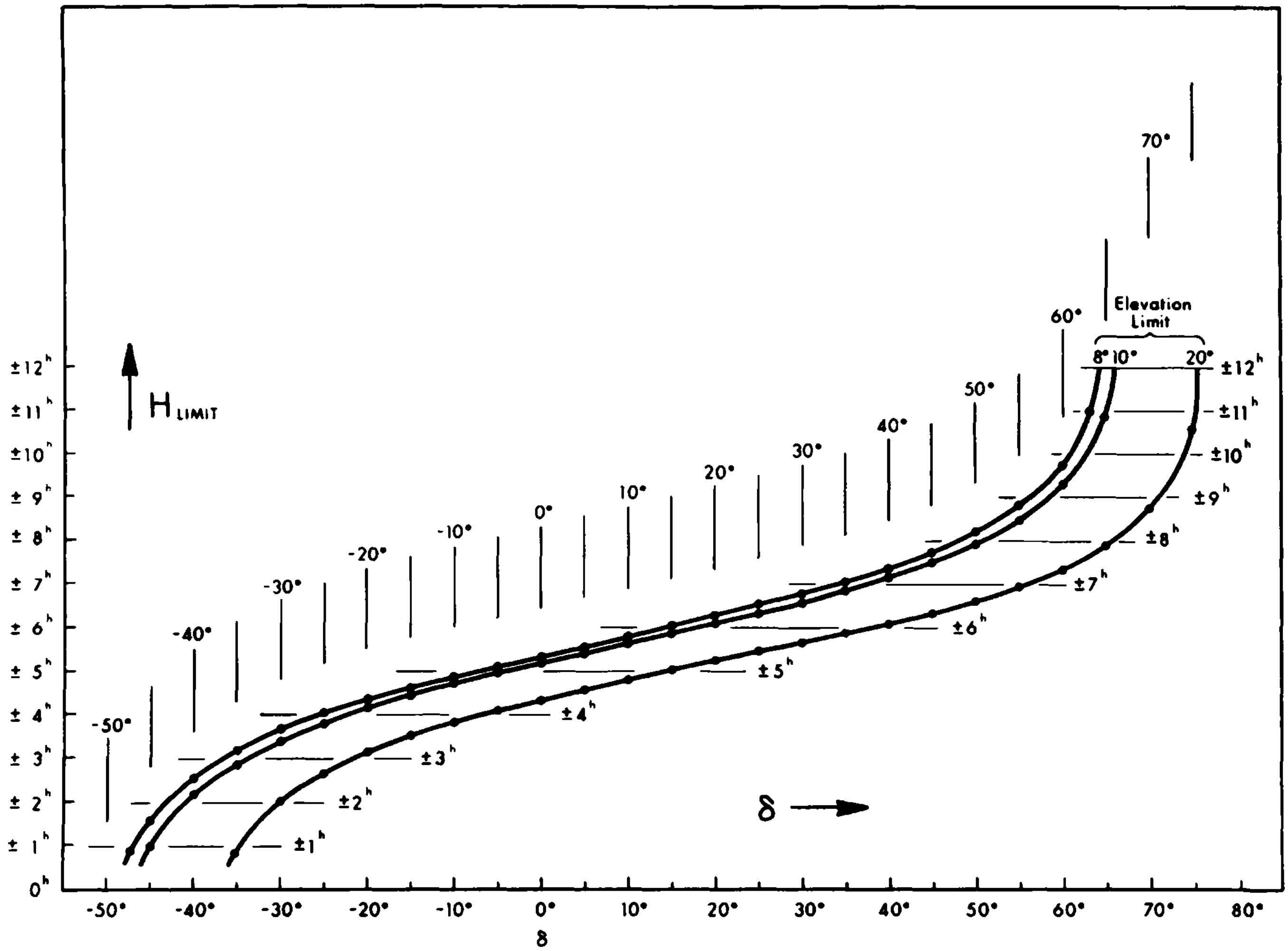


Figure V-5. Plot of hour angle limits as a function of declination for elevation limits of 8, 10, and 20°.

(3) Punching Source Input Cards

Once the details of the observing program for at least the first several hours of the observing run are planned, the observer proceeds to detailed preparation of the program. The first step is to prepare a source input card for any source you might want to observe during the program. This need not include calibrators with known names in VLA calibrator files but certainly includes all other sources. The information on each card is the following:

Name   Right Ascension   Declination   L,C,U,K Gain Codes

where the name is eight characters or fewer without imbedded blanks or commas, the right ascension follows after one or more spaces with format hh mm ss.sss, then the declination in format ±dd mm ss.ss after one or more spaces, and, finally, four gain codes corresponding to the maximum strength expected for the source at each of the four VLA observing bands, with one or more spaces before and after each gain code. With the exception of what has been stated, the column format of these cards is variable. These cards will be used a number of times as input to the OBSERV program used to prepare source list files. Since one of the main reasons for punching these cards is to avoid human errors in typing critical parameters, it is then wise to double-check the punched source input cards, writing on each of them at least the origin of the position.

The next step is to use the OBSERV program in the on-line computer system to prepare the detailed source list files that will control the observing.

3. Preparing and Modifying Source List Files - OBSERV and SEDIT

(a) Introduction

Once the source input cards with names, positions, and gain codes are available, the next step is to prepare the source list files that will control observing. This is best done using an on-line computer program called OBSERV. Once an initial source list file is available on disk, it can then be modified by either the OBSERV program or the SEDIT source text editor.

Both OBSERV and SEDIT are run from terminals in the computer room next to the on-line MODCOMPs. Because the average user will seldom use SEDIT, we will mainly discuss the OBSERV program.

(b) Running OBSERV in the MODCOMPs

Once you sit down to a MODCOMP terminal to run OBSERV to prepare your source list files, the first thing you do is type

$JOB

after which, if the background job for running OBSERV is available, the computer responds with either

$$

or a carriage return and you can proceed. If you receive any other response, you may need to activate the background job. Ask the array operator to help you get going since there may be special problems.

Next, you decide what name you wish to assign to your source list file and call up the OBSERV program to prepare this file by typing

$OBSERV,filename

where filename is your selected name of up to eight characters. If you forget to supply a file name, you will find it given the name STUPID when you eventually catalog it. Once you are in OVSERV, the first thing you do is supply some identification information by typing

ID,lastname,programmernumber

or

ID lastname programmernumber

where LASTNAME is your last name which will be truncated to six characters, and PROGRAMMERNUMBER is your assigned DEC-10 programmer number. The latter is used to assign your data base files to the correct DEC-10 disk area.

If you are preparing the file for the first time, you can proceed. However, if you want to start with a previously cataloged source list file, you need to bring it into the OBSERV workspace by typing

RECover,filename

or

RECover filename

where FILENAME is the old file name. Note that either commas or spaces can separate portions of a command. We will from now on mostly use commas, but spaces are equally acceptable. We will also denote command names in OBSERV (and SEDit) by capitalizing the first three letters and using lower case for the rest. This is because only the first three letters really need to be used in commands; however, the remaining letters may help indicate the purpose of the command.

A special case of RECover is of interest if you have exited from OBSERV without having cataloged your file, or if the computer system has crashed after you have put a lot of work into preparing a source list file. In either case, typing

RECover

alone results in the OBSERV workspace being restored from disk in the state it was in when OBSERV was last run.

Once your OBSERV workspace contains what you want, you then proceed to set up input or parameter initialization for OBSERV. The first step is to read in your source input cards. First you turn the card reader on. When ready, you put the source input cards in the hopper, followed by an EOF card ($$ punched in columns 1 and 2), hit the RESET button on the card reader, and then type

USE,CR

and the cards will be read in. When done, it will tell you it encountered an End Of File; if this doesn't happen, you forgot the $$ card and had better punch one and read it in. When done, you can ask for a listing of your source input cards by typing

USE,LIST

and you will have it displayed on the terminal screen.

The equivalent information for calibrators known to the system need not be supplied as long as you plan to identify them by a standard name or the IAU designation. However, if you wish to use sources in your source input list as calibrators, you need to indicate this by typing

CAL,<code>,name1,name2,...,name N

after which sources with these names will be labeled as calibrators on the source request card images, where <code> = A, B, C, D, E, or F.

The next step is to set up input parameters for source request cards that will remain constant for some time. The possibilities for this are extensive, but most frequent use is for setting up the bandwidth or frequency. The command for this is SET and you can, for example, set up a general situation for 6 cm observations with 50 MHz bandwidth by typing

SET,BAND=CC

SET,WIDTH=0000

and these settings will be used until changed by another SET command or overridden.

The last step before beginning actual preparation or modification of a source list file is setting up the input format for the ADD command. This is done by typing

INFormat,identifier1,identifier2,...,identifierN where the identifiers are one of a possible list that we will give in the next subsection. As will be seen, a typical INFormat command will be

INFormat,name,qualifier,band,duration

or

INFormat,name,band,width,stop

after which the terminal screen will supply a gory display of all the defaults for all the source list cards you might ever, but generally don't want to, use. You are then ready to use the ADD command to supply input according to your previously defined input format. You get yourself into the mode for ADDing source request card images by first typing

ADD

after which the computer will prompt you with a header corresponding to the input format you requested, as, for example,

NAM QUA BAN DUR

after which you type in successive lines of this information (NAME, QUALIFIER, BAND, DURATION), with one line per source request card image. This input can continue indefinitely and is terminated only when a ./<command> , like ./LIST, is typed. This terminates the ADD mode and returns you to OBSERV command level. Note that ./<command> is a normal form of OBSERV commands; however, the program has evolved to the point where the ./ prefix is required only when you wish to terminate ADD or CHAnge mode.

Once all or a portion of the source list file is prepared, you can list its contents by typing

LISt

after which a complete listing of the source list file will scroll across the screen. If you wish to see part of it at leisure, you hit the special F1 key once, then, when you wish to resume scrolling through the listing of the file, you hit the F2 key.

Once all or any portion of a source list file has been prepared, it should be CHEcked by typing

CHEck,SB1

or

CHEck,DEC

depending upon whether you want the results of the CHEck command output to the terminal screen or to a file that can be printed out on the DEC-10 line printer. In either case, the computer then asks you for an LST start time, an elevation limit, and the year, which you type in, using the format

hh mm ss elev year

at which point the program checks for obvious errors, such as missing ra and dec or sources below the elevation limit at scan start or scan end. If there are no complaints, the program has not found any of the obvious errors it is programmed to look for. It should be mentioned that a common error is to mistype a source name. The program treats this as a source for which no position or gain information is available so it puts in incorrect defaults.

If the form CHEck,DEC is used, the DEC file must be printed out after exiting from OBSERV. The printout is obtained by typing

$JOB

$EXEc PRInter,,U1

after which the DEC-10 printer will print out the CHEck results with a header MODCOMP.DAT. There is only a single DEC file in the MODCOMPs, so check with your neighbor to avoid interference problems.

When the source list file is finished and checked out, you can then catalog it on disk by typing

CATalog

after which the workspace of OBSERV containing the newly prepared or modified source list file will be stored on disk in the so-called OBS area under the name given when you first ran the OBSERV program. If there was a file there with the same name, it will replace it with the new file, backing up the old one under a name consisting of a period followed by up to seven of the letters of the file name. At the same time you are EXITed from OBSERV and end up at MODCOMP monitor program level, which is where you are when you run OBSERV or SEDIT.

Sometimes you may choose to EXIT from OBSERV without cataloging. This is done by typing

EXIT

after which you are back at monitor level. You can then run OBSERV again and RECover the old source list file from the workspace.

Before listing the possible OBSERV commands and OBSERV identifiers, let us classify the OBSERV commands according to their behavior. There are three classes of OBSERV commands. Commands of the first type execute some function as soon as they are typed and terminated with a carriage return. Most OBSERV commands are like this. The second type of OBSERV command requires further action or input before any function is executed. Examples of the second type of command are the USE,CR and CHECK commands previously discussed. Finally, there are two commands of the third type which you put into a special mode where a specific action is carried out an indefinite number of times until terminated by typing a ./<command> and a carriage return. Commands of the latter type are the ADD command already mentioned and the CHAnge command that has not yet been discussed.

Finally, it should be mentioned that OBSERV is oriented towards a pointer that is always located at one of the 1 to N card images in a source list file. Additions, changes, etc. are all made by going to the line number to be changed or added on to. The user will need to keep in mind the location of this pointer in many aspects of using OBSERV.

(c) List of OBSERV Commands with their Syntax and Purpose

There are a large number of OBSERV commands. The following is a list and description of the major ones:

Table V-3

OBSERV Commands

Class	Name	Syntax	Purpose
1	BACk	BAC n	Backspace pointer n card images.
1	CAL	CAL LIST	List recognized calibrators.
1	CAL	CAL name1,...,nameN	Identify these names as calibrators.
1	CATalog	CAT	Catalog source list file on disk.
1	DELete	DEL n,m	Delete lines numbered n through m.
1	DUPlicate	DUP n,m	Duplicate lines n through m here.
1	DURation	DUR	Convert stop times to durations.
1	EXIt	EXI	Exit from OBSERV to monitor level.
1	FORward	FOR n	Move pointer n lines forward.
1	GOTo	GOT n	Go to line n.
1	ID	ID,lastname,number	Supply name and programmer number.
1	INFormat	INF,id1,id2,...,idN	Define ADD input format.
1	LINe	LIN	Type out line number of pointer.
1	LISt	LIST	Type out source list contents.
1	MODify	MODify,id1= ,id2=	Modify one or more things on card.
1	OUTformat	OUT,id1,id2,...,idN	Specify list output format.
1	PRInt	PRI	Type out line where pointer is.
		PRI,n	Type out next n lines, without pointer being moved.
1	RECover	REC	Recover last source list made.
		REC,filename	Recover source list filename.

1	SET	SET,id1= ,id2=	Set values of identifiers.
1	STArttime	STA hh,mm,ss	Convert durations to stop times, assuming LST start hh mm ss.
1	USE	USE,LIST	List source input list.
2		USE,CR	Read in source input cards.
2	CHEck	CHEck,device	Check source list putting output to specified device, SB1 or DEC.
3	ADD	ADD	Begin mode of adding source request cards one after another, starting after current line.
3	CHAnge	CHA,identifier,n	Change this identifier in the next n card images.
3	CHAnge	CHA,identifier	Change this identifier in successive card images (asking for a new value each time), until stopped.

(d) List of OBSERV Identifiers

Identifiers are specific parameters specified by the observer or by default in various OBSERV commands. Each identifier corresponds to a parameter of a source request card, an LO card, an antenna wrap (AN) card, a line (LI) card, or a moving source (PM) card. The following are the major OBSERV identifiers and their syntax or possible values.

Table V-4

OBSERV Identifiers

Identifier	Possible Values and/or Syntax
BANd	LL, CC, UU, KK corresponding to 20, 6, 2, and 1.3 cm and 18 or 21. First letter is for IF channel A, second for IF C.
CALibrator	A, B, C, D, E, F codes for calibrators, C is generic.
DEC	Declination specified as dd mm ss.sss
DURation	hh mm ss format, specified duration of an observation when there is a $ in column 14.

EPOch

Blank	Epoch 1950.0 position
C	Epoch 2000.0.
D	Position apparent position of date
Yyyyy	Position for equinox of yyyy.0

GAIn Integer gain code such that

Gain Code	0	1	2	3	4	...	8
20 or 6 cm flux	<2	<4	<8	<16	<32		<256 Jy
2 or 1.3 cm flux	<6	<12	<24	<48		...	<768 Jy

LO1xx First local oscillator frequency for IF channels
xx = AB or CD, where permissible values are:

19.3, 19.4, 19.6, 19.7, 19.9, 20.0	GHz	for 2 cm
17.2, 17.6, 17.8, 18.2, 19.3	GHz	for 1.3 cm
-3.2		for 20 cm

LOSYx Frequency synthesizer setting, in MHz,
for x = A, B, C, or D, where permissible values are
$50*n \pm 10$

MODe Observing mode, with

blank	for normal interferometer mode
PA or PC	for single dish pointing mode, IFs A or C
IA or IC	for interferometer pointing mode, IFs A or C
D	for delay setting mode
TF	for front end testing mode

NAMe Source name with 8 or fewer characters, no imbedded blanks or commas

ODU Source observation duration in format hh mm ss

CDU Calibrator observation duration in format hh mm ss

PMDRA Moving source right ascension rate (seconds per day)

PMDDEc Moving source declination rate (arcsec per day)

PMEPOch Epoch for moving source coordinates in format hh mm ss.
Date for epoch is date of observing.

QUAlifier Numerical source qualifier, integer less than 32768

RA Right ascension in format hh mm ss.sss

STOptime Local sidereal stop time in format hh mm ss
ss may be omitted if STOPTIME is last thing specified

WIDth Bandwidth in format wwww, where w = 0 means 50 MHz
= 2 means 12 MHz
= 4 means 1.5 MHz

(e) An Example using the OBSERV Program

Let us follow up the introduction to running the OBSERV program and the listing of OBSERV commands and identifiers by going through an example. This example corresponds to actual observations carried out September 15, 1978. There are two sources in the program, Nova Vulpecula 1976 and Nova V1500 Cygni. The scheduled period for these observations is from 1700 LST on one day to 0500 LST on the next day. The positions for the two objects are epoch 1950.0 with (RA, DEC) = ($19^h27^m04.06^s$, + $20^o21'43.3''$) and ($21^h09^m52.818^s$, + $47^o56'41.29''$), respectively. From Figure V-5 one finds that the hour angle limits for the two novae are about ± 6^h for one object and ± 7^h40^m for the other object, which we will hereafter refer to as NVUL76 and V1500CYG, respectively, corresponding to the names we will assign in the OBSERV program. Thus, NVUL76 is observable from about 1330 to 0130 LST while V1500CYG is observable from about 1330 to 0450 LST.

The first step in preparing the program is to punch source input cards. Using the keypunch in the control room at the VLA site, we punch, in free field format, the following three cards:

```
NVUL76    19 27 04.06  +20 21 43.3    0 0 0 0
V1500CYG  21 09 52.818  47 56 41.29   0 0 0 0
$$
```

where gain codes of 0 are assigned to the sources for L, C, U, and K bands, and the card with $$ in columns 1 and 2 is the End Of File card for the MODCOMPs.

Since NVUL76 is the primary source in the program, we plan to observe it along with the nearby calibrator 3C395, also known as 1901+319, from 1700 to 0130 LST. The purpose of the program is to measure the flux of the source at 20 cm, 6 cm, and 2 cm as it is evolving from an optically thick thermal radio source to an optically thin radio source. Three months previously, NVUL76 was 7, 14, and 14 mJy, respectively, at these three wavelengths. We decide to adopt a strategy of observing CAL-SOURCE-CAL at each wavelength once an hour. We also decide to observe 3C286 first, since it is a primary flux calibrator, so the less well-known flux density of 3C395 can be boot-strapped from 3C286. We know that V1500CYG has evolved to the optically thin state so we plan to observe it only at 6 cm. The plan is thus to observe 3C286 with the following schedule:

3C286	20 cm	10 min
3C286	6 cm	5 min
3C286	2 cm	5 min

followed by observations of NVUL76 paired with 3C395 with the following cycle:

3C395	20 cm	3 min
NVUL76	20 cm	14 min
3C395	20 cm	3 min
3C395	6 cm	3 min
NVUL76	6 cm	14 min
3C395	6 cm	3 min
3C395	2 cm	3 min
NVUL76	2 cm	14 min
3C395	2 cm	3 min

and then, after 0130 LST, to observe V1500CYG paired with the calibrator 2005+403 with the following cycle:

2005+403	6 cm	4 min
V1500CYG	6 cm	26 min

every half hour from 0130 to 0500 LST.

With a set of source input cards and a specific plan for the observing program, one is ready to prepare the source list file with OBSERV. The following is most of the dialogue one might have with the computer to accomplish this, with occasional comments on the right that describe the rationale for each step.

$JOB	Typed by you to start things out.
$$	Response by the computer.
$OBSERV,RMHAH3	Run OBSERV, assigning file name.
ID,HJELLMING,11	Type identification information.
USE,CR	Type after loading source input cards.
EOF found	Response when cards have been read in.
USE,LIST	Type request to list source input info.
NVUL76 19 27 04.060 +20 21 43.30 0 0 0 0	
V1500CYG 21 09 52.818 +47 56 41.29 0 0 0 0	
SET WIDTH=0000	Select 50 MHz bandwidth.
INF,NAME,BAND,DURATION	Specify ADD inputs format.
ADD	Initiate ADD mode.
NAM BAN DUR	Prompt with ADD input format.
3C286 LL 0 10 0	First scan on 3C286.
3C286 CC 0 5	Second scan at 6 cm.
3C286 UU 0 5	Etc.
3C395 LL 0 3	
NVUL76 LL 0 14	
3C395 LL 0 3	
3C395 CC 0 3	
NVUL76 CC 0 14	
3C395 CC 0 3	
3C395 UU 0 3	
NVUL76 UU 0 14	
3C395 UU 0	
./LIST	Terminate ADD mode and type source list.

```
 1 /.HJELLM  11
 2  3C286     $00 10 00 13 28 49.66    +30 45 58.70    LL    C 2 0000
 3  3C286     $00 05 00 13 28 49.66    +30 45 58.70    CC    C 2 0000
 4  3C286     $00 05 00 13 28 49.66    +30 45 58.70    UU    C 0 0000
 5  3C395     $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
 6  NVUL76    $00 14 00 19 27 04.06    +20 21 43.3     LL      0 0000
 7  3C395     $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
 8  3C395     $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
 9  NVUL76    $00 14 00 19 27 04.06    +20 21 43.3     CC      0 0000
10  3C395     $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
11  3C395     $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
12  NVUL76    $00 14 00 19 27 04.06    +20 21 43.3     UU      0 0000
13  3C395     $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
Got 13                           Move pointer to line 13.
DUP 5 13                         Duplicate lines 5-13 after line 13.
GOT 13                           Repeat cycle six more times.
DUP 5 13
GOT 13
DUP 5 13
GOT 13
DUP 5 13
GOT 13
DUP 5 13
GOT 13
DUP 5 13
GOT 13
DUP 5 13                         Now we have cycle repeated for 8 hours.
GOT 5                            Start CHAnge of cards 5 and 6 to
CHA DUR                            adjust first cycle so it will end
                                   at 1830 LST and allow for move time.
0 8 0
 5  3C395     $00 08 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
./FOR                            End CHAnge and skip forward to card 6.
```

```
CHA DUR
0 19 0
 6  NVUL76      $00 19 00 19 27 04.06    +20 21 43.3     LL      0 0000
./PRI                       End CHAnge mode.
 6  NVUL76      $00 19 00 19 27 04.06    +20 21 43.3     LL      0 0000
LIST                        Look at resulting source list.
 1 /.HJELLM  11
 2   3C286      $00 10 00 13 28 49.66    +30 45 58.70    LL    C 2 0000
 3   3C286      $00 05 00 13 28 49.66    +30 45 58.70    CC    C 2 0000
 4   3C286      $00 05 00 13 28 49.66    +30 45 58.70    UU    C 0 0000
 5   3C395      $00 08 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
 6  NVUL76      $00 19 00 19 27 04.06    +20 21 43.3     LL      0 0000
 7   3C395      $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
 8   3C395      $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
 9  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     CC      0 0000
10   3C395      $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
11   3C395      $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
12  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     UU      0 0000
13   3C395      $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
14   3C395      $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
15  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     LL      0 0000
16   3C395      $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
17   3C395      $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
18  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     CC      0 0000
19   3C395      $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
20   3C395      $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
21  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     UU      0 0000
22   3C395      $00 03 00 19 01 02.312   +31 55 13.75    UU    C 2 0000
23   3C395      $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
24  NVUL76      $00 14 00 19 27 04.06    +20 21 43.3     LL      0 0000
25   3C395      $00 03 00 19 01 02.312   +31 55 13.75    LL    C 2 0000
26   3C395      $00 03 00 19 01 02.312   +31 55 13.75    CC    C 2 0000
```

27	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	CC	0 0000
28	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
29	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
30	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	UU	0 0000
31	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
32	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
33	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	LL	0 0000
34	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
35	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
36	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	CC	0 0000
37	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
38	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
39	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	UU	0 0000
40	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
41	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
42	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	LL	0 0000
43	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
44	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
45	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	CC	0 0000
46	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
47	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
48	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	UU	0 0000
49	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
50	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
51	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	LL	0 0000
52	3C395	$00 03 00 19 01 02.312	+31 55 13.75	LL	C 2 0000
53	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
54	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	CC	0 0000
55	3C395	$00 03 00 19 01 02.312	+31 55 13.75	CC	C 2 0000
56	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000
57	NVUL76	$00 14 00 19 27 04.06	+20 21 43.3	UU	0 0000
58	3C395	$00 03 00 19 01 02.312	+31 55 13.75	UU	C 2 0000

```
59  3C395      $00 03 00 19 01 02.312  +31 55 13.75   LL   C 2 0000
60  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    LL     0 0000
61  3C395      $00 03 00 19 01 02.312  +31 55 13.75   LL   C 2 0000
62  3C395      $00 03 00 19 01 02.312  +31 55 13.75   CC   C 2 0000
63  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    CC     0 0000
64  3C395      $00 03 00 19 01 02.312  +31 55 13.75   CC   C 2 0000
65  3C395      $00 03 00 19 01 02.312  +31 55 13.75   UU   C 2 0000
66  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    UU     0 0000
67  3C395      $00 03 00 19 01 02.312  +31 55 13.75   UU   C 2 0000
68  3C395      $00 03 00 19 01 02.312  +31 55 13.75   LL   C 2 0000
69  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    LL     0 0000
70  3C395      $00 03 00 19 01 02.312  +31 55 13.75   LL   C 2 0000
71  3C395      $00 03 00 19 01 02.312  +31 55 13.75   CC   C 2 0000
72  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    CC     0 0000
73  3C395      $00 03 00 19 01 02.312  +31 55 13.75   CC   C 2 0000
74  3C395      $00 03 00 19 01 02.312  +31 55 13.75   UU   C 2 0000
75  NVUL76     $00 14 00 19 27 04.06   +20 21 43.3    UU     0 0000
76  3C395      $00 03 00 19 01 02.312  +31 55 13.75   UU   C 2 0000
SET BAND=CC                     Set up for pure 6 cm observations.
INF NAME DURATION               Change ADD format to shorter form.
GOT 76                          Go to end of list for more ADDing.
ADD                             Get into ADD mode for V1500CYG scans.
NAM DUR                         Computer prompt with ADD input format.
V1500CYG 0 26                   Type in enough to make a full hour
2005+403 0 4                      of the new cycle.
V1500CYG 0 26
2005+403 0 4
./LIST                          Terminate ADD mode and list results.
 1 /.HJELLM  11
 2  3C286      $00 10 00 13 28 49.66   +30 45 58.70   LL   C 2 0000
 3  3C286      $00 05 00 13 28 49.66   +30 45 58.70   CC   C 2 0000
 4  3C286      $00 05 00 13 28 49.66   +30 45 58.70   UU   C 0 0000
```

```
 5  3C395       $00 08 00 19 01 02.312  +31 55 13.75    LL    C 2 0000
 6  NVUL76      $00 19 00 19 27 04.06   +20 21 43.3     LL      0 0000
 7  3C395       $00 03 00 19 01 02.312  +31 55 13.75    LL    C 2 0000
 8  3C395       $00 03 00 19 01 02.312  +31 55 13.75    CC    C 2 0000
    etc.
76  3C395       $00 03 00 19 01 02.312  +31 55 13.75    UU    C 2 0000
77  V1500CYG    $00 26 00 21 09 52.818  +47 56 41.29    CC      0 0000
78  2005+403    $00 04 00 20 05 59.560  +40 21 01.80    CC      2 0000
79  V1500CYG    $00 26 00 21 09 52.818  +47 56 41.29    CC      0 0000
80  2005+403    $00 04 00 20 05 59.560  +40 21 01.80    CC      2 0000
GOT 80                          Go to end of list with pointer.
DUP 79 80                       Duplicate a half hour of new cycle.
GOT 80
DUP 77 80                       Duplicate another hour of cycle.
GOT 80
DUP 77 80                       Duplicate one more hour to get 3½ hours.
STARTTIME 17 00 00              Convert to LST's with start at 1700.
3C286       17 10 00 13 28 49.66   +30 45 58.70     LL    C 2 0000
3C286       17 15 00 13 28 49.66   +30 45 58.70     CC    C 2 0000
3C286       17 20 00 13 28 49.66   +30 45 58.70     UU    C 0 0000
3C395       17 28 00 19 01 02.312  +31 55 13.75     LL    C 2 0000
NVUL76      17 47 00 19 27 04.06   +20 21 43.3      LL      0 0000
3C395       17 50 00 19 01 02.312  +31 55 13.75     LL    C 2 0000
3C395       17 53 00 19 01 02.312  +31 55 13.75     CC    C 2 0000
    etc.
V1500CYG    04 26 00 21 09 52.818  +47 56 41.29     CC      0 0000
2005+403    04 30 00 20 05 59.560  +40 21 01.80     CC      2 0000
V1500CYG    04 56 00 21 09 52.818  +47 56 41.29     CC      0 0000
2005+403    05 00 00 20 05 59.560  +40 21 01.80     CC      2 0000
CAT                             Catalog source list file as RMHAH3.
```

Study of the previous example will reveal the main reason why the user is advised to plan observing in terms of cycles and durations of scans. The conversion to LST can then be made if desired and it tends to be less work than planning everything in terms of LST stop times. We will not illustrate the results of CHEck because the error messages are fairly self-explanatory.

The previous discussion of OBSERV should be sufficient to get the user started. There are many other possibilities or ways to use the OBSERV program. When the user desires more information, the manual for the OBSERV program may be consulted.

(f) Modifying Old Source List Files

It is very common that the user will want to add on to a previously prepared source list file or have some other reason to start with one to make modifications for future use. This can be done either with OBSERV or the MODCOMP text editor called SEDIT.

Modifying source list files with OBSERV is a simple process. Using one of the variants in the previous discussion, you type:

```
$JOB
$OBSERV,newfilename
ID,lastname,programmernumber
RECover,oldfilename
```

after which you can LIST the RECovered source file to verify that it is the one you want before ADDing or CHAnging the files as desired. When finished, you CATalog the file. In the above example we showed the general form where a file named "oldfilename" is modified and given a new name "newfilename". You can, of course, use the same name, in which case the result of a CATalog command will be that the new version will replace the old version.

There are a few circumstances when it may be much more efficient to use the text editor SEDIT to change source list files. The following shows how to use SEDIT to accomplish this:

$JOB	The usual preface to running a program.
$EXE SEDit	Run SEDit.
ASS USL OBS	Assign User Source Library to OBS.
POSition filename	Set up to edit file "filename".
RANdom	Get in mode for any changes of file.
LIST	List file with line numbers.
GOTo linenumber	Go to line where change begins.
CHAnge :old: :new: 1 ncards	Change old to new once in ncards cards.
OVER :^ xxxx: ncards	Replace text with xxxx text.
FORward n	Move pointer forward n lines.
BACk n	Move pointer back n lines.
LINenumber	Type out current line number of pointer.
PRI n	Type current and next n-1 lines.
SCAT filename	Catalog file with backup of old.

The OVER command is useful for small changes where you have a typed-out line under which you replace selected characters. The space after OVER is required, as are the four character word OVER and the caret after the semicolon. Nonblank characters replace characters in the old line at the column where they are located. Other characters are not changed. To replace a character in the old line with a blank, type an & in the appropriate position.

The CHAnge command is the command with great advantage in making a large number of replacements quickly. Any character string can be replaced with any other character string for as many card images as desired. For example, to change from LL band to CC band in all card images with LL band designation, you can type

GOT n

CHA :LL: :CC: 1 999

which will result in 999 or fewer changes in band in and after line number n.

The similarity of some commands in SEDIT and OBSERV is not accidental. The OBSERV program actually calls on SEDIT to execute its catalog command. However, the OBSERV program is safer and more oriented to source list preparation. SEDit has the insidious danger that you may inadvertently replace character strings that you had not expected to change, so use SEDit with caution and only if you are sure of what you are doing.

4. 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 subarrays; 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 the array, VLA array operators are trained and 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

Until the full 27-antenna VLA is in normal operation, there will be specific limitations on the extent to which malfunctioning equipment will be repaired for the observer's convenience. Much of the time there will be a technician available to locate and replace specific modules found to be faulty; however, a full set of replacement modules may not always be available. Equipment repairs are not generally undertaken during the night. Major efforts to fix equipment that require diverting senior technicians and engineers from their construction duties will not always be made. The array operator is the best single source of advice concerning whether fixes of problems are practicable and, generally, when fixes are possible, they will initiate all necessary action themselves. Beyond certain points, the organization in 1978 and 1979 is not yet geared up to providing equipment repair on the time scale that an observer might like. The user is asked to use restraint in requesting repair services because individuals are sometimes too quick to respond, to the detriment of their prime responsibilities to the construction project.

(c) The Start-up Process

Unless the observer is scheduled to follow after other observers, a process known as start-up may precede observing. This occurs when the array has been out of operation. Normally, observing begins anew at 1630 local time, following start-up. Hours before, the array operator, with any needed help from programmers, technicians, and engineers, begins a process of pointing antennas and bringing their electronics under functioning control of the on-line computer system. The observer generally has no involvement in this process; however, when equipment is found to be malfunctioning, the observer is frequently consulted about priorities in attempting repairs. Once available antennas are being pointed under control of standard source list files, observations to check pointing constants are carried out and various programs exercising the electronics are run. If an antenna has just been moved to a different station, this antenna is normally operated in a test subarray for several hours to determine pointing and baseline constants. If everything goes well, the observing desired by the observer will begin at roughly 1830; however, this beginning time is not guaranteed if necessary tasks have not been completed. The array operator, in consultation with VLA staff, is responsible for deciding when to make the transition from start-up to astronomical observing.

(d) Operation of a Test Subarray

A few antennas are designated for primary use in a so-called test subarray that runs simultaneously but independently of the astronomical subarrays. The user will have use of these antennas only when no tests are under way. Any antenna designated as part of the test subarray may be taken from the observer's subarray at any time, although in practice some warning and consultation occurs ahead of time. The observer is advised to become aware of which antennas are designated for astronomical observing and which may or may not be used in the test subarray.

(e) On-line Programs and Displays

In late 1978 there are two terminals and a line printer in the control room devoted entirely to communication with the on-line computers and, through them, with the antennas and electronics. The line printer continuously prints out any messages of complaint generated by the on-line data checker program, CHK. The two terminals are normally used for specific status or data displays, but can be used to send specific commands to antennas and electronics, which override on-line control programs. They are also used to generate special status listings on the line printer. One of the terminals is mostly used for display of antenna status parameters and the sending of commands. The other terminal tends to be used mainly for column listings of output visibility data, but also is used for modification of control files and skipping around source lists to change the observing situation. The program listing visibility data on on-line terminal or line printer is called D10. It lists a single baseline at a time. When D10 is running on a terminal, the baseline displayed can be selected by typing

/D10/R,antenna1,antenna2

where two antenna numbers are specified. Only if the operator is satisfied that you can do this safely should you do this yourself. Mistakes made on this terminal can crash the entire system.

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.

(f) 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 program called FILLER is always kept running by the array operators while observing is going on, in the DEC-10. 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, most users will 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 mess up the operation of the array and the gathering of data by making mistakes. The worst case would be to destroy the 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, it is recommended that the user run DEC-10 programs during the observing process to monitor the course of the observations. Frequently one can learn things that lead to changes in the observing program.

(g) 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. The array operators routinely display calculations of antenna gain on an on-line terminal; and they regularly run a standard batch job in the DEC-10 that gives an overall listing of the performance of antenna gains and phase centers. This CHECK listing is available to the user. Under many circumstances no other evaluation of system performance on calibrators will be necessary. However, some situations arise where the above-mentioned evaluation reveals that some antenna-IF channels are behaving erratically and the exact nature of the problem is not obvious. 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 that will be discussed in Chapter VI provide the primary means for this type of evaluation. As an example, plots of calibrator phases should be stable and simple curves. 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. As an example, it has happened that the clock is set in error by, say, a second. A user reporting very rapid phase wind in calibrators causes the array operator to check the clock setting, sometimes finding it in error.

In the final VLA system such investigation activities are unlikely to be needed on the part of observers. However, while the array is being constructed and equipment fixes and evaluation programs and procedures are under development, enough problems will arise that it is useful for observers to participate in the process of monitoring calibrators.

(h) 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 during "shadowing" when very close antennas are pointed in particular directions. This is due to leakage from vertex room equipment. Even nastier, because of its unpredictability, are occasions when problems with correlator and sampler hardware occur 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 that 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. It is strongly recommended that other experiments involving strong sources be accompanied with some mapping of "blank" sky. A half-hour investment in this at some convenient place in the observing schedule will be sufficient to reveal these effects if they are present during the observing run.

(i) Useful Practices

There are a number of useful practices that will help the observer. We mention a few of them here because often only hindsight will teach you about when certain things are needed.

(1) Copies of ANTENNAS and Source List Files

During and after the observing the user 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.

(2) Tables of Properties of Usable Antennas

Observing with a dozen or so antennas leads to special problems in keeping track of what antennas were where and with what operational equipment. Because of this, it is strongly recommended that observers adopt a habit of recording this information in a form convenient for reference during the process of working with the data. Each user will want to tailor such bookkeeping to his own needs and taste, but everyone will need something. Prime examples of this type of record-keeping are tables of antenna location and tables of which antennas and IFs are working at which frequencies. Let us illustrate this by showing the type of record-keeping that was useful for an observing run in February 1978 when nine antennas were nominally available for observing but in the end selected subsets of only seven were really usable. Before the observing started, one could walk into the control room and, using the status boards on the wall, make the following list of possibly available antennas:

1	2	3	4	5	6	7	8	9	10
AW1	AW4	DW3	AW2	DW2	AW3	DE4	AW5	AW6	DE3
W8	W32	W3	W16	W2	W24	E4	W40	W48	E3
0.48	5.2	0.09	1.6	0.045	3.2	0.15	7.7	10.5	0.09 km.

In practice, at that time, the Wn, En, Nn notation was not used so we show both the old information about stations and the new system. We also write down rough values for the radial distances along arms as an indicator of station separation. Examination of this information will reveal that most people will have difficulty remembering which antenna pairs have what spacings. It is, therefore, useful to adopt some scheme that will help. One such scheme is to rearrange the above information in the order of radial distance along arms, e.g.,

10	7	5	3	1	4	6	2	8	9
DE3	DE4	DW2	DW3	AW1	AW2	AW3	AW4	AW5	AW6
E3	E4	W2	W3	W8	W16	W24	W32	W40	W48
0.09	0.15	0.045	0.09	0.48	1.6	3.2	5.2	7.7	10.5 km.

With this type of table you can see at a glance what antenna pairs will have what spacing to first order. It does not give two-dimensional information, of course, but it will help. The user will find the order of antennas very useful in the MATRIX display of the LISTER program because it will result in amplitude displays where spacings increase or decrease down columns and across rows. The user will very quickly be able to grasp information about the relative amounts of flux in different spacing, using this type of order and this display.

In practice, you quickly discover that some antennas are not available to you. In this case, for example, antenna 10 was not really operational, at times 3 and 5 were used in the test subarray, and certain antennas did not work well at all frequencies. By the time the observing run was finished and the maximum set of usable antennas for each band was known, it could be described by a table like the following:

1FEB11[14,11] Data Base

	7	1	4	6	2	8	9
	E8	W8	W16	W24	W32	W40	W48
1465	7		4	6	2		9
4885	7	1	4	6	2	8	9
14765			4	6			9
22485	7		4	6	2		9

The user will find it invaluable to develop habits of recording tables like the above for reference while working with the data. The gaps in this table resulted after editing was complete, since some antennas and IFs were recording "bad" data that were not flagged appropriately. For this reason, tables of this type tend to evolve from the initial one you would make at the beginning of an observing run to the one you have when the process of evaluating and editing is complete.

Finally, all time specifications in the off-line computer system are oriented towards IAT dates and times. For this reason, the user should, from the beginning, identify occurrences that affect the data in terms of IAT dates and times. Since the uniform syntax for an IAT date is yyMONdd, where yy are the last two digits of the year, MON is the first three letters of the month, and dd is the date, the user might as well start using this notation at the beginning. Similarly, IAT times are expressed as hh:mm:ss, so the user might as well get used to this early. In this way recorded information about occurrences affecting data can easily be turned into commands for listing, plotting, flagging, etc.

CHAPTER VI

OFF-LINE DATA PROCESSING

1. Theory of Off-line Data Processing

Before discussing the practical details of the programs that carry out off-line data processing in the DEC-10 and its dedicated minicomputers at the VLA site, let us review the objective of this processing and formulate a notation for discussing it in terms of equations.

Off-line data processing has three principal stages:

1. visibility data processing,
2. map computation, and
3. map processing and display.

Visibility data processing begins with the measured visibilities, flags which are judgments of quality generated in the on-line computer system, and associated information supplied by the on-line system. One generally has data for N antennas, giving N(N-1)/2 measured complex visibilities that we will denote by double-primed quantities

$$V''_{jkp}(t) = A''_{jkp} \exp\,[i\Phi''_{jkp}(t)] \qquad \text{(VI-1)}$$

for 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 ($j < k$), and

$$p = 1, 2, 3, 4, 5, 6, 7, 8$$

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, one will also encounter variables for single antennas and for those the convention will be

$$p = 1, 2, 3, 4$$

or

$$p = A, C, B, D \quad ;$$

with circularly polarized signals for which

A or C = L for left circular polarization

and

B or D = R for right circular polarization.

Let us also denote the visibilities put out by the on-line system by single-primed quantities

$$V'_{jkp}(t) = A'_{jkp} \exp \left[i\Phi'_{jkp}(t)\right] \quad . \qquad \text{(VI-2)}$$

The V'_{jkp} data form the starting point of nearly all data processing in the off-line system.

Finally, let us denote visibilities that have been subjected to all off-line corrections and calibration as unprimed quantities

$$V_{jkp}(t) = A_{jkp} \exp\left[i\Phi_{jkp}(t)\right] \quad . \qquad \text{(VI-3)}$$

With this double-primed, single-primed, and unprimed notation for visibilities, amplitude, phase, etc., we can distinguish between the major stages of processed VLA data.

The on-line system also associates with each V'_{jkp} an integer flag that we will denote by $f'_{jkp}(t)$. In the off-line system the meaningful values of f'_{jkp} are:

$$f'_{jkp} = \begin{array}{llll} 0 & \text{for} & \text{"good"} & \text{data} \\ 1 & \text{for} & \text{"fair"} & \text{data} \\ 2 & \text{for} & \text{"poor"} & \text{data} \\ 3 & \text{for} & \text{"bad"} & \text{data} \end{array} \qquad \text{(VI-4)}$$

corresponding to value judgments about data quality programmed into the on-line data flagging program which uses monitor data as the main basis for judgment.

Editing in the off-line system means: (1) upgrading or degrading flag values based upon user judgment and off-line programs; and (2) choosing a PASSFLAG level for each processing step indicating what level of data quality is acceptable for the purpose at hand. Most of the time $f'_{jkp} = 3$ means the data really are unusable, but the choice between $f'_{jkp} = 0$, 1, or 2 is a matter of judgment not yet completely worked out for the VLA programs.

Let us use the notation f_{jkp} to denote the final flags the user has associated with his data after he has imposed his own judgments of value. In most cases, hopefully, the f_{jkp} will be the same as the f'_{jkp}.

In the off-line processing of visibility data the original V'_{jkp} stored on disk are never modified in any way. The process of correction and calibration is completely based upon application of a so-called "gain" table which contains complex correction and calibration factors to be applied to complex visibility data. The user then gets corrected and calibrated data by specifying that the gain table be applied in obtaining data for some purpose, whether it is listing, plotting, map-making, or anything using visibility data.

As discussed in detail in Chapter II, 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:

$$V'_{jkLL} = g'_{jL}(g'_{kL})^{*}V''_{jkLL} \qquad \text{(VI-5)}$$

$$V'_{jkRR} = g'_{jR}(g'_{kR})^{*}V''_{jkRR} \qquad \text{(VI-6)}$$

$$V'_{jkLR} = [g'_{jR}(g'_{kL})^{*}V''_{jkLR}-D'_{jL}V'_{jkRR}-(D'_{kR})^{*}V'_{jkLL}]\ \exp\ (-2i\phi_{p}) \qquad \text{(VI-7)}$$

$$V'_{jkRL} = [g'_{jL}(g'_{kR})^{*}V''_{jkRL}-D'_{jR}V'_{jkLL}-(D'_{kL})^{*}V'_{jkRR}]\ \exp\ (+2i\phi_{p}) \qquad \text{(VI-8)}$$

where ϕ_p is the parallactic angle given by

$$\phi_p = \tan^{-1}[(\cos \lambda_{lat} \sin H)/(\sin \lambda_{lat} \cos \delta - \cos \lambda_{lat} \sin \delta \cos H)] \quad . \qquad \text{(VI-9)}$$

In Equation VI-9, 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

$$V_{jkLL} = g_{jL}(g_{kL})^{*}V'_{jkLL} \tag{VI-10}$$

$$V_{jkRR} = g_{jR}(g_{kR})^{*}V'_{jkRR} \tag{VI-11}$$

$$V_{jkLR} = [g_{jR}(g_{kL})^{*}V'_{jkLR}-D_{jL}V_{jkRR}-(D_{kR})^{*}V_{jkLL}]\ \exp\ (-2i\phi_p) \tag{VI-12}$$

$$V_{jkRL} = [g_{jL}(g_{kR})^{*}V'_{jkRL}-D_{jR}V_{jkLL}-(D_{kL})^{*}V_{jkRR}]\ \exp\ (+2i\phi_p)\ . \tag{VI-13}$$

Note that the parallactic angle correction is applied either in Equations VI-7 and 8 or VI-12 and 13, but not in both.

The on-line system passes the g'_{jp} and D'_{jL} on 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

$$V_{jkLL} = g_{jL}(g_{kL})^{*}V''_{jkLL} \tag{VI-14}$$

$$V_{jkRR} = g_{jR}(g_{kR})^{*}V''_{jkRR} \tag{VI-15}$$

$$V_{jkLR} = [g_{jR}(g_{kL})^{*}V''_{jkLR}-D_{jL}V_{jkRR}-(D_{kR})^{*}V_{jkLL}]\ \exp\ (-2i\phi_p) \tag{VI-16}$$

$$V_{jkRL} = [g_{jL}(g_{kR})^{*}V''_{jkRL}-D_{jR}V_{jkLL}-(D_{kL})^{*}V_{jkRR}]\ \exp\ (+2i\phi_p)\ . \tag{VI-17}$$

Both on-line and off-line correction and calibration factors are stored on disk in the DEC-10 in a gain table as

$$g'_{jR}(t_n),\ g'_{jL}(t_n),\ D'_{jR}(t_n),\ D'_{jL}(t_n)$$

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 a constant time interval assigned at the time on-line output is transferred to the off-line computer system. When the gain table is initially set up in the DEC-10, the primed gains and cross-polarizations are those applied to the data in the on-line system and the unprimed gains and cross-polarizations are initialized with the real parts unity and the imaginary parts zero for the g's, and the D's set to zero.

The process of doing off-line correction and calibration is then one of determining the g_{jp} and D_{jp}, putting them in the gain table, and thereafter specifying that you want to process data that has had the gain table applied.

2. Off-line Computer Hardware

(a) The DEC-10

The off-line computer system available for use at the VLA site in 1978 consists of a medium-size general purpose computer linked to a number of minicomputer systems devoted to special tasks. The main computer in this system is a DEC-10 (Digital Equipment Corporation) with 320K words (36-bit) of core memory and six disk drives, with each disk having 20 million 36-bit words of storage. The DEC-10 also has five magnetic tape units which can handle almost all standard densities of both 7 and 9 track, one-half inch, magnetic tape. Other peripherals are a 600 line/minute upper/lower case line printer, a 300 card/minute card reader, a card punch, and a large number of terminals.

Figure VI-1 is a photograph of portions of the DEC-10 computer, showing card punch/reader and line printer in the foreground, the control console with CPU and five 64K core memory units in the background, magnetic tape drives on the right, and various device control units on the left.

During the 1978-1979 period the DEC-10 will function both as a data processing computer and as a central control computer for two linked minicomputer systems dedicated to map-making and map display/analysis tasks. Figure VI-2 is a schematic diagram showing portions of the DEC-10 system and the two linked minicomputer systems available at the end of 1978. Eventually the DEC-10 will function largely as a control computer for a larger number of linked minicomputer systems that will do most of the actual data processing.

The DEC-10 is a time-sharing computer which can run up to thirty jobs in either batch or interactive (via terminals) mode. Most of the terminals connected to the DEC-10 are scattered around various rooms and offices in the VLA control building; however, there is a telephone link between the DEC-10 and a terminal in the Socorro offices. From the single Tektronix 4012 storage tube terminal, or one of the 16+ refresh terminals, one can: run programs interactively; edit text files stored on disk; prepare batch control files; submit jobs to be run in batch mode; obtain job, system, and file storage information; and communicate with other terminals and the linked minicomputer systems. The DEC-10 system of managing file storage on disk allows users to store, access, and manipulate various types of disk files, including text, source programs, relocatable program modules, executable program modules, and data base files containing visibility data, monitor data, or maps.

Each user is assigned a user or programmer number (PN) upon first arrival at the VLA site. This establishes two potential areas of disk storage that "belong" to the user while processing off-line data at the VLA site: the area with project number (P) 14 is where visibility and map data files are stored; and the area with project number 13 is where working files, temporary files created by the observer, and various programs will be automatically stored.

The mechanics of data processing in the DEC-10 begin with the user logging on the computer in the user's 13 area by supplying project and programmer numbers, i.e., 13, PN, followed by a password assigned when the programmer number is assigned. After this is done, the user initiates desired data processing tasks in some judicious combination of interactive and batch operation. At the end of a data processing session on a terminal the user finishes by logging off the computer and the terminal is freed for other users. Card input and output is available in principle; however, the system is dominantly oriented towards terminal communication to run programs or prepare batch jobs.

Most of the data processing software in the DEC-10 is written in SAIL, an extended version of ALGOL. Although FORTRAN and BASIC are available as programming languages, no subroutines or other aids are available to make access to VLA data possible from programs written in these languages; however, for those interested in direct access to data, an interpretive language called CANDID, created in the course of VLA software development, is available. Most users will deal only with a

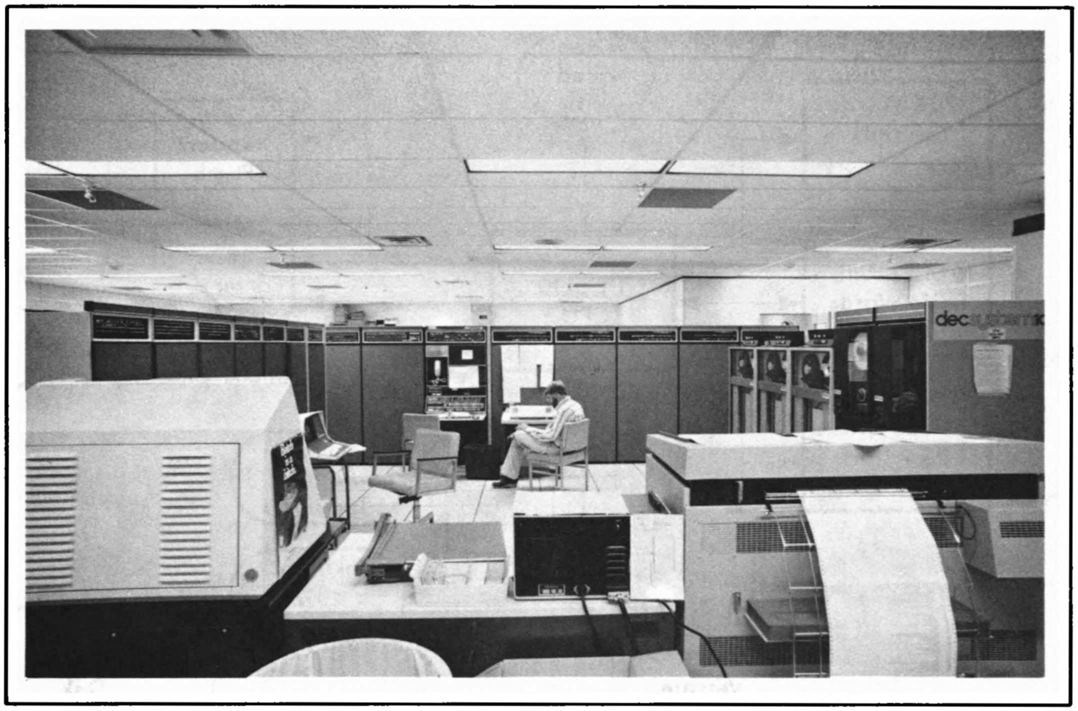


Figure VI-1. A photograph of the DEC-10 portion of the off-line computer system with line printer and card reader/punch in foreground.

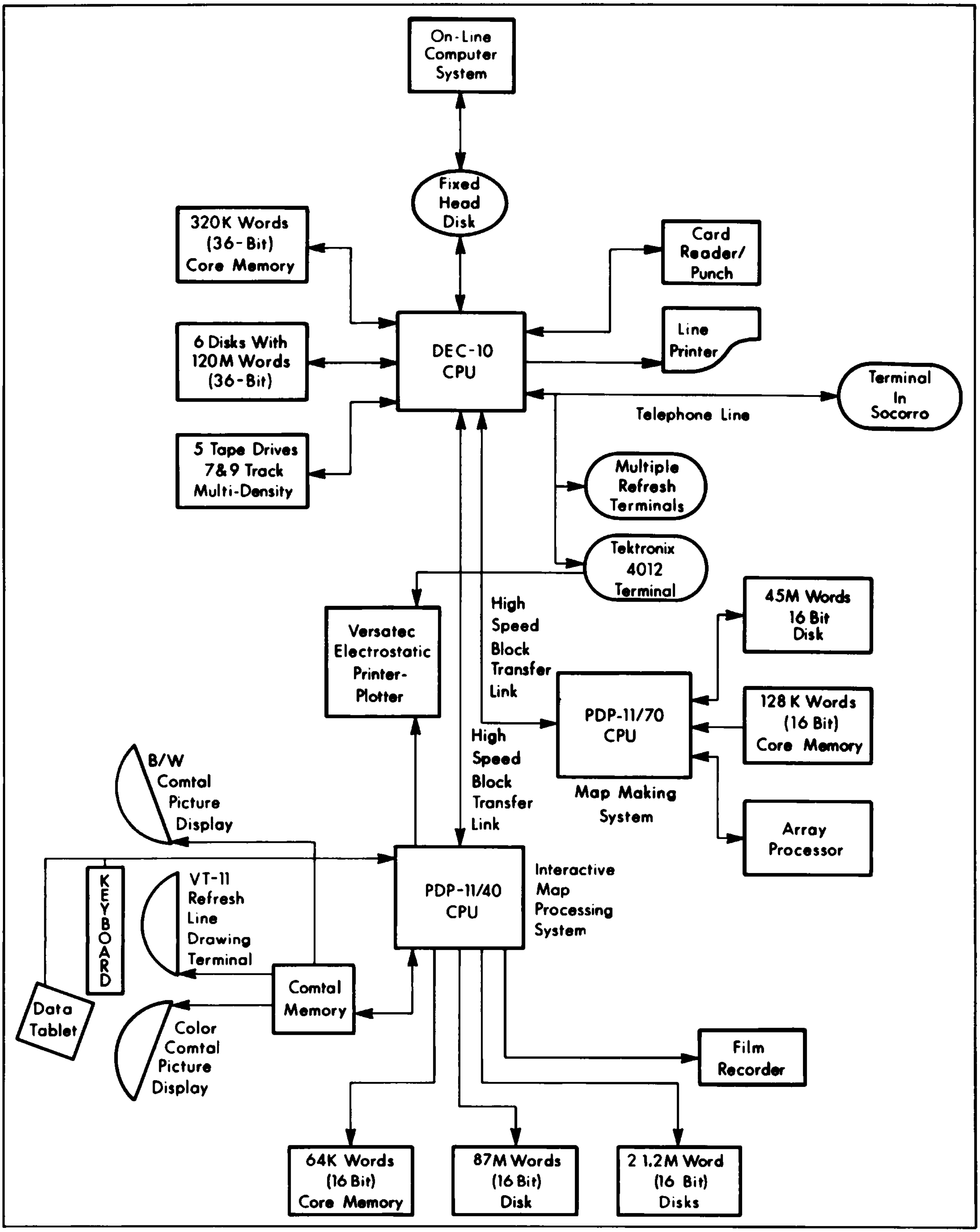


Figure VI-2. A schematic diagram of the off-line computer system hardware.

set of standard programs which carry out the major data processing task.

(b) The PDP 11/40 Map Processing System

One of the minicomputer systems attached to the DEC-10 by a fast, block data transfer link is a PDP 11/40 with special peripherals devoted to map display and analysis tasks. A schematic of portions of this system is shown in Figure VI-2. This system is based upon a COMTAL image display system consisting of a black and white TV monitor with 256 possible brightness levels and a color monitor with 64 possible colors. Both monitors are basically TV screens with 256X256 picture elements or pixels, a nondestructive cursor, and optional 1-bit overlays. The controlling PDP 11/40 minicomputer of the map display and analysis system has 64K 16-bit words of core memory, two disk drives with 1.2 million words of storage each, and one (RP06) disk drive with 45 million words of storage. In addition to the COMTAL system with its own internal memory for image storage and function memory for dynamically changing the mapping of image point values into pixel values, the PDP 11/40 contains a DEC-VT-11 refresh line drawing CRT with 1024X1024 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. The hard copy device for this system (and also for the TEK 4012 terminal attached to the DEC-10) is a VERSATEC electrostatic printer-plotter. This device is used to print text, line drawings, and 16 level pseudo gray scale images based upon a dot matrix with 2000 dots per line. Figure VI-3 shows a user sitting in front of the map display and analysis system, controlling the magnetic contact pen of the data tablet with one hand. In the two parts of this figure, the screen on the left is the black and white TV monitor, the screen on the right is the color monitor, and the keyboard is in front of the VT-11 screen, which is showing a menu in Figure VI-3a and a cross-section plot through the image in Figure VI-3b. The object displayed on all COMTAL screens is the planetary nebula NGC40, with a 6 cm VLA map in Figure VI-3a and an optical picture of the nebula in the Hβ line in Figure VI-3b.

User operation of the map display and analysis system is obtained via a menu-oriented program called IMPS (Interactive Map Processing System).

(c) The PDP 11/70 Map-making System

The second dedicated minicomputer system with a fast, block data transfer link to the DEC-10 is a map-making system based upon a PDP 11/70 with 128K 16-bit words of core memory, a 45 million word disk (RP06), and a Floating Point Systems array processor that carries out a major portion of the map computing. By late 1978 this system will be carrying out most of the mapping tasks formulated by jobs that seem to be run in the DEC-10. In Figure VI-2 a portion of the schematic is devoted to the map-making system and its connection with the rest of the off-line computer.

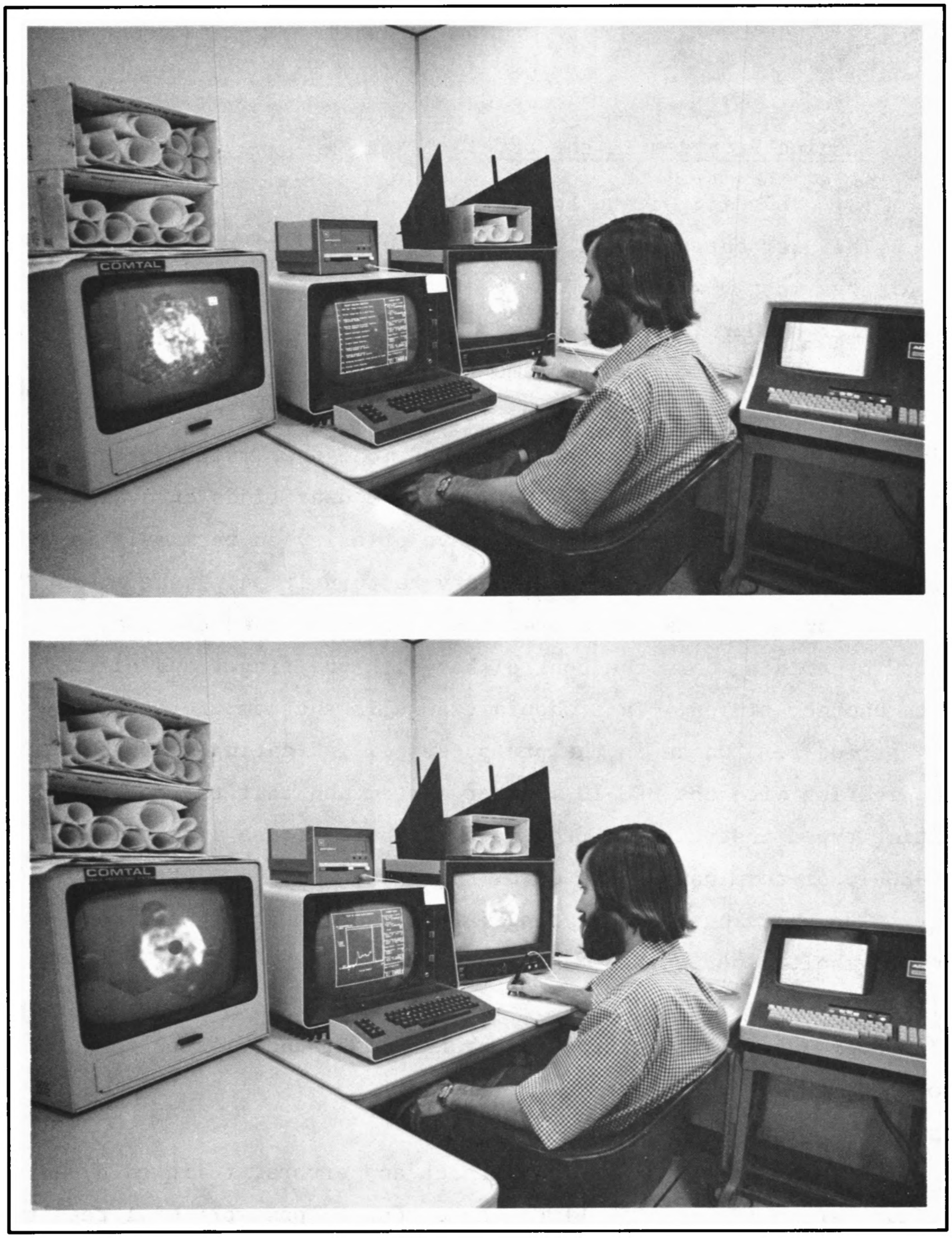


Figure VI-3. Photographs of the PDP 11/40-based map display and analysis system being used to look at radio (top) and optical (bottom) pictures of the planetary nebula NGC 40.

3. Running Programs in the DEC-10

(a) Logging On and Logging Off

The user carrying out VLA data processing at the VLA site communicates mostly with the DEC-10 of the off-line system. Once a programmer number (PN) and a password have been assigned to a user, it is then possible to run programs from an assigned [13,PN] area accessing visibility data and maps in a [14,PN] data storage area on disk. Before this can be accomplished, the user must log on to a terminal attached to the DEC-10. Once the user finds an available terminal, and observers will always have priority on terminals in observers' offices, it may be necessary to turn it on. Once it is turned on, or if it was on before, the user is advised to type CNTRL/C by holding down the control key with one finger and hitting C with another finger. This should result in the computer typing out a period (.), which is the prompt symbol indicating that you are communicating with the DEC-10 monitor system and that the machine is awaiting typed instructions from you. If no response is obtained, the DEC-10 or terminal may be down.

The user logs on by typing (after the computer-generated prompt symbol, a period):

login 13,PN

followed by a carriage return (CR) or NEW LINE, and, if the computer recognizes this, it types:

Password:

whereupon 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 # for a prompt symbol, indicating that you should type 13,PN again, and once again you will be asked for your password. Sometimes the computer will complain about your attempt to log on, requesting 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/f
followed by a carriage return or NEW LINE, to log the miscreant off so that you can log on.

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. We will assume this from now on and not mention typing the carriage return again.

Once the computer has recognized your project, programmer number and password, it will give you some logging on information plus any notices intended for computer users. After this, the period prompt symbol should appear. This always means that the computer is ready to accept monitor system commands or requests to run, compile, etc. programs.

At the end of a session using a terminal, it is essential to log off the terminal and computer. The best way to do this is to type, after a period prompting symbol:
k/f

or

k/fast

The user should be warned that, if his session has produced more files on disk than are available under his "quota", the computer will, while running a batch job, delete files in a seemingly arbitrary manner until the quota limit is reached, before logging you off. Your quota and the amount of free disk space that you have left is one of the important pieces of information that you get when you log on. The amount of disk space you have used and your accumulated CPU time is given to you after you log off. Beware of exceeding your quota because you can lose a lot of work in the form of carefully prepared files.

(b) The DEC-10 File System

Many different entities 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 data reduction programs, etc. All disk files MUST 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 character, 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 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] data area, the file specifications must always contain the [P,PN] information.

(c) Monitor System Commands

There are a number of monitor system commands that can be executed if the computer is prompting you with a period. These commands mainly manipulate files, provide information about files, or provide information about the status of various jobs, queues, or portions of the system. The following table is a brief summary of some of the more important ones that nearly every user will have some occasion to need:

Monitor System Command	Short Form and Syntax	Purpose of Command
direct	dir	List directory of all disk files in the [P,PN] you are logged into.
	dir [P,PN]	List directory of any [P,PN] area.
	dir [P,PN]/L	Put directory listing into an LPT file.
print	print *	Print out all files with extension LPT.
	print name.ext	Print the file name.ext on the line printer.
	pri name.ext[P,PN]	Print out the file name.ext[P,PN].
	pri	Type out the queue list of line printer jobs waiting to be printed.
type	type name.ext	Type contents of name.ext file on your terminal screen.
	type name.ext[P,PN]	Type out the file name.ext[P,PN].
systat s	sy s	Type out system status information.
systat f	sy f	Type out system disk file space information.
systat	sy .	Tell who is logged on this terminal.
queue	q	Type out status of batch and line printer queues.
submit	su	Type status of batch submission queue.
	su name	Submit name.CTL batch control job to the batch queue.
	su name.ext	Submit name.ext batch control job to the batch queue.
	su name=/kill	Delete job you have submitted to batch queue if it has not yet started execution.

copy name1.ext[P1,PN1] ← name2.ext[P2,PN2]		Copy file name2.ext[P2,PN2] into file named name1.ext[P1,PN1].
rename new.ext[P1,PN1] ← old.ext[P1,PN1]		Rename a file.
delete	del name.ext	Delete the file named name.ext.
	del junk.*	Delete all files with names of junk and any extension they might have.
	del *.ext	Delete all files with extension ext.
	del ?am?.?xt	Delete all files with the letters am and xt in names and extensions, but with any character before and after am, and any character before xt.

The use of the TYPE command, or any other thing 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. Typing a CNTL/s causes the listing to be suspended until a CNTL/q is typed to order resumption of the listing. It is, therefore, useful to develop a habit of getting ready to CNTL/s during a listing, otherwise the material will scroll up on the screen too fast for you to be able to read it under most circumstances. The user should also be warned that any time the terminal seems completely unresponsive, it is wise to try typing a CNTL/q because it is not uncommon for an inadvertent CNTL/s to have been typed.

(d) Special Control (CTRL) Characters

There are a number of special characters that accomplish specific things. We have already introduced CTRL/C, CTRL/S, and CTRL/Q. Since there are a number of other characters of this type that are very useful in terminal communication with the DEC-10, let us summarize them briefly. All are produced by holding the CONTROL key down with one finger, usually the little finger of the left hand, while depressing another key with another finger. On some terminals the CONTROL key is labeled CTRL and we use the latter designation. The various control characters and their function are as follows:

Character	Purpose
CTRL/C	Terminate the current task being executed from the terminal, generally returning to monitor level.
CTRL/S	Stop the display of characters on the terminal, usually used to stop text from scrolling off the screen.
CTRL/Q	Continue the display of characters on the terminal screen that was previously terminated with a CTRL/S.
CTRL/H	Back space one character. Equivalent to BKSP key on some terminals.
CTRL/T	Type out a one or two line display of exactly what the computer is doing for you.
CTRL/L	A form feed. Will clear screen of an ADDS terminal.
CTRL/U	Erase the current input line, making no use of it.
CTRL/O	Stop (or restart) output to the terminal without stopping the program.

(e) Running Programs

The general way of running a program that is part of the DEC or the VLA software is to type, after the usual monitor prompting period:

r PNAME

where PNAME is the program name. Examples from the VLA data reduction system are:

r DANEEL

r lister

r visplt

r gtbcor

r antsol

r MAKMAP

r SEEMAP

where 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 a prompt symbol, which is almost always an asterisk (*). At this point the user can type command lines in a syntax appropriate to the particular program. In almost all cases, simply typing HELP will result in a display of information about the commands available in a 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]

with the right program name and area specification.

(f) Editing Text Files - The SOS Program

The user must know how to prepare or edit text files in the DEC-10 mainly because that is the best way to prepare and submit batch jobs. The text editor is a program called SOS (for Son Of Stop-gap, a text editor written by the Stanford Artificial Intelligence Laboratory when a preliminary version called STOPGAP was replaced). 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, and

Edit: oldfil.ext

*

if you were previously editing a file named OLDFIL.EXT. In the first case, the proper response is to type the name of the file (with extension) you wish either to create or reedit. Once this is done, the computer will prompt you with an asterisk (*) indicating it is ready to accept an SOS command. In the second case, you immediately get into a mode for SOS commands for editing the last file you were working on with SOS in the current LOGIN session.

If you have asked to SOS a file that does not yet exist in your area, SOS immediately puts you in 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 line writing mode, a carriage return, or hitting the NEW LINE key, results in the termination of one line and the start of another line with a different line number. You exit from line writing mode to get back to SOS command level by hitting the ESC key or typing CTRL/[, depending upon the terminal.

A more general way to invoke SOS is the following:
sos name.ext[P,PN]
where you immediately supply name, extension, and 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 the following is a list of elementary commands that will suffice for most purposes until the user is experienced and ready for the full complexity and power of SOS;

Command Name	Command Symbol	Possible Syntax	Purpose of Command
print	P	p	Type current line and the next 15 lines.
		pn	Type line number n.
		pn:m	Type lines n through m.
		p↑:*	Type all lines from beginning to end for the current page.
		p/.	Type all lines on current page.
insert	I	in	Insert lines after line n.
		in,s	Insert lines after line n with a new increment s for line numbers.
replace	R	rn	Replace line number n.
		rn:m	Replace lines n through m.
delete	D	dn	Delete line n.
		dn:m	Delete lines n through m.
number	N	n	Renumber all lines with current increment.
		n,s	Renumber all lines, changing the line number increment to s.
lineprinter	L	l	Produce an LPT file of the text file for print out by typing PRINT asterisk after exiting from SOS back to monitor level.

exit	E	e	Exit from SOS back to monitor level, storing newly edited text in the file and backing up the old version if any.
world-save	W	w	Save current version of text file, with backup.
substitute	S	s<t1>$<t2>$n:m	Substitute the character string <t1> for the character string <t2> for all instances where it occurs in lines n through m, where $ means hitting the ESC key or CNTRL/[.
transfer	T	tm,nl:n2	Transfer lines nl through n2 to a position following line m.
help	H	h	Type a (very garrulous) discussion of command formats.

The default increment in line writing mode in SOS is 100, and text lines then have numbers 100, 200, 300, etc. An insert command will result in in-between line numbers. Line insertion terminates when lines would become out of order; to continue you either use the insert command with a smaller line increment or renumber with the n command before using the insert command.

The following is an example of creating and submitting a batch job control file that did not exist before, an activity the user will need to carry out frequently:

Text of Example	Comments
.sos list.ctl	Run SOS request.
Input: LIST.CTL	Computer response.
00100 .r lister	Type 1st line running LISTER.
00200 dbname may21[14,11]	Supply data base name.
00300 band 6cm	Select band for listing.
00400 antennas 1 2 3 4 5 6 7 8 9 10	Supply list of antennas.

00500 list scan amp/jy	Name listing options.
00600 average scan vector	Name averaging options.
00700 outfile lpt:cmay21	Request LPT output with label.
00800 go matrix	Execute matrix form of listing.
00900 finish	Exit from LISTER to monitor level.
01000 .print *	Print out all LPT files.
01100 $	ESC or CNTRL/[to end type-in mode.
*e	Exit from SOS.
[DSK:LIST.CTL[13,11]]	Computer response as it exits from SOS after putting current text in
EXIT	the file LIST.CTL[13,11] on disk.
.submit list	Submit to batch queue.

In the above example all commands from r lister to print * will not be executed until the job is run in the batch stream, and the command submit list
is the command which places the job in the batch queue where it waits its turn to be run in the batch stream. The LISTER commands will be discussed shortly. We use it here as 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.

If we then wanted to substitute AMPSCALAR for VECTOR averaging, add a specification of source to be listed, and resubmit this new job to the batch stream, the full computer dialogue would be

```
.sos list.ctl

Edit: LIST.CTL

*svector$ampscalar$600
```

```
average scan ampscalar

*i300

00350  source 3C286:*

*e

.submit list/time:122
```

where this time we overrode the default time specification of 5 minutes by a specification of 1 minute and 22 seconds.

There are many more SOS commands and powerful capabilities for intraline editing; however, to avoid confusing the beginning user with all the possibilities, we will not discuss them. When ready for it, the user is referred to an SOS manual.

(g) Batch Execution of Programs

We have now mentioned how to run data reduction programs interactively on a terminal and how to prepare a batch control file with SOS to run the job in batch mode. Let us now further discuss essential aspects of doing data reduction in batch and running batch control files. We will also mention how batch control files can be run interactively.

Once a batch control file has been prepared with SOS, the general syntax for submission to the batch queue is:

```
submit <file specification>/time:hhmmss/out:n/after:+hhmmss
```

where we have introduced three optional switches that specify special things about the batch job. Without the time specification the job would have been run with a default limit of 5 minutes run time, which is related to CPU time. The OUT switch is n=0 if the LOG file is to be stored on disk but not printed out on the line printer when the job is completed, and is n=1 if the LOG file is to be stored on disk AND printed out on the line printer when the job is completed. The default gives a printout of the log file. The optional AFTER switch can be used to delay submission to the batch stream by a specified period of time; thus you can submit long jobs for delayed execution during the night.

The execution of every batch job results in the production of a log of statements executed in the job, which looks identical to what you would see on the terminal screen if the same commands were run interactively; however, other information is supplied at the beginning and end and all lines have labels including the time of execution of the line. The log file is always given the same name as the batch control file and the extension LOG. Successive execution of batch jobs with the same name results in additions to the log file of the appropriate name. Thus the user will frequently want to delete old log files before resubmitting jobs with the same name.

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 with only two or three actually being executed at any one time. By typing the following, as mentioned previously:

```
submit
```

the user can obtain on a terminal a summary of the jobs in the batch queue. An example to show a typical result from doing this is the following text showing what is written into the log file for a batch job named EXAMP.CTL which contains only the commands

```
submit

print

queue

sy s

sy f
```

so you can see an example of a number of previously mentioned status request commands:

```
10:43:27 BAJOB  BATCON version 13(1071)-1 running EXAMP sequence
10:43:27 BAJOB  9925 in stream 2 for HJELLMING
10:43:27 BAFIL  Input from DSKEO:EXAMP.CTL[11,11]
10:43:27 BAFIL  Output to  DSKEO:EXAMP.LOG[11,11]
10:43:27 BASUM  Job parameters
                Time:00:00:30    Unique:YES    Restart:NO

10:43:27 MONTR
10:43:27 MONTR  .LOGIN 11/11
10:43:30 USER   JOB 19 6.03 Version 5.1 TTY37
10:43:37 USER   [LGNJSP Other jobs same PPN:17]
10:43:37 USER   1043    25-Aug-78    Fri
10:43:41 MONTR
10:43:41 MONTR  .submit
10:43:48 USER   INPUT QUEUE:
10:43:48 USER   PTY  PPN    JOB    SEQ PRIO  NAME      TIME   CORE AFTER
10:43:48 USER   6   11,11  EXAMP   9925 10 HJELLMING 00:00:30  25
10:43:49 USER   5    1,2   BACKUP 9922 10 FAILSA    03:00:00  25
10:43:49 USER       13,24  FILL3  9921 10 DADDARIO  00:29:59  25
10:43:49 USER   4   13,115 LPLOT  9923 10 PERLEY    00:20:00  25
10:43:51 USER
10:43:51 USER   TOTAL (includes all jobs)
10:43:51 USER   INP:   4 jobs;  03:50:29 sec. run time
10:43:51 MONTR
10:43:51 MONTR  .print
10:43:55 USER   The queue is empty
10:43:55 MONTR
10:43:55 MONTR  .queue
10:43:59 USER   INPUT QUEUE:
10:43:59 USER   PTY  PPN    JOB    SEQ PRIO  NAME      TIME   CORE AFTER
10:43:59 USER   6   11,11  EXAMP   9925 10 HJELLMING 00:00:30  25
10:43:59 USER   5    1,2   BACKUP 9922 10 FAILSA    03:00:00  25
10:44:00 USER       13,24  FILL3  9921 10 DADDARIO  00:29:59  25
10:44:00 USER   4   13,115 LPLOT  9923 10 PERLEY    00:20:00  25
10:44:26 USER
10:44:26 USER   TOTAL (includes all jobs)
10:44:26 USER   INP:   4 jobs;  03:50:29 sec. run time
10:44:26 MONTR
10:44:26 MONTR  .sy s
10:44:28 USER   1     [OPR]   DET      DAEMON    18+SPY
10:44:28 USER   2     [OPR]   DET      MIC       4+14
10:44:28 USER   3     [OPR]   POJ25    QUEUE     5+15
10:44:28 USER   4     [OPR]   P1J25    BATCON    7+6
```

```
10:44:28 USER    5     [OPR]     P2J25    LPTSPL    5+7
10:44:28 USER    6     [OPR]     P3J25    OPROMO    6+13
10:44:28 USER    7     11,153    14       SOS       9+16
10:44:28 USER    8     13,115    P4J4     VISPLT    58+144
10:44:28 USER    9     [OPR]     P5J4     BACKUP    26
10:44:28 USER   10     10,14      1       QUEUE     5+15
10:44:28 USER   11     13,115    26       QUEUE     5+15
10:44:29 USER   12     13,146     4       PARTS     33+13
10:44:29 USER   13     10,14      0       SOS       9+16
10:44:29 USER   14     13,113    11       SYSTAT    13+SPY
10:44:29 USER   15     13,146     5       DIRECT    6+20
10:44:29 USER   16     11,31      2       SAIL      100+58
10:44:29 USER   17     [SELF]    12       QUEUE     5+15
10:44:29 USER   18     13,77      3       COMPIL    5+8
10:44:29 USER   19     [SELF]    P6J4     SYSTAT    13+SPY
10:44:29 USER   25     [OPR]     CTY      OPSER     2+5
10:44:29 USER   Jnn is the controlling job, Pnn corresponds to TTY31+nn
10:44:29 USER
10:44:29 USER
10:44:29 MONTR
10:44:29 MONTR  .sy f
10:44:30 USER
10:44:30 USER   System File Structures:
10:44:30 USER   Name    Free     Mount
10:44:30 USER   DSKG    28106    18
10:44:30 USER   DSKB    13772    21
10:44:30 USER   DSKC    17032    21
10:44:30 USER   DSKD    18802    21
10:44:30 USER   DSKE    29492    21
10:44:30 USER   DSKF    3644     18
10:44:30 USER   Total Free 110848
10:44:30 USER
10:44:30 MONTR
10:44:30 MONTR  .KJOB DSKEO:EXAMP.LOG=/W/B/Z:0
10:44:34 KJOB   Other jobs same PPN
10:44:37 LGOUT  Job 19, User [11,11] Logged off TTY37 1044 25-Aug-78
10:44:37 LGOUT  Another job still logged in under [11,11]
10:44:37 LGOUT  Runtime 8.20 Sec
```

The above example illustrates a large number of different things. First of all, it is an example of the LOG of a batch job. Secondly, it shows that batch jobs are treated like a LOGIN and LOGOUT from a fictional terminal (TTY37). Thirdly, it contains an example of the result of typing submit; the numbers under the header PTY (pseudo-teletype) indicate that three jobs are running in three separate batch streams, and there is another waiting its turn in the batch queue. One batch stream is for jobs under five minutes, another is for jobs under ten minutes, and a third batch stream is for longer jobs. For all batch jobs, in execution or waiting, various pieces of information about the origin of the job and its option switches are supplied. Fourthly, you see that the print queue at the time contained nothing. Jobs waiting in the print queue would have been listed, with a few asterisks attached to the listing for a print request in the process of coming out on the line printer. Fifthly, you see the result of a "sys s" request, which shows information about all interactive, batch, and systems jobs running in the DEC-10 at that instant. Sixthly, you see the result of a "sys f" request giving the number of 128 word blocks free on the disk structures of the DEC-10. The user will need to be aware of the space free on DSKF and DSKG because all data bases for all users are stored there during processing, and sometimes you will run into space problems that can be cured only by consultation with VLA staff.

Batch control files can also be executed interactively. This is accomplished by typing, after a period prompting symbol,

do name.ext

where name.ext is the name of the batch control file, with a CTL or any other extension. The contents of the name.ext file will then be executed, line by line, on your terminal. This feature is not a substitute for batch submission, but rather allows careful preparation of complicated commands where it is desirable to minimize typing errors or allow repetition of complicated procedures that vary only in small ways from one time to the next.

A limited version of batch operation can also be obtained interactively without any use of batch control files. One of the commands available in the standard programs is a BATCH command.

With these commands the parameters of a single program can be set up interactively and then submitted to the batch stream by a single command typed into the terminal without exiting from the program. This will be further discussed when the standard commands are discussed.

(h) Handling Magnetic Tapes

During 1978 the DEC-10 system is not organized with operators always on duty to mount and dismount magnetic tapes. The system is organized so that individual users can and must handle their own tape mounts and dismounts. The typical user will be doing this only when creating data bases from tape using FILLER and MONFIL, or when storing visibility and map data bases using BACKUP.

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 monitor level so that, after the usual period prompting symbol, he can type that tape mount request:

mount mta:name/reelid:Vnnn

if tape number Vnnn is to be read only, or

mount mta:name/reelid:Vnnn/wenable

if the tape is to be written upon. The designation mta: means any of the 9 track, 1600 bpi tapes the user will normally be dealing with, "name" is a name assigned by the user, and Vnnn is the tape reel ID number.

Once the request for a tape mount is typed, the user proceeds to the console teletype (or DECwriter) of the DEC-10, where he will normally see a typed out request for a mount of tape Vnnn on m(0), m(1), or m(2), which will be one of the three 9 track, 1600 bpi tape drives. One then mounts the tape on the requested tape drive, after checking the status of the write-ring to make sure it is removed if you want to read the tape, and inserted if you want to write on the tape. When you approach the tape drive, the door will normally be open, with the tape lock handle disengaged. You put the tape, with the reel jacket still on, on the right-hand reel, and then you engage the tape lock handle. After this, you hit a sequence of buttons at the top of the tape drive: RESET, LOAD, START. The tape should then automatically load and position itself at the beginning of the tape, indicating so by the READY and then the BOT light coming on. You then proceed to the console terminal or DECwriter and type

m-n

where n is the tape drive number the tape is mounted upon. 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, at monitor level:

skip mta:n files

and when you get the period prompt again, you are ready to go with FILLER, MONFIL, or BACKUP.

Occasionally you will want to run more than one job, getting data off a single tape. In that case you may need to do a tape REWIND to get back to the beginning of the tape. This is accomplished by typing, at monitor level:

rewind mta:

after which you may need to skip to the file you are interested in before running the program needing the tape.

After you have finished using the tape, you then type at monitor level:

unload mta:

deassign mta:

and the tape will rewind and unload itself, with the door to the tape drive open but the tape lock handle still engaged. You then go to the tape drive, disengage the tape lock handle, and remove the tape before storing it in the proper place in the tape storage room just off the computer room.

If you have any problems, almost anybody wandering into the computer room will have a reasonable chance to help you out, and, if the array operator is not occupied with more urgent activities, he or she will be able to help you out.

4. Visibility, Monitor, and Map Data Bases - The Standard Data Files

(a) Introduction

Before discussing any of the programs that process data in the off-line computer system, it is important to have some idea of where data associated with an observing run are located. The on-line computer system provides data to the DEC-10 in two forms: on separate magnetic tapes containing visibility and monitor data; and on the fixed head disk where visibility data are written in real time. For the latter, a program called FILLER can be made to run "continuously" in the DEC-10 during observing, so visibility data can then be accessed in nearly real time in the DEC-10. The same FILLER program takes visibility data off magnetic tapes and places it in data bases on disk in the DEC-10. Similarly, a program called MONFIL gets monitor data off tape and places it in a monitor data base. The phrase "data base" is a name commonly used for data written in specific formats on one or more related disk files.

There are three principal types of data bases the user will deal with in the DEC-10: visibility data bases, monitor data bases, and map data bases.

(b) Visibility Data Bases

The visibility data base is always generated in the DEC-10 by a program called FILLER, which takes as input either data written in real time on the fixed head disk while observing, or data taken from magnetic tapes written in real time while observing. The filler program writes the visibility data base files into the users [14,PN] area. Three different files are generated by FILLER:

dbname.INX[14,PN]	which contains an index of information global to a particular observing scan, but no actual visibility data or flags,

dbname.VIS[14,PN]	which contains visibility data (V'_{jkp}) and flags (f'_{jkp}), and
dbname.GAI[14,PN]	which contains a table of antenna-based complex gain calibration data: (g'_{jR}, g'_{jL}, D'_{jR}, D'_{jL} and g_{jR}, g_{jL}, D_{jR}, D_{jL})

where DBNAME is a file name of six or fewer characters that can be assigned by the user, but defaults to the form

nMONdd

when FILLER runs in real time, where

n = subarray number (1, 2, 3, 4, or 5)
MON = JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, or DEC
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 obtained from the visibility data tape. During the off-line calibration process a file named dbname.CAL[14,PN] is created every time the ANTSOL program solving for antenna-based calibration constants is run. In addition, successive execution of standard data processing programs results in successive additions to a text history file named dbname.HST[14,PN]. This file can always be typed or printed out to see the accumulative history of the data processing applied to a visibility data base.

For those who would like some idea about the detailed contents of the visibility data base, the following is a formal description of the contents of the INX, VIS, and GAI files:

dbname.INX[14,PN]:

1 INX (0:NSCANS-1)	STRUCTURE	
2 nifs	INTEGER	number of ifs (2 or 4)
2 source	CHARACTER (10)	source name
2 qual	INTEGER	source qualifier
2 mode	INTEGER	observing mode
2 cal	INTEGER	calibrator code
2 gain	INTEGER	gain code used on-line
2 sort	INTEGER	sorting status code
2 avgt	REAL	averaging time in sec.
2 sptr (1:2)	INTEGER VECTOR (1)	pointers to data entries
2 apt	INTEGER	
2 gptr (1:2)	INTEGER VECTOR (1)	pointers to gain entries
2 antbits	INTEGER	code listing antennas used
2 pos50	REAL VECTOR (2)	(ra,dec) epoch 1950
2 posobs	REAL VECTOR (2)	(ra,dec) epoch obs. time
2 startMJAD	REAL	scan start mod. Julian date
2 stopMJAD	REAL	scan stop mod. Julian date
2 startIAT	REAL	IAT time of scan start
2 stopIAT	REAL	IAT time of scan stop
2 LST	REAL	LST time at scan start
2 IFname (1:4)	CHARACTER (5)	IF label array
2 band (1:4)	CHARACTER (5)	band (IF) label array
2 freq (1:4)	REAL	freq (IF) array
2 bw (1:4)	REAL	bandwidth (IF) array
2 sumLO (1:4)	REAL	sumLO (IF) frequency array
2 FILLERID	INTEGER	version of FILLER used

2 obsol2	INTEGER	unused word
2 SI	REAL	Stokes I flux density
2 SQ	REAL	Stokes Q flux density
2 SU	REAL	Stokes U flux density
2 SV	REAL	Stokes V flux density
2 calgain	INTEGER	
2 padding (1:4)	REAL	

dbname.VIS[14,PN]:

1 VIS (0:NVISRECS-1)	STRUCTURE	
2 uv	HALFWORD VECTOR (2)	u and v in nanosec
2 bldate	HALFWORD	coded antenna IDs (j,k) and date
2 time	HALFWORD	IAT time
2 wwt	HALFWORD	w (delay) and weight in code
2 flags	HALFWORD	flag (f'_{jkp}) status info
2 data (1:nifs)	HCOMPLEX	(= V'_{jkp}, p = 1:nifs)

The 0 to NVISRECS-1 are integer pointers corresponding to the inx.sptr[1:2] stored in the DBNAME.inx record. Each inx.sptr[1:2] in an index record describes the beginning and ending pointers in a scan.

dbname.GAI[14,PN]:

1 GAI (0:NGAINRECS-1)	STRUCTURE	
2 date	REAL	modified Julian date
2 time	REAL	IAT time
2 nom (1:NANTENNAS,1:2)	COMPLEX	
2 corr (1:NANTENNAS,1:2)	COMPLEX	
2 pnom (1:NANTENNAS,1:2)	COMPLEX	
2 pcorr (1:NANTENNAS,1:2)	COMPLEX	

The integers 0 to NGAINRECS-1 are pointers corresponding to the inx.gptr[1:2] array in the DBNAME.inx file, and

$$\text{gai.nom(1:nantennas,1:2)} = g'_{jR} \text{ and } g'_{jL} \quad ,$$

$$\text{gai.pnom(1:nantennas,1:2)} = g_{jR} \text{ and } g_{jL} \quad ,$$

$$\text{gai.corr(1:nantennas,1:2)} = D'_{jR} \text{ and } D'_{jL} \quad ,$$

$$\text{gai.pcorr(1:nantennas,1:2)} = D_{jR} \text{ and } D_{jL} \quad ,$$

where j = 1:nantennas

(c) Monitor Data Bases

A program called MONFIL takes information from the monitor data tape produced in the on-line computer system while observing and produces a monitor data base. This data base consists of two files stored in a special disk area, [11,1]. If xyz are the first three letters of the month, and nm is the date the observing run begins, then MONFIL puts index or summary records into a file Mxyznm.IND[11,1] and monitor data arrays into a file named Mxyznm.MON[11,1].

Amongst the monitor data are the values of the 5 and 600 MHz round trip phase which are frequently useful for editing purposes. The measured system temperatures are also in the monitor data base and these data must be used by the GTTSYS program to carry out off-line corrections for system temperature variations.

(d) Map Data Bases

Radio maps made from edited, corrected, and calibrated data in a visibility data base are written into map data base files created by the MAKMAP program. Each map has a name supplied by the user and an optional category name. The map data array and associated information are written into a specific format in a file named

mapnam.XYZ[14,PN]	if the category is not used, and
mapnam.XYZ[14,PN,category]	if the category is used,

where X = is missing if it is a map made from real data, or
= B if it is a synthesized beam,
Y = I, Q, U, or V, depending upon which Stokes parameter is mapped, and
Z = L, 6, 2, or U, depending upon whether the map is for 20 cm, 6 cm, 2 cm, or 1.3 cm.

The following is a formal description of the contents of the current map data base:

1 map	STRUCTURE	
2 residue	CHARACTER (30)	Residual map name (if cleaned).
2 database	CHARACTER (30)	Visibility data base name.
2 mapname	CHARACTER (30)	Name of map.
2 beammajax	REAL	Major axis of clean beam.
2 beaminax	REAL	Minor axis of clean beam.
2 beamPA	REAL	Position angle of clean beam.
2 pad1 (1:3)	INTEGER	Three unused words.
2 gain	INTEGER	Gain factor from INX file.
2 source	CHARACTER (10)	Source name.
2 qual	INTEGER	Source qualifier.
2 cal	INTEGER	Calibrator or not, and type.
2 remarks	CHARACTER (40)	Text of remarks about map.
2 times (1:8,1:2)	REAL	Array of start/stop IATs.
2 dates (1:8,1:2)	REAL	Array of start/stop dates.
2 errorlevel	REAL	Passflag level of data in map.

2 antennas (1:28)	INTEGER	List of antennas used.
2 pad2 (1:4)	INTEGER	Four unused words
2 band	CHARACTER (5)	Observing band.
2 freq	REAL	Frequency of map (Hz).
2 bandw	REAL	Bandwidth (Hz).
2 avgt	REAL	Averaging time (sec) of data.
2 polariz	CHARACTER (5)	Stokes parameter of map.
2 ra1950	REAL	Right ascension of map center.
2 dec1950	REAL	Declination of map center.
2 raobs	REAL	Precessed map center RA.
2 decobs	REAL	Precessed map center Dec.
2 mapdate	REAL	Date map was made.
2 observer	INTEGER	Observer or programmer number.
2 dx	REAL	RA*cos Dec cell size (radians).
2 dy	REAL	Dec cell size (radians).
2 bscale	INTEGER	Binary scaling factor for map.
2 Nx	INTEGER	Number of cells in x coord.
2 Ny	INTEGER	Number of cells in y coord.
2 Imax	REAL	Maximum flux (Jy) in map.
2 xmax	REAL	x coord. of maximum.
2 ymax	REAL	y coord. of maximum.
2 Imin	REAL	Minimum flux (Jy) in map.
2 xmin	REAL	x coord. of minimum.
2 ymin	REAL	y coord. of minimum.
2 tweight	REAL	Sum of (u,v) plane points.
2 weighting	CHARACTER (5)	N (cell sum) or U (cell avg).
2 taper	CHARACTER (5)	Gauss or Lin taper function.
2 taperwidth	REAL	Sigma or distance to zero.
2 convolv	CHARACTER (5)	Box or Gauss(ian) convolution.
2 convwidth	REAL	Width or sigma of convolution.
2 xshift	REAL	Shift of map center relative
2 yshift	REAL	to tracking center.

2 aplgains	INTEGER	Was gain table applied?
2 undgains	INTEGER	Were real-time gains undone?
2 ufreq	REAL	Upper bound on frequency.
2 lfreq	REAL	Lower bound on frequency.
2 pad3 (1:13)	INTEGER	Thirteen unused words.
2 kind!of!map	CHARACTER (5)	MAP, AMP, COVER, or BEAM.
2 Ncx	INTEGER	x size of cleaned area.
2 Ncy	INTEGER	y size of cleaned area.
2 cx	REAL	Coordinates of center of
2 cy	REAL	cleaned area.
2 loopgain	REAL	Clean loop gain.
2 clnlimit	REAL	Minimum flux cleaned.
2 niter	INTEGER	Number of clean iterations.
2 nboxes	INTEGER	Number of areas cleaned.
2 W (1:10)	REAL	West, east,
2 E (1:10)	REAL	south, and north limits
2 S (1:10)	REAL	of selected regions
2 N (1:10)	REAL	(boxes) cleaned.
2 pad4 (1:5)	INTEGER	Five unused words.
2 maxampl	REAL	Maximum amplitude of input data.
2 Isub (1:4)	REAL	Intensities subtracted.
2 xsub (1:4)	REAL	Coordinates of subtracted
2 ysub (1:4)	REAL	intensities (radians).
2 ungrid	INTEGER	Inverse SINC applied to map?
2 components	INTEGER	Number of combined maps.
2 operation	INTEGER	Type of combination operation.
2 compwts (1:2)	REAL	Weights of combined maps.
2 compfiles (1:2)	CHARACTER (30)	Component file names.
2 pad5 (1:10)	INTEGER	
2 map (-Nx/2:-Nx/2-1,Ny/2:Nx/2-1)	HALFWORD	Scaled map array numbers.

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 them and their purposes.

Program 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 disk area [14,PN].
MONFIL	Takes monitor data from a monitor data tape and places it in IND and MON data base files on disk.
MONLST	Lists data for selected monitor data points on terminal or line printer.
MONPLT	Plots data for selected monitor data points on terminal or line printer.
FILANT	Gets antenna position information from visibility data tape and places it in a dbname.ANT[14,PN] file.
FLAGER	Modifies or lists flag (f_{jkp}) information in a dbname.VIS[14,PN] file of a visibility data base.
SETJY	Modifies or lists flux density (Stokes parameters) information in dbname.INX[14,PN] file of visibility data base.
LISTER	Lists on terminal or line printer selected visibility data with or without application of complex gain calibration.
VISPLT	Plots on terminal or line printer selected visibility data with or without application of complex gain calibration.
BASFIT	Solves for baseline errors for individual baselines, using information in a visibility data base.
GTBCOR	Puts antenna-based correction into gain table (.GAI file).
GTTSYS	Using monitor data information about system temperatures, puts gain factor corrections for system temperature variations into gain table (.GAI file).
ANTSOL	Using calibrator visibility data and gain table, solves for system gain and phase center calibration constants before storing in dbname.CAL[14,PN] file of data base.

GTBCAL	Applies ANTSOL-generated calibration constants in dbname.CAL[14,PN] file to gain table (.GAI file).
MAKMAP	Makes radio maps and/or synthesized beams from selected visibility data in data base, using all corrections and calibrations in the gain table.
SEEMAP	Displays map information in a map data base on terminal or line printer; or prepares map display file for COMTAL or other display in PDP 11/40 map display and analysis system.
CLNMAP	Uses the CLEAN algorithm to remove effects of sidelobes from dirty maps using dirty maps and dirty beams, with the final result being cleaned maps in a map data base.
DANEEL	Controls program inside of which all of the above data reduction programs can be run with parameter passing between programs and saving of final parameters of all programs executed under DANEEL control.
BACKUP	A DEC-10 system program with its own commands and syntax that is used to back up or store data base or other files on magnetic tape and then put them back on disk at a later time.
AVGVIS	Creates another data base with a longer averaging time, including all on a selected subset of the original data base.
DBCON	Concatenates selected data from one or two data bases into a third data base.

Figure VI-4 is a schematic diagram describing the usage and relationship between these programs and the visibility, monitor, and map data bases.

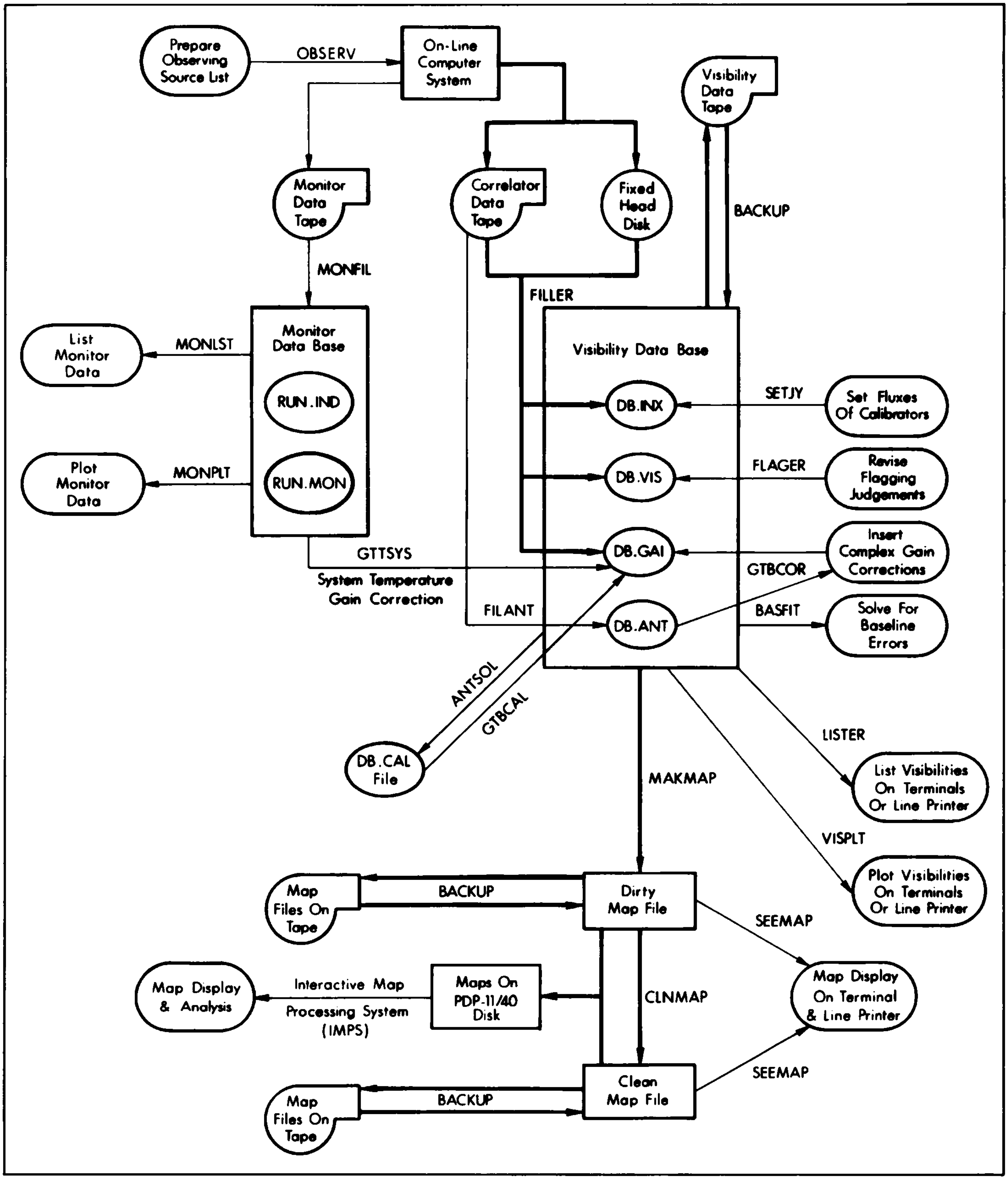


Figure VI-4. A schematic diagram showing relationships amongst data bases, programs, and objectives of the off-line data reduction system.

6. Standard Program Syntax and Methodology

(a) Introduction

Most of the programs the user will encounter in carrying out off-line data reduction in the DEC-10 share common features both in commands and syntax. All of the programs listed in the previous summary section, except for BACKUP, are of this type.

The syntax for standard commands is always either

<command name>

or

<command name> <option or parameter list>

and all command names have so-called "minimum redundancy", that is, the first n letters of a command name are all that need to be supplied, where n is less than or equal to 4. This saves a considerable amount of typing once the user learns how to use it.

All execution of specific tasks within a program are initiated with a GO command. The syntax for the GO command is either

GO

for the case where the program has only one type of execution, or

GO <option>

where the program has a number of execution options or purposes.

Most commands simply supply parameters which are not used for any purpose until a GO or GO <option> command is executed. In this case, the command name is the name of a parameter and the list of parameters to be specified is to the right of the command name.

Three major commands present in all programs serve only to provide the user with information. These are HELP, INPUTS, and EXPLAIN. Typing HELP without an option name produces a listing of all the commands available in that program, together with some syntax and purpose information. In the HELP listing, various options to the HELP command are listed that allow access to smaller subsets of the full HELP listing. Typing INPUTS without an option name produces a listing of all parameter-type commands and the current values of all their parameters. The same option subsets as for the HELP command can be used to obtain shorter listings of parameters. Finally, the EXPLAIN command gives the user access to more detailed information about programs and miscellaneous subjects. Typing EXPLAIN without any option results in a listing of information about the program the user is in the process of running. Typing EXPLAIN <program name> at any time results in an explanation of a particular program. Finally, typing EXPLAIN EXPLAIN will result in a listing of: (1) general information about the EXPLAIN command, (2) a list of the standard programs for which EXPLAIN <program name> will provide meaningful information, and (3) a list of names for miscellaneous subjects for which information can be obtained by typing EXPLAIN <miscellaneous subject name>.

A user with a reasonable knowledge of what he wants to do in general should be able to find out most of what he needs to know about anything related to VLA data reduction by judicious use of the HELP, INPUTS, and EXPLAIN commands in all standard data reduction programs.

(b) Commands Common to All Standard Programs

The following is a table of all 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 <kind>	Display summary information about a subset of commands of a particular type.
inputs	Display all parameter-type commands together with all current values of the parameters.
inputs <kind>	Display a subset of parameter-type commands together with current values of their parameters.
explain	Display more detailed information about the program currently being run.

explain <name>	Display more detailed information about either a program specified by name or the name of a category for which information is available.
savecommands	Save in a file named <prog.name>.TMP[13,PN] a listing of all current parameter-type commands and their current parameters.
savecommands name.ext[13,PN]	Save in a disk file named name.ext[13,PN] a listing of all current parameter-type commands and their parameters.
getcommands	Retrieve and execute all parameter-type commands in a previously saved <prog.name>.TMP[13,PN] file.
getcommands name.ext[13,PN]	Retrieve and execute all commands in a file named name.ext[13,PN].
setdefaults	Replace all parameters of parameter-type commands with the default values built into the program.
finish	Finish or exit from the program and return to monitor level, or DANEEL, if running under DANEEL control.
go <option>	Execute a specific option of the program or the sole executable function of the program if no option is necessary.
batch <option>	Submit this program to batch queue with current INPUTS parameters, executing the same options associated with GO.
jobname <name.ext>	Name of batch job when submitted.
jobtime hh:mm:ss	Time limit for batch job.

The HELP, INPUTS, and EXPLAIN commands have already been discussed in more detail in the previous subsection.

The use of SAVECOMMANDS and GETCOMMANDS allows the user to save current values of all parameters on disk files for retrieval at a later time. There is another very useful dimension of use for the GETCOMMANDS command. The files retrieved with this command are immediately executed in sequence; therefore, since these are files that can be TYPEd, PRINTed, and SOSed, one can edit a file to contain ANY command. In this way a complex sequence of commands 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. For example, source lists and flux densities for a number of sources and a number of frequencies can be typed into a file interspersed with GO SETJY and GO LIST commands so the process of inserting fluxes and verifying the results can be done by a simple GETCOMMANDS <name.ext of file> command executed in the SETJY program.

The SETDEFAULTS command causes all parameter-type commands to have their parameters reset to standard values built into each program. These defaults are those found when first running a program, before any parameters have been changed.

The BATCH command allows the user to prepare a set of input parameters for a particular program in batch mode, and then to submit a job with these parameters to the batch stream without leaving the program.

(c) Standard Data Selection Commands Common to Many Programs

All the programs dealing with access to visibility data bases have a set of common data selection commands of the parameter type. Some of these commands use some special symbols that require explanation. The asterisk symbol (*) as a command parameter means "all", "everything possible", etc. The symbols "|" and "&|" will be frequently encountered. The symbol "|" means OR, while "&|" means either or both. The following is a list of these commands, together with their parameter syntax and some sample parameters.

<table>
<tr><th><u>Command with Syntax</u></th><th><u>Sample Parameters</u></th></tr>
<tr><td>dbname name[14,PN]</td><td>1may21[14,11]
1may21</td></tr>
<tr><td>timerange <d1> at <t1> to <d2> at <t2></td><td>78may21 at 1:12:13 to ...
78may21 at 12:
78may21 to 78may23
1:12:13 to 6:01:20</td></tr>
<tr><td>sources <name>:<qual> <name>:<qual> ...</td><td>3C286:0 3C147:0
3C286:* *:1
3C286 3C147
:</td></tr>
<tr><td>calcodes * | A | B | C | D | E | CAL</td><td>*
CAL</td></tr>
<tr><td>antennas ID1 ID2 ID3 ... IDn | *</td><td>1 2 3 4 5 6 7 8 9 10
7 1 3 10 5 2 4 6 8 9
*</td></tr>
<tr><td>antennas ID1 ... IDn with IDm ... ID1</td><td>1 2 3 with *
3 4 with 5 6 7 8
* with 1</td></tr>
<tr><td>ifs A &| C | *</td><td>a c</td></tr>
<tr><td>ifpairs AA &| CC &| AC &| CA | *</td><td>aa cc ac ca</td></tr>
<tr><td>bands 20cm &| 6cm &| 2cm &| 1.3cm | *</td><td>20cm 6cm
*</td></tr>
<tr><td>passflag 0 | 1 | 2 | 3</td><td>2</td></tr>
</table>

These data selection parameters operate such that all selected data must satisfy all the specified parameters. Many of the parameters of these commands contain specific units suffices discussed in the next subsection.

(d) Units of Command Parameters

Units of inputs parameters to commands can, and in some cases must, be supplied. Units are specified as suffices and the following are meaningful.

Suffix	Description	Suffix	Description
e, E, @	power of 10 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	milliJanskys
psec	picoseconds	uJy	microJanskys
K	degrees Kelvin	yd	year and day of year
C	degrees Centigrade	ymd	year-month-day

Time range specifications 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 name 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:, 8:0:, and 8:0:0 are valid expressions for the same time.

(e) Automatic Saving of INPUTS Parameters

All the standard 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 saved INPUTS parameters. The user can thus generate his own "default" parameters in this way. This feature means the user can kill the execution of any program running interactively, and then find the same parameters when running the program again. This is useful when you realize a mistake has been made. This feature also makes it important to remember to use the SETDEFAULTS command appropriately when running programs in the batch mode.

7. DANEEL Control vs. Separately Run Programs

Running the standard data reduction programs individually by typing, after a period prompting symbol,

r PNAME

requires the user to run a number of programs in sequence. Many times this means typing in largely the same parameter commands a number of different times. A control program called DANEEL is provided for users who would like to have parameters of previous programs automatically passed on to the next program being run. If you choose to run programs under DANEEL control, you begin your data reduction session by typing, after the usual period prompt symbol indicating that you are at monitor level:

r DANEEL

after which DANEEL introduces itself. DANEEL is a program with standard command syntax, so HELP, INPUTS, and EXPLAIN are available. The inputs commands for DANEEL are a few of the major data selection commands that tend to be used by a large number of programs. Running a program under DANEEL control is simply a matter of typing, after the prompt symbols "DANEEL *":

go PNAME

after which the program PNAME is run, just as it would have been run at monitor level. However, the prompt symbol for any program being run is no longer the omnipresent asterisk but is, in general,

PNAME *

where PNAME is the program name. At this point the inputs parameters of a program will be the same as those previously used in other programs run under DANEEL control. In addition, when starting a new data reduction session under DANEEL control, all the parameters of all the programs run under DANEEL control in a previous session will be the defaults when you first run the programs in the new session. This allows the user to evolve his own favorite defaults for data reduction programs, and always have the data reduction programs begin with his defaults rather than with those built into the programs. Of course, the setdefaults command can be used to replace the inputs parameters of any programs with the program defaults.

When a user finishes with running a program under DANEEL control, typing FINISH or FIN results in a return to DANEEL so another program can be run by the appropriate "go PNAME" command. If the user wishes to return to monitor level, another FINISH should be typed. A special exception to needing to return to DANEEL before running another program exists for MAKMAP and SEEMAP. These two programs have such frequent need for going back and forth, they alone have the capability, so that, while in MAKMAP, you go run SEEMAP by typing

go SEEMAP

and, while in SEEMAP, you can run MAKMAP by typing

go MAKMAP

thus providing a way to avoid returning to DANEEL before running either program.

There are dangers in running programs under DANEEL control. You may forget that running a previous program caused a parameter to be set to one thing while you are thinking it is set to the program default. For this reason, the beginning user is advised to dominantly run programs under DANEEL control or to dominantly run programs separately. Mixing the two modes causes the most confusion to the beginner. The main advantage to running under DANEEL control is the passing and saving of parameters that can save a considerable amount of repetitive typing.

Another small advantage of DANEEL may exist to the intermittent user of the VLA who only vaguely remembers the data reduction system. In this case, the user can keep in mind that he need only remember how to log on the DEC-10 and type "r DANEEL", after which he can use the HELP, INPUTS, and EXPLAIN to remind himself about what programs are available and how to run them.

8. Program Documentation

(a) Introduction

In this section we present some documentation of the major programs in the off-line data reduction system. The programs will be discussed in alphabetical order. The first two pages of the documentation for each program will be in the same format on left-hand and right-hand facing pages.

The left-hand page will be the first page of documentation of each program, containing the name of the program, its purpose in the scheme of things, and a copy of an INPUTS listing for the program. The right-hand, or second page of the documentation for each program, will contain the name of the program in the upper right corner, followed by the first part (or all) of the complete HELP listing for the program. If either or both of these two pages have available space, this space may be used for the beginning (or all) of a more extended discussion of the program. Continuing (or beginning) on the third page of the documentation for each program will be any remains of the HELP file listing, followed by the rest (if any) of the description of the program. This description will continue for as many pages as necessary, with the name of the program repeated on the upper left- or upper right-hand corner of each page.

With this documentation format, the user should be able to riffle through pages, looking for the details on each program.

(b) ANTSOL

ANTSOL is a program that takes selected calibrator data from a data base (dbname[14,PN]), and then solves for complex antenna gains. Each time ANTSOL is run, it produces a table of complex gains as a function of time, which is stored in a file called dbname.CAL[14,PN]. ANTSOL applies the gain table before solving for the complex gains. When ANTSOL is used as part of the calibration process, the calibrators should have had correct flux densities inserted in the data base by the SETJY program.

The dbname.CAL[14,PN] table is then used by the GTBCAL program to apply the calibration represented in this table of complex gains to the dbname.GAI[14,PN] file in the data base.

```
ANTSOL INPUTS
====== ======
timerange . . . . 78MAR28 at 17:00:00 to 78APR01 at  4:00:00 IAT
dbname. . . . . . 1MAR28[14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
refants . . . . . 2  4  6 (Physical IDs)
ifs . . . . . . . A, C
bands . . . . . .  6.0cm
passflag. . . . .  2
minamp. . . . . .      .0500
uvlimits. . . . .      .0nsec, 70000.0nsec
outfile . . . . . TTY:
listoptions . . . AMPLITUDE, PHASE
average . . . . . SCAN
amp/jy. . . . . . YES
closurelimit. . .   .05,  5.00d
xaxis . . . . . .   -3h00m00s TO    6h00m00s HA
yaxis . . . . . .   .100 TO   .300 AMPLITUDE
```

```
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 PLOT                         Plot solution on TEK terminal.
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
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
passflag 0 | 1 | 2 | 3                  Highest acceptable flag.
minamp <value>                          Minimum acceptable amplitude in
                                          actual correlation units.
uvlimits <min> <max>                    Limits on baseline length for
                                          data selection in nsec.
outfile dev:file.ext[p,pn]              Output file.
listoptions AMPLITUDE|PHASE|AMP*AMP     Select type(s) of listings.
average <time>|SCAN                     Averaging time.
amp/jy YES|NO                           Divide amplitudes by source flux
closurelimit <amplimit> <phaselimit>    Maximum amp. and phase closure
                                          errors before typing message
xaxis <number> TO <number> IAT.DAYS|    Range and kind of xaxis. No
      IAT.24HR|LST.DAYS|LST.24HR|HA|    range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC
       UVDISTANCE
yaxis <number> TO <number>  AMPLITUDE|  Range and kind of y-axis.
                  AMP*AMP|1/AMP|PHASE
```

ANTSOL

ANTSOL selects data from a visibility data base on the basis of the following standard data selection commands:

DBNAME	TIMERANGE	SOURCES	CALCODES
BANDS	ANTENNAS	IFS	PASSFLAG

The selected data will give meaningful solutions only if the selected sources are point sources. ANTSOL always applies the gain table of the data base to the selected data before solving, with the GO SOLVE command, for the antenna gains (G_j's) and phases (ϕ_j's) according to the formula

$$V_{jk} = G_j G_k \exp (\phi_j - \phi_k) \quad .$$

Additional limitations upon the selected input data to ANTSOL can be imposed with the MINAMP and UVLIMITS commands, which exclude small amplitude data and data with too small and/or too large values of $(u^2+v^2)^{0.5}$, respectively, by specifying appropriate limits. MINAMP allows exclusion of sources with poor signal to noise and UVLIMITS allows exclusion of data where sources have extended components and/or are partially resolved.

Normally, the AMP/JY command parameter is set to YES, because only with amplitudes divided by flux densities are all calibrators on a common basis in determining the system gain. AMP/JY is set to NO when it is necessary to use ANTSOL on "raw" amplitudes for diagnostic purposes.

The only other ANTSOL command that affects the solutions obtained and written into the dbname.CAL[14,PN] file is the AVERAGE command, which controls the averaging interval (up to scan averaging) that is used in creating the solution and the calibration table.

The remaining commands affect only the diagnostic, listing, or plot output 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 error reports are displayed upon either terminal screen (TTY) or line printer (LPT), depending upon the OUTFILE specification.

The listings produced with the GO LIST command of ANTSOL are column displays of the contents of the complex gains in the dbname.CAL[14,PN] file. With the LISTOPTIONS command one can choose to list any combination of AMPLITUDE or AMPLITUDE*AMPLITUDE, and PHASE. For output to TTY a maximum of eight columns of such information can be displayed, and for output to LPT up to twenty columns of such information can be displayed; therefore, one must select small enough subsets of antennas, IFs, and the displayed information to fit the output capacities of the chosen display device. The production of antenna gain and phase listings by ANTSOL is of great importance in evaluating calibrator and system behavior. This is because it is much easier to make sense of N antenna gains and phases than it is to make sense of N(N-1)/2 correlator gains and phases.

Finally, one can plot amplitude and phase information using the GO PLOT command, with choice of type and range of x- and y-coordinates determined by the XAXIS and YAXIS commands.

(c) AVGVIS

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.

Use of AVGVIS is strongly recommended to decrease the amount of disk space being used for data bases. In general, once an initial data base has been edited, corrected, and calibrated, AVGVIS is used to produce the most compact data base that will not average source data more than desirable for scientific reasons. The disk space occupied by the original data base may be released after putting it on magnetic tape with the BACKUP program.

```
AVGVIS INPUTS
====== ======
jobname . . . . . AVGVIS
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
bands . . . . . . *
modes . . . . . . '  '
passflag. . . . .  2
outfile . . . . . DSK:You must specify me.[14,]=EXTEND
average . . . . .  0:01:00
```

The DBNAME command in AVGVIS specifies the name of the original data base, with data selection on the basis of SOURCES, QUALIFIERS, CALCODES, ANTENNAS, BANDS, MODES, and PASSFLAG. A new visibility data base named with the OUTFILE command is "filled" with these data, with a new and larger averaging time specified by the AVERAGE command.

```
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
                                        paired with all antennas in list 2
bands 1.3cm|2cm|6cm|20cm|<freq>|*       Bands or frequencies
modes '  '|IA|<2char>|*                 Observing mode names
passflag 0 | 1 | 2 | 3                  Highest acceptable flag.
outfile  <filename[p,pn]>               Output averaged database
average <time>                          Averaging time
```

If one commands OUTFILE newdb[14,PN]=EXTEND, the newly selected and averaged data are added on the end of any previously existing data base named newdb[14,PN]. Only if you specify OUTFILE newdb[14,PN]=OVERWRITE will the old version of newdb[14,PN] be replaced with the new and averaged data. As averaged records are written into the new data base, the source names, qualifiers, start dates, start times, bands, and numbers of initial and averaged records for each scan are listed in column format on the terminal screen.

(d) BASFIT

BASFIT is a program that takes phase data for calibrators in a visibility data base and solves for "baseline errors". The parameters that can be solved for are any combination of phi0, dBx, dBy, dBz, and dBa, where phi0 is the phase center, (dBx,dBy,dBz) is the correction vector for the baseline vector B_k-B_j for the j-th and k-th antennas, and dBa is the difference in axis intersection defect parameters for the two antennas. The values of dBx, dBy, dBz, and dBa can be inserted in the gain table by the GO BASECORR command in GTBCOR with

BASELINEERR dBx dBy dBz dBa

for the j-th antenna (j < k), or

BASELINEERR -dBx -dBy -dBz -dBa

for the k-th antenna.

```
BASFIT INPUTS
====== ======
jobname . . . . . BASFIT
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . 1MAY21(14,)
sources . . . . . *:*
calcodes. . . . . CAL
antennas. . . . . 1, 2
ifpair. . . . . . AA
band. . . . . . .  6.0cm
passflag. . . . .  2
outfile . . . . . DSK:BASFIT.BFT=NONE
calibration . . . NONE
fitterms. . . . . xyz
```

Only point source data should be selected for input to a BASFIT solution. These input data are selected using the following standard commands:

DBNAME	TIMERANGE	SOURCES	CALCODES
ANTENNAS	IFPAIR	BAND	PASSFLAG

Since BASFIT uses data for only one correlator at a time, the ANTENNAS command may specify only two antennas at a time, and only one BAND and IFPAIR can be named.

```
BASFIT 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                                        Do fit for baseline components.
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 BASFIT
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
ifpair AA|CC|AC|CA                        IF pair or correlator.
band 1,3cm|2cm|6cm|20cm|<freq>            Band or frequency.
passflag 0 | 1 | 2 | 3                    Highest acceptable flag.
outfile <file specification>=<type>       Output file and type
calibration NONE|APPLY|UNDO,MODCOMP       Calibration using gain table.
fitterms xy|xyz|xyzk|z|zk|k               Baseline parameters to fit
```

One can choose to apply or not apply the gain table by using the CALIBRATION command. Depending upon the parameter of the OUTFILE command, the solution information can be put out to a disk file or a terminal screen. Finally, with the FITTERMS command one chooses the combination of unknowns to be solved for. The BASFIT program displays the information about the solutions and their errors, in units of nanoseconds and wavelengths, but does not provide any output directly usable by the GTBCOR program. The user takes results of BASFIT and applies judgment before generating antenna station corrections for the BASELINEERR and GO BASCORR commands in GTBCOR.

(e) CLNMAP

CLNMAP is a map processing program used to apply the map cleaning algorithm to all or part of a "dirty" map. The resulting "cleaned" map has, in principle, been partially or fully corrected for effects of synthesized beam sidelobes.

To obtain a cleaned map of size CLNSIZE X CLNSIZE, the program must have access to both a dirty map of this size or larger, and a "dirty beam" that is larger by at least a factor of two in both dimensions.

```
CLNMAP INPUTS
====== ======
jobname . . . . . CLNMAP
jobtime . . . . .  0:05:00
stokes. . . . . . I
band. . . . . . .  6.0cm
clnsize . . . . .  128
nboxes. . . . . .    0
box . . . . . . .
subpercent. . . . 50.000
limpercent. . . .   5.00
maxiteration. . .  100
posclean. . . . .    0
fitbeam . . . . .  0d0'0.0"  0d0'0.0" 0d0'0.0"
restartsubtract . YES
dmap. . . . . . . DCYGX2 (DIRTY MAP)
dbeam . . . . . . DCYGX2 (DIRTY BEAM)
cmap. . . . . . . CCYGX2 (CLEAN MAP)
rmap. . . . . . . RCYGX2 (RESIDUE MAP)
```

The input information for the map to be cleaned by the CLNMAP program is obtained from: the STOKES command specifying the Stokes parameter of the map; the BAND command specifying the observing band; the DMAP command supplying the name of the dirty map which is to be cleaned; and the DBEAM command supplying the name of the dirty beam corresponding to the dirty map.

```
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
help <kind> | <nothing>                 Type help text. No argument gives
                                          all help text. Legal kinds are:
                                          general,dataselect,misc,plot,
                                          CLNMAP
setdefaults                             Set INPUTS to original defaults
finish                                  Stop program and leave.
dmap                                    specify dirty map name
dbeam                                   specify dirty beam name
cmap                                    specify clean map name
rmap                                    specify residue map name
go SUBTRACT|RESTORE                     Subtract or restore components
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 (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
                                          (loop gain).
limpercent  <percentage>                Cleaning limit percentage.
maxiteration  <number>                  Maximum number of iterations in
                                          one subtract pass.
posclean  <number>                      First iteration for negative
                                          component removal.
fitbeam <major> <minor> <pangle>        Fit or specify beam parameters
                                          (angular  units).
restartsubtract YES|NO                  Begin cleaning original dirty
                                          map OR continue cleaning
                                          residual map.
```

CLNMAP

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 file <name>.CMP[14,PN] on disk. The parameter-type commands controlling the component subtraction step are:

CLNSIZE	Size of the square area of the dirty map to be cleaned.
NBOXES	Number of boxes or areas of the dirty map from which components are to be subtracted.
BOX	Command supplying location parameters for the n boxes.
SUBPERCENT	The percentage of each map extrema to be subtracted as a component, frequently called the loop gain.
LIMPERCENT	The percentage of the original maximum in the dirty map at which component subtraction terminates.
MAXINTER	The maximum number of iterations (components) to be solved for in a single GO SUBTRACT step.
POSCLEAN	The number of the first component at which negative extrema in addition to positive extrema may be subtracted.

Once component subtraction begins, it continues until the LIMPERCENT level of component subtraction is reached, the MAXITERATION number of components has been subtracted, or the process fails to converge.

If the RESTARTSUBTRACT command is set to NO, the execution of a GO SUBTRACT command results in continuation from the point where any previous subtraction left off. If the RESTARTSUBTRACT command parameter is set to YES, then another GO SUBTRACT results in component fitting and source subtraction starting from the beginning again. During the execution of GO SUBTRACT the parameters of each component solved for and subtracted is displayed. At the same time the difference between the original map and a map consisting purely of the subtracted components is stored in the file named by the RMAP command.

One carries out enough GO SUBTRACT iterations with different parameters to attain a state where you are satisfied with the convergence and properties of the cleaning process. At this point you then proceed to restore the CLEANed map.

Map restoration is a process whereby each fitted component is added back into the residual map, but with a clean beam shape of limited extent rather than the shape of the dirty beam that was originally subtracted. The FITBEAM command allows you to specify the parameters of the clean beam, which is assumed to be a two-dimensional Gaussian, with a major axis, a minor axis, and a position angle. If the FITBEAM parameters are set to zero, the first part of the GO RESTORE process is the fitting of a two-dimensional Gaussian to the core of the dirty beam. The next result of the GO RESTORE step is a display of successive iterations of the clean beam fitting parameters, followed by a side by side comparison of dirty and clean beams in the form of two-dimensional character maps where intensities are shown on an integer scale of 0 to 10. Following this, a new map is created in the file named by the CMAP command which is the sum of (1) all the subtracted or fitted components restored with the shape of the clean beam and (2) the residual map. This map is the final cleaned map. At the end of this process, the total flux of restored components is listed, together with the intensity and position of the new maxima and minima in the clean map.

The CLNMAP program should be used with caution, since it is well known that under certain conditions the CLEAN algorithm can generate spurious results. The only general advice that can be given is the following: avoid too large values of SUBPERCENT, the loop gain parameter; subtract as small an area of the map as you can; and be careful about believing things that appear in clean maps which look very similar to features in the dirty beam.

(f) DANEEL

DANEEL is a program under which any of the standard programs can be run. The primary purpose of DANEEL is to pass parameters between different programs. The secondary purpose of DANEEL is to save the previous values of all previously executed programs for the next time DANEEL is run.

```
DANEEL INPUTS
====== ======
timerange . . . . 76JAN01 at 00:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
bands . . . . . . *
modes . . . . . . ' '
passflag. . . . .  2
```

```
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 0 | 1 | 2 | 3                  Highest acceptable flag.
```

The usage of the DANEEL program, together with a discussion of its advantages and disadvantages, is covered in an earlier subsection of this chapter.

(g) DBCON

DBCON is a program for taking selected visibility data from either one or two data bases and "concatenating" this data into a third visibility data base.

```
DBCON INPUTS
===== ======
jobname . . . . . DBCON
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
bands . . . . . .  6.0cm
modes . . . . . . ' '
passflag. . . . .  3
outfile . . . . . DSK:DBNAM3[14,]*EXTEND
infiles . . . . . DSK:DBNAM1[14,]   DSK:DBNAM2[14,]
```

The INFILES command is used to name one or two input data bases. Which data are taken from the one or two INFILES is determined by the standard commands:

SOURCES CALCODES ANTENNAS BANDS MODES PASSFLAG

With the OUTFILE command you specify both the name of the new data base file, and whether you want to EXTEND or OVERWRITE any data base of that name that already exists. The EXTEND feature allows three data bases to be concatenated together at one time. 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.

```
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>
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
                                           paired with  antennas in list 2
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .  Bands or frequencies
modes '  '|IA|<2char>|* . . .            Observing mode names
passflag 0 | 1 | 2 | 3                   Highest acceptable flag.
outfile  <filename[p,pn]>                List concatonated database.
infiles  <filename[p,pn]> ...            List one or two input databases.
```

(h) FILANT

FILANT is a stopgap program used to create a table of antenna position information from a visibility data tape. Output from FILANT goes into a file called dbname.ANT[14,11]. The dbname.ANT[14,PN] file must be present for the corrections in GTBCOR that require a knowledge of the station positions used while observing.

```
FILANT INPUTS
====== ======
jobname . . . . . FILANT
jobtime . . . . .  0:05:00
dbname. . . . . . [14,]
infile. . . . . . DSK:
```

FILANT is actually only the last stage of an inconvenient four-stage process for getting antenna position information from MODCOMP visibility data tapes. Let us describe this process in cookbook fashion:

(1) Knowing that the data you want is in the n-th file of a MODCOMP data tape labeled Vxyz, you compute m = 3n - 2, mount the tape on a DEC-10 tape drive, and skip to the correct file by typing, at monitor level:

```
.mount mta:/reelid:Vxyz
.skip  mta:m files
```

```
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                                      Read ANTENNAS file, fill data base
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
infile dev:file.ext[p,pn]               Specify input file
```

(2) then you create a file named, say, antenn.dat, by running FMT2:

```
.r fmt2
*infile mta:antennas
*outfile antenn.dat
*go
```

and, when you are done, you UNLOAD and DEASSIGN mta:,

(3) then you SOS the file named antenn.dat created with the FMT2 program, deleting the first line with FILE:ANTENNAS in it;

(4) and finally you run the FILANT program as follows:

```
.r filant
*dbname <name>[14,PN]
*infile antenn.dat
*go
```

where <name> is the name of the data base to which you want the <name>.ANT[14,PN] file attached, and antenn.dat is the name of the file created by the FMT2 program.

(i) FILLER

FILLER is a program that takes visibility data from either the Fixed Head Disk or the visibility data tape written by the on-line computer system and writes it into a DEC-10 visibility data base.

FILLER runs in real time, as the observing goes on, when it takes data from the Fixed Head Disk.

```
FILLER INPUTS
====== ======
user                    ALL
detach                  NO
infile                  MTA:
log                     FILLER.LOG
subarray                1
gaininterval            0:10:00
timerange               76JAN01 at 0:00:00 to 85DEC31 at 24:00:00 IAT
dbname                  1may21[14,]
passflag                3
average                 0:00:30
```

The only circumstances under which a user should run FILLER is when it is desirable to recreate a data base from a MODCOMP data tape. Only array operators ever use the features of FILLER that are important for running the program in real time, taking data from the fixed head disk. Commands used only by operators are referred to as for WIZARDS only.

In using FILLER with tape input, one first mounts the tape and skips to the appropriate data file, as described for the FILANT program. Then, after running FILLER, the user specifies his USER number to be his PN or ALL and makes sure the INFILE parameter is mta:. One then specifies the SUBARRAY number for the data you want to take off tape. The LOG parameter is either TTY: or DSK:<name>.<ext> corresponding to terminal or disk file storage with the name <name>.<ext>. Data selection for FILLER is carried out with the standard commands TIMERANGE and PASSFLAG. It is good practice to use a PASSFLAG of 3 most of the time. Finally, the data is written into a data base that you specify with the DBNAME command, with an

```
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 with data for given user no.
detach YES|NO                             Whether FILLER is to run detached
                                          from the user's terminal.
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 1st
effective NOW|USERCHANGE|<date/time>      Tell FILLER when to implement the
                                          parameters.   WIZARDS ONLY
shutdown <subarray>                       Stop filling data for a subarray
                                          WIZARDS ONLY
go                                        Start or resume FILLER
explain <program name> | <empty>          Type explanation of the given
                                            program. <empty> gives FILLER
infile <dev>:                             Set up input device for FILLER.
log <file>                                Set up log file for FILLER.
gaininterval <time>                       Set longest gain table interval
timerange <start> to <stop>               Time period <start>,<stop> syntax:
                                            <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]                 Database to be used
passflag 0 | 1 | 2 | 3                    Highest acceptable flag.
average <time>|SCAN                       Averaging time
```

averaging time specified by the AVERAGE command. Once the FILLER parameters are satisfactory, the initiation of the filling of the data base is by the GO command. FILLER is a fairly time-consuming program; for this reason, and the usual desire to avoid mistakes, it is wise to prepare a batch control file for filling a data base. The DETACH command can be used to have FILLER detach itself from a terminal while it executes, in which case the LOG cannot be TTY.

(j) FLAGER

FLAGER is a program for changing and listing the values of flags associated with visibility data. For each antenna-IF pair the associated complex visibility is assigned a flag with values 0, 1, 2, or 3, corresponding to "good", "fair", "poor", and "bad" data. With the FLAGER program the values of these flags, initially determined by the on-line computer system, can be modified.

FLAGER, therefore, is the main program used to "edit" visibility data.

```
FLAGER INPUTS
====== ======
jobname . . . . . FLAGER
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . 1, 2 WITH 1, 2 (Physical IDs)
ifs . . . . . . . *
ifpairs . . . . . AA
bands . . . . . .  6.0cm
outfile . . . . . TTY:FLAGER
newflag . . . . .  3
flagoption. . . . ANTENNA
```

```
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 | describe                List flag values, change values,
                                           or GO DESCRIBE FLAGER usage
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
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
                                         paired with 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.
newflag  0 | 1 | 2 | 3                   New value of the data flag.
flagoption  antenna|correlator           Type of flagging.
```

FLAGER

Using the notation developed earlier, the correlator visibility V_{jkp}, where j and k are antenna numbers and p = AA, CC, AC, or CA, has associated with it an integer flag f_{jkp}. The on-line system uses monitor data to set initial values of the flag, which we denote by f'_{jkp}. The FLAGER program is used to both modify and list the flags in a data base. We have described the process of reflagging as changing the f'_{jkp} to new flag values of f_{jkp}. Note that the f'_{jkp} are destroyed when changed to f_{jkp}, since they occupy the same physical space in the data base.

The selection of flags to be modified or listed is determined by the parameters of the following standard commands:

DBNAME SOURCES CALCODES ANTENNAS IFPAIRS IFS BANDS

Flagging can be done either by antenna-IF or by correlator pair. Antenna-IF based flagging is done if FLAGOPTION is set to ANTENNA, and correlator based flagging is done if FLAGOPTION is set to CORRELATOR. During antenna-IF flagging the IFS command parameters are used, while during correlator flagging the IFPAIRS command parameters are used. The syntax of the ANTENNAS command also depends upon the FLAGOPTION, with the syntax

ANTENNAS <ID list> WITH *

being necessary during antenna-based flagging, and the syntax

ANTENNAS <ID list> WITH <ID list>

being necessary during correlator flagging. Most flagging is more conveniently done in terms of specifying antennas and IFs; therefore, FLAGOPTION ANTENNAS is used most often.

For both FLAGOPTIONS the NEWFLAG command parameter must be set to the new flag value (f_{jkp}) that you wish to associate with selected visibility data. The GO FLAG command initiates the process of changing the flags of selected data to the value set by the NEWFLAG command. Most flagging is used to label data as "bad", and most of the time the NEWFLAG command parameter is 3.

FLAGER

A description of some aspects of the use of the FLAGER program can be obtained by using the GO DESCRIBE command. Execution of the GO LIST command results in a display of the FLAG values of selected data. This display is put out to TTY:, LPT:, and DSK:, depending upon the specification of the OUTFILE command. The GO LIST command will work only with the ANTENNAS command parameter list of syntax <ID list> WITH <ID list>. The format of the flag listing is, for example:

```
SOURCE = 2005+403   DATE = 78MAY21   BAND = 6
 IAT       2-13 4-13 6-13 8-13 9-13
 6:22:45   3333      3333 3333 3333
 6:22:55   3233      3233 3233 3233
 6:23:05   3233      3233 3233 3233
```

etc.

where the display is for ANTENNAS 2 4 6 8 9 with 13, and each block of numbers represents the flag values for the IFPAIRS AA, CC, AC, and CA. Absence of any flags means there is no data for that particular correlator. In the above example, the first records are all flagged 3, which is often true because the subreflector is still moving to the right position, and the 13A IF is flagged as bad.

FLAGER should be used with great caution because erroneous changes of data with mixed flags of 0, 1, and 2 to level 3 are almost impossible to restore without recreating the data base from tape. For this reason it is recommended that most of the use of FLAGER be in batch control files, both to emphasize careful preparation and to be able easily to redo the flagging if it becomes necessary.

(k) GTBCAL

GTBCAL is a program that takes a calibration table that has been produced with the ANTSOL program and enters that calibration in the gain table (dbname.GAI[14,PN] file) for selected data.

The creation of a calibration table with ANTSOL and the modification of the gain table by GTBCAL must follow in sequence. This is because each execution of ANTSOL causes replacement of the calibration table needed by GTBCAL.

```
GTBCAL INPUTS
====== ======
timerange . . . . 78MAR28 at 17:00:00 to 78APR01 at  4:00:00 IAT
dbname. . . . . . 1MAR28[14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
ifs . . . . . . . A, C
band. . . . . . .  6.0cm
calsources. . . . BLLAC:*  2005+403:*
outfile . . . . . TTY:GTBCAL
average . . . . .  2:00:00
caltype . . . . . PHASE
pastonly. . . . . NO
interpfunct . . . BOXCAR
weight. . . . . . UNIFORM
xaxis . . . . . .   -3h00m00s TO    6h00m00s HA
yaxis . . . . . .   .100 TO   .300 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]), produced by the ANTSOL program, will be used to calculate the entries in the gain table. Selection of data used from the calibration table is by means of the CALSOURCES and CALCODES commands. 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 .

GTBCAL COMMANDS

```
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 part of gain table
go reset                                 reset specified part of gain table
go calibrate                             Put calibration in gain table
go plot                                  plot gain table on TEK
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
outfile dev:file.ext[p,pn]               Output file.
average <time>                           Averaging time.
caltype AMP PHASE                        Calibrate AMP and/or PHASE
pastonly YES | NO                        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. No
      IAT.24HR|LST.DAYS|LST.24HR|HA|     range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC
       UVDISTANCE
yaxis <number> TO <number>  AMPLITUDE|   Range and kind of y-axis.
          AMP*AMP|1/AMP|AMp/JY|PHASE
```

GTBCAL

Gain table entries are computed by GTBCAL from selected calibration table entries by interpolating or taking weighted averages. One can enter amplitude and/or phase calibration with the execution of the GO CALIBRATE command, depending upon the parameter(s) of the CALTYPE command. The WEIGHT command parameter determines the weighting of calibration table entries, depending upon the time separation between the calibration table entry and the gain table entry.

The slightly misnamed INTERPFUNCT command is used to choose the type of interpolation or averaging with which gain table entries are computed. With INTERPFUNCT BOXCAR, all data within a time specified by the AVERAGE command are averaged to compute a gain table entry; however, with the PASTONLY command, you can choose to limit the averaged data to calibrator observations made before the gain table entry. This is useful for applying calibration to a data base still being filled because observing is going on. For boxcar averaging, if an antenna drops out, the last gain entry is repeated. Messages are displayed informing you when antennas come on line, drop out, and come back on line again.

For INTERPFUNCT 2POINT, calibration table entries which surround each gain table entry are used in a linear interpolation formula to compute gain table entries at the correct time. If an antenna drops out permanently, the gain table entries are repeated until the TIMERANGE stop time or the end of the gain table, whichever comes first.

GTBCAL has a GO RESET command that can be used to reset selected amplitude factors to unity and/or phase shifts to zero. However, the use of GO RESET in GTBCAL tends to be limited, since it will also remove any corrections inserted by GTTSYS or GTBCOR.

With the GO LIST command one can list specified portions of the gain table on the device (TTY:, LPT:, or DSK:) and file named by 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 the TEK 4012 terminal by use of the GO PLOT command. The type and range of the x- and y-coordinates of the plot are specified by the XAXIS and YAXIS commands.

Since the process of using ANTSOL to create calibration tables and GTBCAL to make entries in 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 GTTSYS into a temporary disk file. By doing this you don't have to redo corrections every time you want to redo the calibration applied to the gain table. One way to accomplish this is to type, at monitor level:

```
.copy dbname.BAI[14,PN] ← dbname.GAI[14,PN]
```

for saving the corrected gain table, and then

```
.copy dbname.GAI[14,PN] ← dbname.BAI[14,PN]
```

whenever you want to go back to the corrected gain table to impose a different calibration.

Given a calibration table prepared by ANTSOL, it is frequently useful to run GTBCAL a number of times to achieve so-called "local" calibration. With local calibration you specify one or more calibrators with the CALSOURCES commands, which are close to one or more program sources, named with the SOURCES command. Repeated execution of GTBCAL, for as many times as you have localized regions with sources and calibrators, will achieve local calibration for all sources. This type of local calibration removes, to first order, effects that are dependent on hour angle and declination. Notable amongst effects that can be minimized in this way are antenna position errors and some aspects of the atmosphere. In doing local calibration you must, of course, be careful to never name the same source twice in the SOURCES list for different runs of GO CALIBRATE.

(1) GTBCOR

GTBCOR is a program that can be used to correct visibility data in a data base for a variety of effects. The corrections that can be applied are: antenna location (baseline) changes; source position changes; time error corrections; amp*(1 + kcoeff*sec z)/(1 + kcoeff) multiplication; amplitude multiplication; addition of a constant to phases; correction for antenna shadowing effects; and insertion of polarization correction parameters.

When a correction is applied by GTBCOR, all that happens is that appropriate amplitude and/or phase corrections are placed in the gain table (dbname.GAI[14,PN]) associated with the visibility data file (dbname.VIS[14,PN]).

```
GTBCOR INPUTS
====== ======
jobname . . . . . GTBCOR
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
ifs . . . . . . . *
bands . . . . . .  6.0cm
outfile . . . . . TTY:FLAGER
listoption. . . . CORRECTION
baselineerr . . .  .0000,  .0000,  .0000,  .0000 (in nsec)
laterror. . . .      .000sec
coeffsecz . . . .  .120,  .055,  .040,  .040  (20, 6, 2, 1.3cm)
positionerr . . .     .00"    .00"
ampfactor . . . .   1.000  1.000
phaseshift. . . .    .000d    .000d
xaxis . . . . . .  IAT,DAYS
yaxis . . . . . .   .000 TO  2.000 AMPLITUDE
```

```
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 with AMPFACTOR
go PHASECORR                              Correct phases with PHASESHIFT
go BASECORR                               Correct phases with BASELINEERR
go TIMECORR                               Correct phases using 'iaterr'
go RADECCORR                              Correct phases with POSITIONERR
go SECZCORR                               Correct amplitudes with COEFFSECZ
go SHADOWCORR                             Correct amplitudes for
                                            geometrical antenna shadowing
go POLCORR                                Correct pol part of gain table
                                           with AMPFACTOR and PHASESHIFT
go LIST                                   List selected antenna-IF(s) gain
                                            table entries.
go PLOT                                   Plot selected antenna-IFs on
                                            TEK terminal.
go RESET                                  Reset selected part of gain table
go RESET AMPLITUDE                        Reset ampl. part of gain table
go RESET PHASE                            Reset phase portion of gain table
go POLRESET                               Reset 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.
listoption NOMINAL | CORRECTION           List nominal and correction or
                                            only correction part of gain table
baselineerr <dBx>, <dBy>, <dBz>, <dBa>    Baseline error components in nsec
```

GTBCOR

```
                                          (do not specify units)
iaterror <value>                         Specify IAT time error
coeffsecz <20cm>, <6cm>, <2cm>, <1.3cm>  Coefficients for sec z correction
                                          (no units)
positionerr <deltaRA>, <deltaDEC>        Position offsets in RA and DEC
                                          (angular units)
ampfactor <start>, <stop>                Starting and stopping amplitude
phaseshift <start>, <stop>               Starting and stopping phase
xaxis <number> TO <number> IAT.DAYS|     Range and kind of xaxis. No
      IAT.24HR|LST.DAYS|LST.24HR|HA|     range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC
       UVDISTANCE
yaxis <number> TO <number>  AMPLITUDE|   Range and kind of y-axis.
          AMP*AMP|1/AMP|AMP/JY|PHASE
```

GTBCOR inserts corrections for selected data in the gain table (dbname.GAI[14,PN]) of a visibility data base. The selection of the data for which corrections are inserted in the gain table involves the following standard commands:

DBNAME TIMERANGE SOURCES CALCODES ANTENNAS IFS BANDS .

There are eight different types of corrections that can be applied with GTBCOR. Each type of correction has its own GO command and most have an associated command supplying the parameters of the correction. The following table is a table of the GO <type> commands, their associated parameter command, and information about each:

<type>	Parameter Command	Comments
AMPCORR	AMPFACTOR <start> <stop>	Linear function from AMPFACTOR at <start> time to AMPFACTOR at <stop> time multiplies AA and CC amplitudes.
PHASECORR	PHASESHIFT <start> <stop>	Linear function from PHASESHIFT at <start> time to PHASESHIFT at <stop> time added to AA and CC phases.
BASECORR	BASELINEERR <dBx><dBy><dBz><dBa>	Phase correction for antenna position error and axis intersection defect.
TIMECORR	IATERROR <dIAT>	Phase correction for time error. Requires antenna position information in dbname.ANT[14,PN] file.
RADECCORR	POSITIONERR <dRA> <dDEC>	Phase correction for change in reference position. Requires information in dbname.ANT[14,PN] file.
SECZCORR	COEFFSECZ <20cm><6cm><2cm><1.3cm>	Multiply amplitudes by (1+COEFF*sec z)/(1+COEFF) compensating for T_{sys} contribution due to atmosphere (only when T_{sys} correction not applied).
SHADOWCORR		Multiply amplitudes of shadowed antennas by geometric blocking factors.
POLCORR	AMPFACTOR <start> <stop> PHASESHIFT <start> <stop>	Correct for instrumental polarization with AMPFACTOR and PHASESHIFT.

GTBCOR

The resetting of amplitude factors to unity (or zero) and phaseshifts to zero is an important function of GTBCOR. With GO RESET you reset amplitudes to unity and phases to zero for the complex g_{jR} and g_{jL} in the gain table. With GO POLRESET you reset both amplitudes and phases of the complex D_{jR} and D_{jL} to zero. Amplitudes and phases can be reset separately with the GO RESET AMPLITUDE and GO RESET PHASE commands, respectively. The RESET commands ignore the SOURCES command specification. Be sure to reset selected portions of the gain table whenever you need to redo any correction or calibration of these data because otherwise the correction or calibration would be inserted in the gain table more than once. Since we recommend application of corrections and calibration in batch control files, we suggest that the following appear in sequence in such batch files: (1) after executing a SETDEFAULTS command, and naming the data base, GO RESET the gain table with GTBCOR; (2) apply all desired corrections with GTBCOR; (3) apply corrections with GTTSYS if they have not been applied on-line, if desired; (4) use ANTSOL to create the calibration table; and (5) apply empirical calibration with GTBCAL. By always doing these in this sequence, you can avoid the common error of inadvertent multiple application of corrections and/or calibration.

The GO LIST command in GTBCOR can be used to list, on the devices (TTY:, LPT:, or DSK:) specified by the OUTFILE command, portions of the gain table (dbname.GAI[14,PN]). Choice of the NOMINAL part of the gain table by the LISTOPTIONS command means display of corrections already applied in the on-line system, which can be undone with the UNDO option of the CALIBRATION command which appears in many programs. LISTOPTIONS CORRECTED means to list the off-line correction portions of the gain table, which is the part you are mostly dealing with in running GTBCOR, GTTSYS, ANTSOL, and GTBCAL. The GO PLOT command allows plots of selected gain table entries to be displayed on the TEK 4012 terminal (or equivalent), where the range and type of x- and y-coordinates are specified by the XAXIS and YAXIS commands.

(m) GTTSYS

GTTSYS is a program for applying corrections for gain variations due to changes in system temperature. The corrections are made using system temperature measurements stored in a monitor data base and are inserted in 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
====== ======
timerange . . . . 78MAR28 at 17:00:00 to 78APR01 at  4:00:00 IAT
dbname. . . . . . 1MAR28[14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . *
ifs . . . . . . . A, C
bands . . . . . .  6.0cm
datatype. . . . . VALUE
mondbname . . . . DSK:[11,1]
outfile . . . . . TTY:GTBCAL
gtinterval. . . .  0:10:00
xaxis . . . . . .   -3h00m00s TO    6h00m00s HA
yaxis . . . . . .   .100 TO   .300 AMPLITUDE
```

The GTTSYS program plays a role just like the GTBCOR program, except it applies only one type of correction: removing gain variations due to changes in system temperature. GTTSYS basically multiplies amplitudes by the square root of the antenna system temperatures, T_{sys}. The selection of data to be corrected by GTTSYS involves the following standard commands:

DBNAME TIMERANGE SOURCES CALCODES ANTENNAS IFS BANDS .

The data from which the gain corrections are derived are obtained from the monitor data base specified with the MONDBNAME command.

The DATATYPE command allows one to choose various forms of monitor data.

```
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                              Put Tsys variations in gain table
go LIST                                  List gain table
go RESET                                 Reset specified part of gain table
go PLOT                                  Plot gain table on TEK
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
ifs A|C|* . . .                          IFs to be selected.
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .  Bands or frequencies
datatype VALUE|AVERAGE|#2AVERAGE|        Monitor data type.
         ERROR.CNT|STRING|COMP.ORED|
         ORED|PEAK.HI|PEAK.LO|COUNTER
mondbname dev:filename[p,pn]             Specify name of monitor database
outfile dev:file.ext[p,pn]               Output file.
gtinterval <time>                        Gain table entry interval
xaxis <number> TO <number> IAT.DAYS|     Range and kind of xaxis.  No
      IAT.24HR|LST.DAYS|LST.24HR|HA|     range for IAT.DAYS and LST.DAYS.
      ELEVATION|AZIMUTH|PARALLACTIC
       UVDISTANCE
yaxis <number> TO <number>  AMPLITUDE|   Range and kind of y-axis.
          AMP*AMP|1/AMP|AMP/JY|PHASE
```

The GO TSYSCORR command initiates entry of gain table corrections for T_{sys}. The remaining GO LIST, GO RESET, AND GO PLOT commands function as they do in GTBCOR.

(n) LISTER

LISTER is a program for listing visibility data, in different formats, on terminal screens or line printer. LISTER can provide listings 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 successive scans in a visibility data base; column listings of amplitudes, amplitudes/Jy, and/or phases as a function of time (IAT); and a matrix type listing of amplitudes, amplitudes/Jy, and/or phases with a format allowing displays for large numbers of antennas.

Data can be displayed with LISTER with or without application of the gain table.

```
LISTER INPUTS
====== ======
jobname . . . . . LISTER
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
ifpairs . . . . . AA
bands . . . . . .  6.0cm
modes . . . . . . ' '
passflag. . . . .  2
outfiles. . . . . TTY:FLAGER
listoptions . . . SCANHEADINGS
calibration . . . NONE
average . . . . .  0:01:00 VECTOR
scalefactor . . .   1.0E+00
```

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 vis. 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
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
                                        paired with 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 0 | 1 | 2 | 3                  Highest acceptable flag.
outfiles dev:file.ext[p,pn] . . .       Output files.
listoptions SCANHEADINGS|AMPLITUDE|     Types of data to list
        AMP/JY|PHASE|ANTENNAS|RMS
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
```

LISTER

The listing of visibility data in a number of different formats is the sole purpose of LISTER. The selection of data for listing involves the following standard commands:

DBNAME	TIMERANGE	SOURCES	CALCODES	ANTENNAS
IFPAIRS	BANDS	MODES	PASSFLAG	.

With the CALIBRATION command one can APPLY or not apply (NONE) the gain table; one can also specify UNDO.MODCOMP as a parameter to this command, and then corrections and calibrations applied by the on-line system can be removed.

The output of LISTER can be on terminal (TTY:), line printer (LPT:), or disk file (DSK:), depending upon the parameters of the OUTFILE command.

There are four types of listings that can be obtained, corresponding to different GO <type> commands:

<type>	Comments
SUMMARY	Short summary of information about sources, 1950 positions, flux densities, frequencies, and numbers of visibility records. Additional information in LPT: listing not found in TTY: listing.
SCAN	Summary of information about each scan. Additional information in LPT: listing not found in TTY: listing.
MATRIX	A matrix-like display of amplitudes and/or phases.
COLUMN	A columnar display of amplitude and/or phases.

The LISTOPTIONS and AVERAGE commands affect the type of listing you obtain. If SCANHEADING is one of the LISTOPTIONS, each scan listing is preceded by a summary of header information for the scan; without this amongst the LISTOPTIONS, only the source name appears. The LISTOPTIONS command can be used to choose whether one or two of the possibilities, AMPLITUDE, AMPLITUDE/JY, or PHASE are listed with GO MATRIX or GO COLUMN. If AMPLITUDE/JY is included, a flux density of unity is used where no flux density information is available. Use of AMPLITUDE, AMPLITUDE/JY, or PHASE together with RMS in the LISTOPTIONS parameter list will result in association of an RMS with each quantity in a GO MATRIX display. The AVERAGE command allows display of averaged data. The average can be VECTOR, where REAL and IMAGINARY are averaged before deriving amplitude and phase, or AMPSCALAR, where individual amplitudes are averaged in deriving an average amplitude. AMPSCALAR averaging is most useful for strong point source calibrators.

Finally, the amplitude displays of LISTER have built-in scale factors which can be changed with the SCALEFACTOR command. The automatic scale factors are based upon the gain code of the scan; gain code 0 is associated with a scale factor of 10000; gain codes 1 and 2 are associated with a scale factor of 1000; and gain codes of 3 or greater have a scale factor of 100. However, if LISTOPTION AMP/JY is used, the scale factor is 1000 unless overridden by the SCALEFACTOR command.

It is difficult to further describe the LISTER program without showing examples. The following is an example of a complete TTY: dialogue with the LISTER program producing a number of the types of displays that are commonly used. Some repetitive lines are deleted to save space, and extra comments on the right of command lines are enclosed by # symbols.

```
.r lister

LISTER
======
Version 5.0 September 30, 1978 (Antennas<=27)
I list visibility data in a large (but finite) number of formats
*setdef                          # Set parameters to program defaults #
*db imay21                       # Specify data base name #
*bands *                         # List data for all bands #
*timerange 78may21 at 0: to 78may21 at 24:      # One day time range #
*ant 11 3 1 13 12 6 2 8 9                       # All 9 good antennas #
*sources *:*                     # All sources and qualifiers #
*inputs                          # Display all current parameters #

LISTER INPUTS
====== ======
jobname . . . . . LISTER
jobtime . . . . .  0:05:00
```

LISTER

```
timerange . . . . 78MAY21 at  0:00:00 to 78MAY21 at 24:00:00 IAT
dbname. . . . . . 1MAY21[14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . 11,3,1,13,12,6,2,8,9 WITH 11,3,1,13,12,6,2,8,9
ifpairs . . . . . AA, CC
bands . . . . . . *
modes . . . . . . '  '
passflag. . . . .  2
outfiles. . . . . TTY:LISTER
listoptions . . . SCANHEADINGS
calibration . . . NONE
average . . . . .  0:00:00 VECTOR
scalefactor . . .   1.0E+00
*go summary                       # Display a SUMMARY listing on TTY #

LISTER EXECUTION    on    1978OCT27    at   9:25:
====== =========

  #    #Vis                                                  Gain
Scans  recs   Source:Q      C     RA(1950)    DEC(1950)       Flux  Code Band Mode
   5     175 2005+403:1      C 20h05m59.5s  40d21'01.76"  4.400Jy  2    6cm
  27     945    BLLAC:1      C 22h00m39.3s  42d02'08.53"  3.040Jy  2    6cm
        ANTENNAS   1  2  3  6  8  9 11 12 13
*go scan                          # Display a SCAN listing on TTY #

LISTER EXECUTION    on    1978OCT27    at   9:26:
====== =========

***78MAY21***

  Source:Q   C Band   Flux    StartIAT   StopIAT   StartLST    A-Obs. Freq-C
2005+403:1   C  6cm 4.400Jy    6:21:00   6:24:00  15h04m25s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    6:37:10   6:39:40  15h20m38s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    6:57:00   6:59:30  15h40m31s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    7:17:00   7:19:30  16h00m34s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    7:37:00   7:39:30  16h20m38s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    7:56:50   7:59:20  16h40m31s  4885MHz  4885MHz
2005+403:1   C  6cm 4.400Jy    8:17:40   8:19:20  17h01m24s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy    8:36:50   8:39:20  17h20m37s  4885MHz  4885MHz
      .
      .
      .

   BLLAC:1   C  6cm 3.040Jy  15:55:50 15:58:30   0h40m49s  4885MHz  4885MHz
2005+403:1   C  6cm 4.400Jy  16:16:10 16:18:00   1h01m13s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy  16:35:30 16:38:00   1h20m36s  4885MHz  4885MHz
   BLLAC:1   C  6cm 3.040Jy  16:55:30 16:58:00   1h40m39s  4885MHz  4885MHz
*list scan amp/                   # List scan headings and AMP/JY gains #
*calib apply                      # Apply gain table #
*sour BLLAC:*                     # List BL Lac data only #
```

```
*aver scan ampscalar            # Scan average of AMPSCALAR type #
*go matrix                      # Put out a MATRIX-type display #

LISTER EXECUTION    on    1978OCT27    at    9:26:
====== =========

***78MAY21***

  Source:Q    C  Band   Flux   StartIAT  StopIAT   StartLST   A-Obs. Freq-C
   BLLAC:1    C  6cm 3.040Jy   6:57:00  6:59:30  15h40m31s  4885MHz  4885MHz
Scale: x1.0E+03   AA upper right, CC lower left
  A--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11|               945         970   953  1029  1030   955
 3|              1016         947  1028   938   931  1031
 1|   956   978               991   980   965   983  1015
13|   979   962   971
12|   992  1000   994   969         956   984  1023   994
 6|   973   967   970   971   939         972   933  1001
 2|   986   973   977   986   978   980        1009   987
 8|   953   988   988   981   986   987   979         997
 9|  1014   990   985  1025   984   995  1018  1003
Average of above:  6:58:30 <amp>&rms=   983 +/-  24 <phi>=  -6d Navg=62

       .
       .
       .
  Source:Q    C  Band   Flux   StartIAT  StopIAT   StartLST   A-Obs. Freq-C
   BLLAC:1    C  6cm 3.040Jy  16:55:30 16:58:00   1h40m39s  4885MHz  4885MHz
Scale: x1.0E+03   AA upper right, CC lower left
  A--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11|               984        1031   982  1014  1063  1034
 3|              1062        1022  1102  1035   966  1038
 1|  1045  1024              1023  1031  1015   994  1022
13|  1063  1020  1019
12|  1088  1044  1056  1052        1032  1020  1037  1017
 6|  1042  1034  1025  1037  1024        1041   962   977
 2|   996  1032  1010  1011   986  1020         982  1009
 8|  1036  1013  1008  1019  1050  1016  1007        1048
 9|   997  1057  1004   991   990  1017  1057  1001
Average of above: 16:57:02 <amp>&rms=  1023 +/-  27 <phi>=  -2d Navg=62

*list phase                     # Now display phases, no SCANHEADING #
*go matrix                      # Put out a MATRIX display of phases #

LISTER EXECUTION    on    1978OCT27    at    9:28:
====== =========

***78MAY21***
      .
      .
      .
```

LISTER

```
BLLAC:1
AA upper right, CC lower left
  P--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11|                -3            0    -3    -3     8   -11
 3|                 0           -3     1     8   -15     0
 1|    -1     1                 -2     2    -4   -12     3
13|    -1    -2    -1
12|    -2    -3    -2     2           -4     1     8    -6
 6|    -3     1     2    -3    -3            3   -11     3
 2|     0     1     0     0    -2      3         -10     9
 8|     9   -10    -9     8     7    -11    -8          18
 9|     1     2     5    -4    -4      3     5    14
Average of above:  9:38:10 <amp>&rms=  3058 +/-  65 <phi>=   0d Navg=62

BLLAC:1
AA upper right, CC lower left
  P--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11|                -2            1     7     6     8     1
 3|                 1           -1   -10    18   -15   -10
 1|     0     5                  0    -8   -13   -10    -7
13|    -1    -5     0
12|    -1    -5    -1     0            7    12    10     7
 6|     8   -12    -8     6     8            2    -1     2
 2|     9    13    -9     8     8      3          -1     8
 8|     9   -13    -7     7     7      0     2           6
 9|    12   -12    -5     8    10      2     3     2
Average of above:  9:58:00 <amp>&rms=  3066 +/-  69 <phi>=   1d Navg=62

*ant 13 12 6 2 8 9             # Only six antennas fit on screen #
*list amp/ phas                # when you display amp/jy and phases #
*go matrix                     # in a MATRIX type display #

LISTER EXECUTION    on    1978OCT27    at    9:29:
====== =========

***78MAY21***
BLLAC:1
Scale: X1.0E+03   AA upper right, CC lower left
  A--13----12---- 6---- 2---- 8---- 9-- |P---13----12---- 6---- 2---- 8---- 9--
13|                                     |
12|  1018        1028   990  1022   998 |     2           -4     1     8    -6
 6|  1016   980        1015  1011   963 |    -3    -3            3   -11     3
 2|  1008  1019  1013        1017  1040 |     0    -2     3          -10     9
 8|   993   988  1017  1006        1005 |     8     7   -11    -8          18
 9|   979   976  1033   997  1016       |    -4    -4     3     5    14
Average of above:  9:38:10 <amp>&rms=  1006 +/-  18 <phi>=   1d Navg=25

BLLAC:1
Scale: X1.0E+03   AA upper right, CC lower left
  A--13----12---- 6---- 2---- 8---- 9-- |P---13----12---- 6---- 2---- 8---- 9--
13|                                     |
```

```
12|  1030        1019   973  1025  1014 |      0            7    12    10    7
 6|  1016   966         1003  1025   969 |      6     8           2    -1    2
 2|  1009  1004  1008         1014  1041 |      8     8     3          -1    8
 8|  1003   993  1024  1013         1005 |      7     7     0     2          6
 9|  1001   989  1038   998  1021        |      8    10     2     3     2
Average of above:  9:58:00 <amp>&rms=  1008 +/-  19 <phi>=   5d Navg=25

BLLAC:1
Scale: x1.0E+03   AA upper right, CC lower left
  A--13----12---- 6---- 2---- 8---- 9-- |P---13----12---- 6---- 2---- 8---- 9--
13|                                      |
12|  1000        1014   973  1041  1000 |    -14           -4     3     0    -4
 6|  1004   961         998  1044   953 |    -16    -3           4    -2     1
 2|   992  1000  1003         1030  1022 |    -13    -1     4           0    10
 8|   998  1004  1029  1030         1012 |    -16    -4     1     3          7
 9|   999   976  1007   982  1014        |    -14     0     1     3     1
Average of above: 10:38:00 <amp>&rms=  1003 +/-  22 <phi>=  -2d Navg=25

*calib none                     # Now let us not apply gain table #
*ant 6 with 2 8 9               # Reduce number of antennas #
*go column                      # before doing COLUMN- type display #

LISTER EXECUTION    on 1978OCT27    at 9:30:
====== =========

***78MAY21***
 x1.0E+03    2- 6AA     2- 6CC     6- 8AA     6- 8CC     6- 9AA     6- 9CC
   IAT      amp  phi   amp  phi   amp  phi   amp  phi   amp  phi   amp  phi
BLLAC:1
  6:38:40   271   44   295  -32   304  -48   349  160   284 -132   291   74
BLLAC:1
  6:58:40   276   52   303  -24   301  -64   352  145   296 -163   296   41
    .
    .
    .
*fin                            # Finished with running LISTER #
```

(o) MAKMAP

MAKMAP is a program that applies the gain table to selected visibility data for a single source, source qualifier, and band, and uses the resulting data array to compute radio maps or synthesized beams using the FFT algorithm.

After data selection, the program grids the data into a N_x X N_y u-v plane array by uniform or natural weighting and Box or Gaussian convolution. The resulting gridded u-v plane array can then be tapered by different functions with different degrees of tapering, and optionally corrected for the effects of gridding. Finally, the radio map is computed with the FFT algorithm, and map header and map array information are written into a map data base file, mapnam.XYZ[14,PN]; where X is missing if it is a map from data while X = B if it is a beam made by assuming visibility = (1,0); Y = I, Q, U, or V for one of four Stokes parameters; and Z = L, 6, 2, or K, corresponding to whether the map is made with 20, 6, 2, or 1.3 cm data.

```
MAKMAP INPUTS
====== ======
jobname . . . . . MAKMAP
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . [14,]
sources . . . . . *:*
antennas. . . . . *
stokes. . . . . . I
bands . . . . . .  6.0cm
passflag. . . . .  2
category. . . . . [no-map-category]
mapname . . . . . MAKMAP[14,]
remarks . . . . . ''
cellsize. . . . .   .500" by   .500"
mapsize . . . . .  128 by  128 cells
uvweight. . . . . NATURAL
uvtaper . . . . . NONE      .000km
uvconvolve. . . . BOX   1 cell(s)
gridcorr. . . . . NO
subsources. . . . NONE
shiftcenter . . .    0     0 (both in cells)
addmaps . . . . . NONE
typemap . . . . . MAP
```

```
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,
                                           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|ADD|SEEMAP                       Make maps, add two maps,
                                           or go to SEEMAP
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 MAKMAP
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.
antennas <physical IDs>                  Antenna selections
Stokes FORMAL|I|Q|U|V                    Stokes parameter
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .  Bands or frequencies
passflag 0 | 1 | 2 | 3                   Highest acceptable flag.
category  <name> | <nothing>             Identify maps by an SFD name?
mapname <6 char or less>                 Name to be assigned to maps.
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) map cells
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 param.
shiftcenter  <xshift> <yshift>           Map center shift, arcsecs or cells
addmaps <wt1> <map1>,<wt2> <map2>|NONE   Parameters for adding two maps
typemap  MAP|BEAM|AMP|COVER              Type of map to make
```

MAKMAP

The selection of data for making a two-dimensional map with the MAKMAP program involves the following standard commands:

DBNAME TIMERANGE SOURCES ANTENNAS BAND PASSFLAG

with the special restriction that only one source name and only one qualifier (not *) can occur as SOURCES command parameters. Similarly, only one BAND parameter can be specified.

The remaining parameter-type commands in MAKMAP determine the nature of the map and the information stored with it in a map data base. The MAPNAME command supplies the name of six characters or fewer that is used for the name of the map data base stored in the user's [14,PN] area. The CATEGORY command can be (optionally) used to organize different maps under a single label or category that corresponds to a subfile directory (SFD) name. If the CATEGORY command parameter is not blank, and is, for example, CATNAM, the maps made under this category are stored in disk files with names like mapnam.xyz[14,PN,CATNAM].

Remarks about a map can be stored in the map data base with the REMARKS command, whose command parameter can be any string of up to forty characters, enclosed in single quotes if any blanks are included in the string.

The size of the map (N_x X N_y) is determined by the parameters of the MAPSIZE command. If only one command parameter is supplied, it is taken to be both N_x and N_y. If the MAPSIZE parameters are not already numbers representable as powers of two, the program immediately changes them to the nearest numbers that can be represented as powers of two. The size of each cell in the map (dx X dy) is specified with the CELLSIZE command with parameters in angular units. If only one CELLSIZE parameter is supplied, it is taken to be both dx and dy. Once N_x, N_y, dx, and dy are specified, the cell sizes of the u-v plane, produced during the gridding before a map is made, are given by:

$$du = 1/(2\ N_x\ dx\ \nu_{GHz})\ \text{ns.} \quad ,\ dv = 1/(2\ N_y\ dx\ \nu_{GHz})\ \text{ns.}$$

where ν_{GHz} is the observing frequency in GHz, dx and dy are in radians, and the u-v plane cell sizes are in nanoseconds. The size of the u-v plane used to make the map is then $(N_x\ du)X(N_y\ dv)$. Note that, as the map plane cell size decreases, the gridding in the u-v plane becomes coarser and a larger region is gridded, frequently resulting in the only data input being in the center of the gridded u-v plane. Similarly, if the cell size is greater than a critical size, some data will be outside the gridded region and not used in making the map. Let B_{km} be the maximum diameter, in units of km, for the (Hermitian) data region in the u-v plane, then the data region will correspond exactly to the gridded u-v plane when

$$dx = dy = 1.03''\ (\lambda_{cm}/B_{km}) \quad .$$

With the grid size chosen from the above equation, the resulting map will have 2-3 points per synthesized beamwidth. In order to get the 4-5 points per synthesized beamwidth one frequently needs for reasonable map displays, source fitting, etc., one must use a cell size about a factor of two smaller than the above formula. Of course, strong tapering or use of natural weighting will broaden the synthesized beam and change what is needed for various purposes.

There are two types of gridding that are available in MAKMAP: complex averaging of all data within n_c grid cells, which is formally equivalent to BOX convolution; and GAUSSIAN convolution with a convolution range of n_c cells. These result in a convolution of the u-v plane that can be described by the functions:

MAKMAP

BOX convolution
$$C(u,v) = \begin{cases} 1 & \text{if } |u| \leq n_c du/2 \\ 0 & \text{if } |v| \leq n_c dv/2 \end{cases}$$

GAUSSIAN convolution
$$C(u,v) = \exp(-2u^2/(n_c du)^2)\exp(-2v^2/(n_c dv)^2) \quad .$$

The aliasing introduced by these two types of gridding convolution is very different. Since the effects of gridding are equivalent to tapering in the map domain, and since this tapering is the Fourier transform of the convolution function, the effect on the (n,m) cell of each map is multiplication by a function F(n,m):

BOX
$$F(n,m) = \text{sinc}\ (n_c n/N_x)\ \text{sinc}\ (n_c m/N_y)$$

GAUSSIAN
$$F(n,m) = \exp(-2(\pi n_c n/N_x)^2)\exp(-2(\pi n_c m/N_y)^2)$$

which, for $n_c = 1$ and BOX convolution, means reducing intensities by 0.636 at map edges and 0.405 at map corners; and for $n_c = 1$ and GAUSSIAN convolution, means reducing intensitites by 0.0072 at map edges and 0.000052 at map corners. Since this tapering in the map domain continues outside the mapped region, one sees how powerful GAUSSIAN convolution is at suppressing aliasing, while BOX convolution suppresses aliasing very poorly. The GRIDCORR command can be used to correct maps for the taper (F(n,m)) applied in the map domain. While this will give a much truer map in the outer regions, it will also magnify noise bumps.

The weighting of data before convolution and gridding can be either NATURAL or UNIFORM, depending upon the parameter supplied to the UVWEIGHT command. With UNIFORM weighting each cell is given the same weight, irrespective of the amount of data it represents; however, for NATURAL weighting, each cell is given a weight according to the amount of data that went into it. Natural weighting is equivalent to a very strong taper in the u-v plane, and is mostly used when signal to noise is important, as in detection experiments. Uniform weighting, followed by varying degrees of tapering, is more normal for mapping experiments.

Additional tapering of the u-v plane can be imposed with the UVTAPER command. The taper can be either LINEAR or GAUSSIAN, and the degree of tapering can be controlled by the taper width parameter. If W is the taper width in nanoseconds, derived from the taper width in distance units supplied in the UVTAPER command (W = taperwidth/30), the taper functions are:

LINEAR $$T(u,v) = (1 + (u^2+v^2)^{\frac{1}{2}}/W)$$

GAUSSIAN $$T(u,v) = \exp\ (-(u^2+v^2)/(W^2)) \quad .$$

Up to four point sources with parameters (I_i, x_i, y_i) can be subtracted from the u-v plane data before mapping through use of the SUBSOURCES command. Similar in nature is the SHIFTCENTER command which allows a change in reference position (center of map) by an amount (x_{shift},y_{shift}); this shift is accomplished by a phase shift in the u-v plane before mapping.

In addition to making maps with the GO MAKE command, one can make a third map through weighted addition of two other maps of the same MAPSIZE and CELLSIZE. This is accomplished by the GO ADD command, using the map names and weights supplied with the ADDMAPS command.

Once a map has been made, one can immediately transfer to running SEEMAP with the GO SEEMAP command. When running under DANEEL control, all parameters identifying the map are passed to SEEMAP and you can immediately begin map display without respecifying the map.

Finally, one can use the TYPEMAP command to make any of four

MAKMAP

types of maps. With TYPEMAP MAP a map using the selected visibility data is made. With TYPEMAP BEAM, the visibility data that would otherwise go into a map are replaced by a visibility with the real part corresponding to a 1 Jy source, and the imaginary part zero. This corresponds to a 1 Jy source at the center of the map so the result is computation of the synthesized beam or dirty beam. With TYPEMAP COVER one can produce a map of the u-v plane coverage; and with TYPEMAP AMP, one obtains a type of u-v plane display with amplitude strength displayed in the same way map intensities are displayed.

(p) MONLST

MONLST is a program that can be used to list selected monitor data points from a monitor data base, as a function of time (IAT), with output either to a terminal screen or to the DEC-10 line printer.

A list of Data Set numbers and DCS addresses for the monitor data points is available in MONDAT.AID[1,4] and can be obtained, while running any of the standard programs, by using the command EXPLAIN MONDAT.

```
MONLST INPUTS
====== ======
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . MOCT26[11,1]
antennas. . . . . 2 4 6 8 9
dcsaddress. . . . 5:220
datatype. . . . . VALUE
outfile . . . . . TTY:MONLST
listoption. . . . DETAIL
```

MONLST provides summary information or simple columnar displays of selected monitor data points in a monitor data base. Selection of data for display involves: specifying the monitor data base name with the DBNAME command; specifying a time range with the TIMERANGE command; specifying a list of antennas for which you want a listing with the ANTENNA command; specifying the monitor data type with the DATATYPE command; and specifying a specific monitor data point with the DCSADDRESS command. The command parameter for the DCSADDRESS command has the form <data set number>:<multiplex address>. The user should be wary of the defaults of the DBNAME command because monitor data bases are stored in the disk area [11,1] by the array operators. A typical DBNAME command parameter will be MXYZnm[11,1], where XYZ is the month and nm is the day of the month a particular monitor data base began.

```
MONLST 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                                      Generate a listing.
explain <program name> | <empty>        Type explanation of the given
                                          program. <empty> gives MONLST
timerange <start> to <stop>             Time period <start>,<stop> syntax:
                                          <date> at <time>|<date>|<time>
dbname dev:filename[p,pn]               Database to be used
antennas <physical IDs>|0               Antenna selections
dcsaddress <ds>:<mpx> | *               Dcsaddress to be selected.
datatype VALUE|AVERAGE|#2AVERAGE|       Monitor data type.
         ERROR.CNT|STRING|COMP.ORED|
         ORED|PEAK.HI|PEAK.LO|COUNTER
outfile dev:file.ext[p,pn]              Output file.
listoption  SUMMARY | DETAIL            List a summary or real data.

     The form of MONLST output is determined by the OUTFILE command.
Depending upon whether the LISTOPTION command parameter is SUMMARY or
DETAIL the output resulting from a GO command in MONLST is either a
summary of information or a detailed columnar listing of monitor point
data as a function of IAT.
```

The user can find out what data set numbers and multiplex addresses correspond to what monitor data points by using the EXPLAIN MONDAT command while running MONLST or any other standard program. Hard copy of this information can be obtained by printing out MONDAT.AID[1,4] on the line printer.

The form of MONLST output is determined by the OUTFILE command. Depending upon whether the LISTOPTION command parameter is SUMMARY or DETAIL, the output resulting from a GO command in MONLST is either a summary of information or a detailed columnar listing of monitor point data as a function of IAT.

(g) MONPLT

MONPLT is a program that can be used to plot selected monitor data points from a monitor data base, with output either to a terminal screen or to the DEC-10 line printer.

A list of Data Set numbers and DCS addresses for the monitor data points is available in MONDAT.AID[1,4] and can be obtained, while running any of the standard programs, by using the command EXPLAIN MONDAT.

```
MONPLT INPUTS
====== ======
jobname . . . . . MONPLT
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . MOCT26[11,1]
antennas. . . . . 8 9
dcsaddress. . . . 5:220
datatype. . . . . VALUE
skipfactor. . . . 1
outfile . . . . . TTY:MONLST=OVERWRITE
yaxis . . . . . .         .0 TO      2.00
title . . . . . . 'Monitor Data'
pointtypes. . . . LOWERCASE
linetype. . . . . NONE
distinguish . . . NONE
plotoptions . . . DISPLAY  MONSIZE
autoscaleopt. . . CHANGE  TIMERANGE  ALLTIMES
sizeplot. . . . . LPT  (132 by 58)
```

```
MONPLT 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 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 MONPLT

timerange <start> to <stop>            Time period <start>,<stop> syntax:
                                         <date> at <time>|<date>|<time>

dbname dev:filename[p,pn]              Database to be used
antennas <physical IDs>|0              Antenna selections
dcsaddress <ds>:<mpx> | *              Dcsaddress to be selected.
datatype VALUE|AVERAGE|#2AVERAGE|      Monitor data type.
         ERROR.CNT|STRING|COMP.ORED|
         ORED|PEAK.HI|PEAK.LO|COUNTER
skipfactor <n>                         Plot every n'th data record
outfile <file specification>=<type>    Output file and type
yaxis <number> TO <number>             Range of Y-axis.
title <string>                         Specify plot title.
pointtype NONE | VLINE | HLINE |       Specify point type to be plotted
          CROSS | TRIANGLE | SQUARE |
          DOT | <char> | DIGITS |
          LOWERCASE | UPPERCASE |
          SYMBOLS | ALLCHARS
linetype NONE | SOLID | SHORTDASH |    Specify line type to be plotted
         LONGDASH | DOTDASH | <char>
```

MONPLT

```
distinguish NONE|ANTENNAS                What category of thing is to be
plotoptions DISPLAY|NODISPLAY            Display or not on GO PLOT
       MONSIZE|STDSIZE|MAXSIZE             Amount of image for the axis
autoscaleopt CHANGE | NOCHANGE           Change plot range or not
    TIMERANGE | NOTIMERANGE                Look at time range or not
    SELECTEDTIMES | ALLTIMES               Range of time to look at
sizeplot LPT:|TEK:|ADDS:|SUPERBEE:       size of character image
    |IMPS:|<width> by <height>
```

Selection of data for plotting involves: specifying the monitor data base name with the DBNAME command; specifying the time range with the TIMERANGE command; specifying a list of antennas for which you want plots with the ANTENNAS command; specifying the monitor data type with the DATATYPE command; and specifying a specific monitor data point with the DCSADDRESS command. The command parameter for the DCSADDRESS command has the form <data set number>:<multiplex address>. The user should be wary of the defaults of the DBNAME command because monitor data bases are stored in the disk area [11,1] by the array operators. A typical DBNAME command parameter will be MXYZnm[11,1], where XYZ is the month and nm is the day of the month a particular monitor data base began.

The user can find out what data set numbers and multiplex addresses correspond to what monitor data points by using the EXPLAIN MONDAT command while running MONPLT or any other standard program. Hard copy of this information can be obtained by printing out MONDAT.AID[1,4] on the line printer.

Because monitor data is voluminous, a SKIPFACTOR command is provided in MONPLT so one can skip an integer number of data points. Titles may be provided for plots with the TITLE command, with single quotes surrounding the command parameter string if it contains any blanks. The YAXIS command can be used to change the range of data plot. This range, and the TIMERANGE, can be found from the data by the GO AUTOSCALE command, and, when finished, the data ranges are displayed and the TIMERANGE and YAXIS parameters can be set to correspond to these ranges.

The various GO <type> commands of MONPLT play the same role as they do in the VISPLT program; hence, we will not discuss them in detail here. This is also true of the plotting commands POINTTYPE, LINETYPE, DISTINGUISH, AUTOSCALEOPT, and SIZEPLOT.

(r) SEEMAP

SEEMAP is a program for displaying information about radio maps or beams that have been computed with the MAKMAP program and stored in map data bases in a user's [14,PN] area.

SEEMAP provides four types of display of map information. The GO INDEX command in SEEMAP results in a display of header information associated with selected maps. The GO FIT command in SEEMAP can be used to derive and list the parameters of a two-dimensional Gaussian fit to a specified small region of a map or beam. The GO PROFILE command can be used to plot cross sections through any position with any position angle. The output from GO INDEX, GO FIT, and GO PROFILE can be to terminal or line printer. Finally, the GO SHOW command can be used to obtain two-dimensional displays of a map where map intensities are represented by: coded characters if output is to an ordinary terminal or the DEC-10 line printer; contour lines if output is to the TEK 4012 terminal; or an IMPS map display file if the map is to be processed in the PDP 11/40 with the IMPS program.

```
SEEMAP INPUTS
====== ======
jobname . . . . . SEEMAP
jobtime . . . . .  0:05:00
stokes. . . . . . I
bands . . . . . .  6.0cm
outfile . . . . . TTY:
category. . . . . [no-map-category]
mapname . . . . . MAKMAP[14,]
typemap . . . . . MAP
displaynow. . . . YES
fitgauss. . . . .   0    0 (cells)    3    3 (cells)
profile . . . . .   0    0     90d
Irange. . . . . . *
contours. . . . . 0 ...

polarization. . . NO
polskip . . . . .      4
xyskip. . . . . .     1 (cell(s))
window. . . . . . STD
index . . . . . . CURRENT   DETAILED
center. . . . . .     0     0 (Both in cells)
```

```
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|MAKMAP     Make display or go to 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
Stokes FORMALI|I|Q|U|V                    Stokes parameter
bands 1.3cm|2cm|6cm|20cm|<freq>|* . . .   Bands or frequencies
outfile <dev>:<file>                      Specify output device type.
category <name>|<nothing>                 MAKMAP map category
mapname <6 chars or less>                 MAKMAP map name
typemap MAP|BEAM|AMP|COVER                MAKMAP type of map
displaynow yes | no                       show TEK immediately
fitgauss <x y width height>               Parameters for Gaussian fit
profile <x y pa>                          Profile centered at (x,y)
                                            through angle PA
Irange * | <Imin> <Imax>                  Min and Max I(Jy) for display
contours <count> <list>                   Give list of contours for TEK:
                                          display as percentages of Imax.
polarization YES|NO                       Display polarization data?
                                          Only good for TEK: and if you
                                          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 levels
                                            or use standard based on OUTFILE
index *|CURRENT  DETAILED|BRIEF           Index everything or just current
                                            map, and level of detail
center <xcenter> <ycenter>                Center display at this place
```

SEEMAP

The selection of a map for which information is to be displayed by the SEEMAP program requires the correct specification with the following commands:

MAPNAME CATEGORY STOKES BAND TYPEMAP .

The GO INDEX command, which displays a summary of information about map data bases, determines which map(s) will have such information displayed, and to what level of detail, from the parameters of the INDEX command. With the INDEX command one can choose a BRIEF or a more DETAILED display; one can also choose to display information about either the CURRENT map being specified or all (*) maps in the [14,PN] area.

The GO FIT command, which initiates the fitting of a two-dimensional Gaussian to a region of a map, and displays the fit parameters, needs correct specification of a small region where it is reasonable to attempt such a fit. This is accomplished with the FITGAUSS command, where the first two command parameters define the location, and the next two the size, of the fitted region. The result of GO FIT is usually a listing of the fit parameters, but, if a reasonable fit is not possible, it only supplies appropriate complaints.

The GO PROFILE command of SEEMAP requires that the parameters of the on-dimensional profile be supplied with the PROFILE command, and it uses parameters of the IRANGE and WINDOW commands to determine the intensity range and size of the map cross section or profile. The PROFILE command specifies the location of the center of the profile plot, and the position angle (PA) of the profile. The result is a one-dimensional character plot through the specified region. If the OUTFILE device is TTY:, the result is a 20X20 character plot on the screen if the WINDOW is STD, and a XWIDTH X YHEIGHT plot if these parameters have been supplied to the WINDOW command (70X20 is the largest that can appear on a single screen). If the OUTFILE device is LPT:, the result is a plot filling a single line printer page if the WINDOW is STD, and any other size if you supply parameters to the WINDOW command. If the parameter of the IRANGE command is *, the full range of data is plotted; however, the range of the plot can be changed with the IRANGE command.

The remaining commands concern parameters and possibilities for the two-dimensional map displays possible with the GO SHOW command. The IRANGE command can be used to specify that the entire range of map intensities (IRANGE *), from the highest point in the map to the most negative value, are to be displayed; or you can specify the maximum and minimum of the display with IRANGE Imin Imax. Since the map is often much larger than the display format, it is often useful to change the region of display with the XYSKIP and CENTER commands. With the XYSKIP command, one can skip an integer number of cells in the map display, so larger maps can be displayed in smaller sizes. With the CENTER command, the map display center can be shifted to any point in the map by specifying the map coordinates of that point as CENTER command parameters.

The WINDOW command can be used to choose either a default standard (STD) for the display size and number of displayed intensity levels (Isize) in a GO SHOW display, or one can specify the width (x-coord.) and height (y-coord.) of the displayed map and an arbitrary number of displayed intensity levels. For OUTFILE TTY: or LPT:, STD Isize is 21, corresponding to a 21 character representation of intensities, with 'jihgfedcba 123456789T' representing -10, -9, -8, -7, -6, -5, -4, -3, -2, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. The T or 10 corresponds to the maximum intensity displayed.

Finally, there are a variety of special commands that function only for GO SHOW displays on a line drawing terminal (OUTFILE TEK:<name>). If OUTFILE is TEK:, and the POLARIZATION command parameter is NO, then, SEEMAP

using the number of contours and the list of contour levels specified with the CONTOURS command, one obtains either an immediate display (DISPLAYNOW YES) of a contour map, or a contour map is stored (DISPLAYNOW NO) in a file named by the OUTFILE command for later display. When the DISPLAYNOW command parameter is NO, you collect contour plots in the named OUTFILES, and, after exiting from SEEMAP, you display the contour maps on the line drawing terminal by running the nonstandard program called TEKDMP and typing the name of one of the stored files when requested to do so. When the contour map is on the TEK screen, you can obtain hard copy of the map by pressing the MAKE COPY button on the terminal and retrieving the result from the VERSATEC printer-plotter.

The GO SHOW command can be used to display polarization maps on a line drawing terminal (TEK 4012 or equivalent) if the POLARIZATION command parameter is set to YES. In this case, the POLSKIP command specifies the number of pixels to be skipped between polarization vectors. The polarization map obtained with the GO SHOW command is a map of linear polarization showing the length and orientation of linear polarization vectors. In order to obtain a polarization map, it is required both that the STOKES command parameter be set to I and that I, Q, and U maps be available in [14,PN] with the same MAPNAME, BAND, CATEGORY, AND TYPEMAP.

The GO SHOW command can be used to produce maps in the PDP 11/40 system for IMPS. This is achieved by specifying OUTFILE IMPS:<name>, where <name> is the name the map will have in the PDP 11/40.

SEEMAP

(s) SETJY

SETJY is a program that inserts or lists flux density information in selected visibility data scans. This is done mostly for calibrators. The SETJY program normally is used to put flux densities into the data base before the ANTSOL program uses the calibrator data to solve for antenna gain factors. Similarly, the AMP/JY options in LISTER and VISPLT will not be useful unless the SETJY program has put the right flux density information into the data base.

SETJY puts the flux density information into records in the file dbname.INX[14,PN] (index file).

```
SETJY INPUTS
===== ======
jobname . . . . . SETJY
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . MONDEF[14,]
sources . . . . . *:*
calcodes. . . . . *
stokes. . . . . . I
band. . . . . . .  6.0cm
fluxes. . . . . .  .000Jy
```

```
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                   SET, RESET, or LIST 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 FORMAL|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.
```

SETJY

Selection of data, for which flux densities are listed or inserted in scan headers, is done with the following standard commands:

DBNAME TIMERANGE SOURCES CALCODES BAND STOKES .

SETJY takes the list of fluxes in the FLUXES command parameter list and inserts these fluxes into the scan headers of the corresponding SOURCES command parameter list. If there are N sources in the SOURCES parameter list, there must be N fluxes in the FLUXES parameter list; in addition, the j-th source in the SOURCES parameter list must have its flux density (I, Q, U, or V Stokes parameter from the STOKES command) in the j-th position in the FLUXES parameter list.

Only a single BAND and STOKES parameter can be dealt with at any one execution of SETJY. The GO SETJY command initiates the insertion of Stokes parameter data into a data base.

The GO RESET command causes the flux densities of selected data to be set equal to zero.

The GO LIST command allows one to display a scan by scan listing of source name, qualifier, band, the I Q U V Stokes parameters present in the header for each scan.

It is recommended that the user associate a GETCOMMANDS file with the data base for an observing run. The best procedure is to use the SOS text editor to create and fill a file called dbname.SJY[14,PN] containing the following in sequence:

(0) SETDEFAULTS

(1) DBNAME command;

(2) STOKES command;

(3) BAND 20cm command;

(4) SOURCES command with complete list of all sources observed at 20cm for which you wish to supply flux densities;

(5) FLUXES command with corresponding list of fluxes for the Stokes parameter specified in step (2);

(6) GO SETJY command;

(7) GO LIST command;

(8) Repeat of steps (3)-(7) for 6cm if needed;

(9) Repeat of steps (3)-(7) for 2cm if needed;

(10) Repeat of steps (3)-(7) for 1.3cm if needed; and

(11) Repeat of steps (2)-(10) as needed for other Stokes parameters.

With this approach one can place all input flux information in one file. By naming the file dbname.SJY[14,PN] the file is identified with a data base. The file can be typed out and listed on the line printer. However, most importantly, all you need to do to insert the Stokes parameters into a data base and examine the results for all calibrators and all bands is to run SETJY as follows:

```
.r SETJY
*get dbname.SJY[14,PN]
```

and all commands in the file are executed in sequence. Because of the GO LIST following every GO SETJY command, the execution of this file supplies a display of the results for each band and Stokes parameter.

Because an observer typically needs to bootstrap fluxes for some calibrators from data on other known flux calibrators, he tends to make a number of changes in the dbname.SJY[14,PN] file.

(t) VISPLT

VISPLT is a program for plotting visibility amplitudes, amplitudes/Jy, or phase as a function of IAT days, IAT in hours, LST, hour angle, parallactic angle, antenna elevation, antenna azimuth, or radial 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 line drawing terminal (the TEK 4012 or equivalent). Data can be averaged with respect to time, and/or antenna-IF pairs, and/or various ways to combine IFs.

```
VISPLT INPUTS
====== ======
jobname . . . . . VISPLT
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . MONDEF[14,]
sources . . . . . *:*
calcodes. . . . . *
antennas. . . . . * WITH * (Physical IDs)
ifpairs . . . . . AA
bands . . . . . .  6.0cm
modes . . . . . . '  '
passflag. . . . .  2
outfile . . . . . TTY:PLOT=OVERWRITE
calibration . . . NONE
average . . . . .  0:01:00 VECTOR
baselineaver. . . NONE
ifcombination . . NONE
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .      .0000 TO     2.0000 AMPLITUDE
title . . . . . . 'Monitor Data'
pointtypes. . . . LOWERCASE NOBAR
linetype. . . . . NONE SEPARATESCANS
distinguish . . . NONE
plotoptions . . . DISPLAY  STDSIZE
autoscaleopt. . . CHANGE  TIMERANGE  YRANGE  ALLTIMES
sizeplot. . . . . LPT:  (132 by 58)
```

```
VISPLT 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 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
                                        paired with 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 0 | 1 | 2 | 3                  Highest acceptable flag.
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|FORMAL|I|I|Q|U|V     IF combination
  |RATIO|LINEARPOL|CIRCULARPOL|AVERAGE
xaxis <number> TO <number> IAT.DAYS|    Range and kind of xaxis.  No
      IAT.24HR|LST.DAYS|LST.24HR|HA|    range for IAT.DAYS and LST.DAYS.
```

VISPLT

```
      ELEVATION|AZIMUTH|PARALLACTIC
       UVDISTANCE
yaxis <number> TO <number>  AMPLITUDE|  Range and kind of y-axis.
                          AMP/JY|PHASE
title <string>                          Specify plot title.
pointtype NONE | VLINE | HLINE |        Specify point type to be plotted
          CROSS | TRIANGLE | SQUARE |
          DOT | <char> | DIGITS |         and whether or not to draw bars.
          LOWERCASE | UPPERCASE |
          SYMBOLS | ALLCHARS
          NOBAR|RANGEBAR|RMSBAR|ERRBAR
linetype NONE | SOLID | SHORTDASH |     Specify line type to be plotted
         LONGDASH | DOTDASH | <char>      and whether to separate scans.
         SEPARATESCANS | CONNECTSCANS
distinguish NONE|SOURCES|QUALS          What category of thing is to be
    |ANTENNAS-IFPAIRS|BANDS|PASSFLAG    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:      size of character image
    |IMPS:|<width> by <height>
```

The VISPLT program for plotting visibility data is both complex and flexible. This is because there are a large number of plotting-oriented commands with a very large number of possibilities for the way the parameters of these commands can combine.

The selection of data for VISPLT involves the following standard commands:

DBNAME	TIMERANGE	SOURCES	CALCODES	ANTENNAS
IFPAIRS	BANDS	MODES	PASSFLAG	

with the gain table applied or not applied, depending upon the parameter of the CALIBRATION command.

The OUTFILE command 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 output is written into a <name>.DAT file which must be printed out later. A command closely related to, but independent of, the OUTFILE specification is the SIZEPLOT command which sets the size of the character image portion of each plot. By specifying SIZEPLOT parameters of LPT:, TEK:, ADDS:, SUPERBEE:, or IMPS:, the height and width of the plot (in characters) will be set so that it will just fit onto each screen or a single line printer page; however, you can also specify nonstandard <width> and <height> parameters with this command. Doing this is particularly useful for making line printer plots on more than one page. The normal single page plot is 132X61. 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 AVERAGE command of VISPLT allows one to specify either VECTOR (Complex) averaging or AMPSCALAR averaging. Phases are obtained the same way with both options; however, with AMPSCALAR averaging data point amplitudes are averaged and not the real and imaginary parts of the visibilities. The AVERAGE command is by definition a command specifying the averaging with respect to time, and one of its command parameters is any averaging time up to SCAN averaging. Time averaging of individual ANTENNA-IF pairs is obtained when the BASELINEAVER command parameter is set to NONE or when only two antennas are specified by the ANTENNA command. If more than

VISPLT

two antennas are specified and BASELINEAVER is VECTOR or AMPSCALAR, one can plot averages of the selected antennas. Analogous to the BASELINEAVER command is the IFCOMBINATION command. With the IFCOMBINATION command parameter set to NONE, the plots are of individual IFPAIRS as chosen by the IFPAIRS command; however, one can combine IF data in a number of ways: FORMALI, which combines (AA + CC)/2 only if both AA and CC are present; I, which combines (AA + CC)/2; Q, U, or V, which combine IF pairs to compute Stokes parameters; RATIO, which gives AA/CC; LINEARPOL, which combines data to give degree of linear polarization; and CIRCULARPOL, which combines (RR - LL)/2.

The XAXIS command is used to both specify the range of x-coordinate data to be plotted and to choose one of a list of possible x-coordinates: IAT.DAYS where the x-axis is IAT day number; IAT.24HR where the x-axis is IAT time on a 24 hour cycle; LST.DAYS where the x-axis is LST day number; LST.24HR where the x-axis is Local Sidereal Time on a 24 hour cycle; HA where the x-axis is hour angle; ELEVATION where the x-axis is antenna elevation; AZIMUTH where the x-axis is antenna azimuth; PARALLACTIC where the x-axis is the parallactic angle; and UVDISTANCE where the x-axis is $(u^2 + v^2)^{\frac{1}{2}}$.

The YAXIS command is used to both specify the range of y-coordinate data to be plotted and to choose one of a list of possible y-coordinates: AMPLITUDE where the y-axis is visibility amplitude; AMP/JY where the y-axis is amplitude divided by flux density (correlator gain) if a flux density is entered in the scan header, and amplitude if there is no flux density in the scan header; and PHASE where the y-axis is visibility phase. Both x- and y-axes are labeled appropriately. The TITLE command can be used to label plots; if the title contains any blanks, it should be enclosed in single quotes.

The POINTTYPE command of VISPLT has command parameters that specify the type of symbol or character that is to be inserted in plots to represent data points, if any, and command parameters that determine the range or error bar to be plotted with the data point. The command parameters that affect what is plotted at the position of a data point are: NONE meaning nothing to be plotted, which is meaningful if one uses the LINETYPE command to draw lines between data points; VLINE, HLINE, CROSS, TRIANGLE, SQUARE, or DOT which are valid only for OUTFILE TEK: where they correspond to a vertical line, a horizontal line, a cross, a triangle, a square, or a dot; any single character, which is then used as the plot symbol; DIGITS meaning to use numbers for plot characters; LOWERCASE meaning to use the lower case alphabet for plot symbols; UPPERCASE meaning to use the upper case alphabet for plot symbols; SYMBOLS meaning to use any symbols except the numbers or the alphabet; and ALLCHARS meaning to use first DIGITS, then LOWERCASE, UPPERCASE, and SYMBOLS. The use of DIGITS, LOWERCASE, UPPERCASE, SYMBOLS, and ALLCHARS is related to the use of the DISTINGUISH command where you want different symbols to distinguish different sources, source qualifiers, antenna-IF pairs, bands, or passflags. The range or error bar parameter possibilities are: NOBAR where nothing is added; RANGEBAR where the range of data going into the point is plotted; RMSBAR where the range of plus or minus one sigma is plotted based upon the standard deviation of the data going into the plotted point; and ERRBAR where the three sigma error bars are plotted.

The LINETYPE command specifies both parameters of lines connecting data points and whether or not you want the lines to be drawn between different scans. The LINETYPE command parameters that affect the lines drawn between data points within a scan are: NONE meaning no lines drawn at all; SOLID, SHORTDASH, LONGDASH, and DOTDASH which are valid only for TEK plots; and any character, in which case the line(s) are indicated by this character.

The PLOTOPTIONS command has two parameters. One is the DISPLAY or NODISPLAY parameter which determines whether a plot is displayed as result of a GO PLOT command. The NODISPLAY parameter is most useful when you want to prepare TEK plots on another terminal or in batch to be saved for later display. The other parameter of PLOTOPTIONS is STDSIZE or MAXSIZE; for STDSIZE space is used for axis information, but for MAXSIZE you can get a larger plot at the expense of the axis information.

Finally, the AUTOSCALEOPT command gives parameters determining how the GO AUTOSCALE command is to work. GO AUTOSCALE initiates an examination of data selected on all criteria except (possibly) TIMERANGE 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 has found. With NOCHANGE, the axis information is only displayed on the terminal screen. Depending upon whether YRANGE or NOYRANGE is set, GO AUTOSCALE will search or 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 of 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 parameters.

In addition to GO PLOT, which initiates 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. This is necessary because otherwise plots are added to the picture with every execution of GO PLOT. In addition, GO CLEARPIC must be used before changing scales on the x- or y-axis. The use of the GO BLANK command allows one to temporarily delete any of a number of plots sequentially created with the GO PLOT command. Blanked plots can then be restored to the picture with the GO UNBLANK command. Plots are numbered sequentially according to the order of the GO PLOT command producing each plot; therefore, one can deal with them by plot number when this is convenient. Plots 1, ..., N are simultaneously displayed on the same screen except for the ones that have been BLANKED.

With the GO SAVEPIC command, one can store pictures containing N different plots in disk files. These pictures can then be displayed at another time with the GETPIC command. This is most useful for preparing plots in batch, or for preparing TEK plots on a non-TEK terminal.

Some examples of the use of the VISPLT program are presented as part of the discussion of the process of VLA data reduction in the next section of this chapter.

9. The Process of VLA Data Reduction

(a) Importance of a Systematic Approach

Even observations with only ten VLA antennas produce such large volumes of visibility data that observers need to adopt a systematic approach to VLA data reduction. In this section we will discuss one of the possible ways to approach this problem. Part of this discussion will be in terms of specific examples based on a real observing situation on May 21-22, 1978. Many different approaches are possible and experienced users will develop procedures suited to their own tastes and the nature of their scientific and technical problems.

The most basic problem is that the large volume of data makes it difficult to evaluate. With ten antennas there are ninety parallel hand correlators and ninety cross hand correlators. When the full 27-antenna VLA is operational, there will be 351 antenna pairs with four polarizations; however, by that time the quality of data should also be considerably improved. A major fact of life in the 1978-1980 period is the frequent need for data evaluation and editing or re-flagging. This is because the evolving electronics and on-line data flagging system are still not up to the standards that will be commonly supported after 1980. Eventually, nearly all of the data processing initiated by the user will be in the area of map processing, and the user will deal almost exclusively with data in the u-v and map planes. The main reason for the temporary need to evaluate and edit on an antenna by antenna or correlator by correlator basis is the fact that, during the construction phase of the VLA, the subarray used for astronomy will typically contain a combination of "good" antennas, "old" antennas with known problems that still need to be fixed, and "new" antennas with electronic systems that are still in the process of being debugged and tuned up. The on-line flagging system, because complete information on flagging criteria is not yet available, occasionally fails to flag "bad" data. Because of this the observer in the 1978-1980 era should assume that some fraction of the data has not been properly flagged and, therefore, should make data evaluation and reflagging the first order of business in the data reduction process.

The most important things that the observer can do to make data reduction systematic rather than haphazard are: (1) use batch control files for all steps that actually flag, correct, and calibrate the data; and (2) keep a sequential log, on paper, of everything you do, and your conclusions. Interactive use of the data reduction programs is often convenient, but it can lead to confusion and errors unless the user is exceptionally careful, particularly when carrying out the processing that changes flags and puts corrections and calibrations into the gain table.

(b) Data Evaluation and Editing

Evaluation of VLA data is generally done through judicious use of LISTER, VISPLT, and ANTSOL. In the process of data evaluation one accumulates a detailed listing, on paper, of antenna-IFs or correlators to be reflagged for specific IAT time ranges. When the flagging to be done is known, the FLAGER program is used to modify the data flags, and it is strongly recommended that this be done in a single batch control file. For the sake of this discussion, let us name this batch control file REFLAG.CTL. The reason for the importance of reflagging in a batch control file is that it is self-documenting as to what you have done with what selection criteria. You generally add to the list of the flagging to be done and, unless you adopt a policy of re-executing one and only one REFLAG control file, mistakes are easily made. A common mistake is to make an error in data selection for flagging, resulting in erroneous flagging of a lot of data. The best way to recover from such errors is to recreate your data base from magnetic tape with the FILLER program, and then to redo the flagging with REFLAG.CTL after fixing the error. Changing flags for ranges of data erroneously set to level three, for example, back to level two will often include really bad data that was caught by the on-line flagging system. You cannot run everything through the real-time flagging system again.

Data evaluation and editing is, of course, an iterative process. It generally consists of distinct stages: (1) evaluation and editing based upon calibrator amplitudes, which tends to eliminate the gross failures of the system; (2) evaluation, editing, and planning of corrections based upon examination of calibrator phase data; (3) evaluation and editing based upon finding spurious signals in blank sky or weak source data; and (4) evaluation and editing based upon discrepancies found in source data that had been thought to be correctly edited and calibrated.

The first thing everyone should do is evaluate calibrator amplitudes. In order to do this most conveniently, it is best to have determined fluxes for all your calibrators and inserted these fluxes in the data base with the SETJY program. If you cannot find accurate fluxes for calibrators, you will need to pause and bootstrap flux determinations from known calibrators to the unknown calibrators. Once calibrator fluxes are inserted in the data base, one can then examine listings or plots of antenna-IF or correlator gains with the AMP/JY display options, searching for failures to maintain constant or slowly drifting antenna-IF gains. One of the most useful tools for carrying out this evaluation is the ANTSOL program. ANTSOL uses correlator data to solve for individual antenna-IF gains and in the process it reports failures to attain closure. That is, any failures for N(N-1)/2 correlators for a single IF to adequately fulfill the assumption that they can be fit by N antenna gain factors are reported. If the calibrator is known to be a point source, failures of amplitude closure in ANTSOL are indicators of some types of problems. However, even a bad antenna-IF can fit well into an antenna-IF gain solution, so one also evaluates calibrators by examining listings or plots of antenna-IF gains and/or phases. Examination of tables of antenna-IF gains and phases as a function of time is the most compact means of calibrator evaluation simply because it is easier to make sense out of N antenna-IF gains than it is to make sense out of N(N-1)/2 correlator gains. However, when discrepancies are noted, it is usually necessary to look at correlator data in more detail. For example, if for one scan the average antenna-IF gain is low, you need to look at listings of pieces of this data to see if all or part of the scan is "bad". In general, this is done with LISTER or VISPLT, using a simple technique of listing or plotting data for the suspect antenna correlated with data from antennas that seem to be behaving reasonably. Developing a habit of evaluating things in terms of a "reference" antenna and a number of other antennas is a useful tool for coping with the volume of VLA data.

Let us now discuss the flagging associated with an observing run carried out May 21-22, 1978. The objective of this observing run was to use the improved sensitivity of the VLA to find out if the Cyg X-2 radio source was present at low levels. During the period 1971-1972 the source had been occasionally observable at the 4-8 mJy level with the Green Bank interferometer, but from 1973-1975 the source was distinctly less than 4 mJy, and VLA observations in 1977 indicated it was less than 1 mJy. A last attempt to go deeper on the source and see if there was any sign of a pair of companion sources for which there had previously been very marginal evidence was carried out with nine antennas for about twelve hour periods on both May 21 and May 22, 1978. Observations were at 6 cm only, and the calibrators 2005+403 and BLLAC were alternately observed once every half hour. For this observing run, antennas 1, 2, 3, 6, 8, 9, 11, 12, and 13 provided useful data. Antenna 4 was down being retrofitted, antenna 5 had a hot cryogenic system and was out of the array, antenna 7 had a jammed subreflector and was also out of the array, and antenna 10 was temporarily decommissioned. During the observing it was known that IF A of antenna 13 had a stuck band select switch, so the 13A data needed reflagging to level 3. Examination of listings of the amplitudes revealed that both IFs of the antenna pair 3-11 showed erratic variations. Rather than attempt to salvage part of the data, it was decided to reflag all data for this antenna pair to level 3. It was also noted that, during the observing run, phase jumps of varying magnitudes occurred on antennas 6, 8, 9. Months later the cause of these jumps was found to be improper termination of the waveguide run down the southwest arm.

Because the phase jump on antenna 6 on 78MAY22 had an uncertainty of location, it was also decided to edit out all data for this antenna from 11:15:10 to 11:32:10. Thus the editing file, REFLAG.CTL, was created with the following entries:

```
.r flager
setdefaults
dbname lmay21[14,11]
band 6cm
antenna 13
ifs a
time 78may21 at 0: to 78may22 at 24:
newflag 3
flagoption antenna
go flag
antenna 6
ifs a c
time 78may22 at 11:15:10 to 78may22 at 11:32:10
go flag
time 78may21 at 0: to 78may22 at 24:
flagoption correlator
antennas 3 with 11
ifp aa cc ac ca
go flag
finish
```

which was executed by submitting REFLAG.CTL to the batch stream (but also could have been executed, without production of a LOG file, by typing DO REFLAG.CTL on a terminal). The preparation of most of the commands in REFLAG.CTL need no special explanation; however it should be emphasized the SETDEFAULTS is necessary after first running FLAGER to avoid possible carryover of erroneous parameters from previous use of FLAGER.

(c) Correction and Calibration - Preparing the Gain Table

Once data evaluation and editing is completed, at least to first order, one proceeds to correction and calibration of the data base. In the VLA off-line software system this means preparing the gain table. Gain table entries that are due to known corrections are produced by GTTSYS and GTBCOR. Empirical calibrations of antenna-IF gains and phase centers are determined by ANTSOL and applied by GTBCAL.

Because GTTSYS, GTBCOR, and GTBCAL make accumulative entries in the gain table of a data base, one must be very careful to avoid making corrections or applying calibration more than once.

In order to lend specificity to this discussion, let us explicitly discuss the process of preparing the gain table to the data base 1MAY21[14,11] containing data taken May 21-22, 1978 on the calibrators 2005+403 and BLLAC, and the source CYGX-2. We will explicitly discuss the processing of only the May 21 data, just to avoid excessive length.

It was noted from the first time ANTSOL was run that phase jumps occurred in antennas 8 and 9 on May 21. Next, we will show the output of a batch run of VISPLT oriented to delineating the nature of the phase jumps. In this and following examples we will adopt the convention of adding explanatory comments surrounded by # symbols to explain the motives for various commands.

```
.r visplt                       # Run VISPLT to make plots #

VISPLT
======
Version 27 - September 15, 1978
Ï plot visibility data
    (SIZEPLOT parameters have been set to 79 by 24)
*db 1may21                      # Specify data base #
*band 6cm
*ant 6 8                        # Do plot for 6 8 antenna pair first #
*time 78may21 at 6: to 78may21 at 17:30         # Pick time range #
*yax -180d 180d pha             # Plot phase on y-axis in -180 to 180 #
*ifp aa cc                      # Plot for both AA and CC correlators #
*pointtype lower                # Plot lower case symbols #
*dist ant                       # Distinguish antenna-IF pairs #
*calib none                     # Do not apply gain table #
*go plot                        # Make plot for specified data #

VISPLT EXECUTION    on    1978OCT21   at   14:49
====== =========

64 data points were plotted.
Type <return> to see the plot or N<return> to cancel the display.
                                                   Visibility Data
                                                             Phase
              .....|..........|.........|..........|.........|b..
              .  bb.          .         .          .         .  .
              .    .          .         .          .         .  .
              ...................................................<100.
              .    .          .     a a a          .         .  .
              .    .          .      a  .          .         .  .
              .    .          .         .          .         .  .
              .    .          .         .      a   a    aa   .  .
              ..a...a...a..aa..a.aa........aa.a..aa..aa..........<0
              .    . a a a    a         .          .       aa.  .


              .  aa.          .       b b          .         .a .
              .    .          .     bb  .          .         .  .
              ...................................................<-100.
              .    .          .         .      b   b    bb  b.  .
              .    .b   b  bb .b bb     .  bb b  bb. bb    b .  .
              ..b..|.b.b.b....b.........|..........|.........|...
               141.3      141.4     141.5     141.6     141.7
1MAY21(14,]                     Time (IAT, day number within 1978)
1        Phase  ?:*            *   6.0cm   6-8   AA,CC       Cal:N
                     TAve:None       BAve:N  PFlg:2  Mode:
         Sources: 2005+403:*, BLLAC:*
    Distinguished IFpairs:  a AA; b CC
```

```
*go clear                       # Clear out the previous plot #

VISPLT EXECUTION    on    1978OCT21   at   14:50
====== =========

    (All of the plots have now been killed.)
*ant 6 9                        # Now make plot for 6-9 pair #
*go plot                        # Initiate preparation of plot #

VISPLT EXECUTION    on    1978OCT21   at   14:50
====== =========

64 data points were plotted.
Type <return> to see the plot or N<return> to cancel the display.

                                                   Visibility Data
                                                             Phase
              .....!..........!.........!..........!.........!...
              .    .          .         .          .         .  .
              .    .    b  b  .         .          .         .  .
              .......b...b..b.bb..b.bbb...........b...b..........<100.
              . bb .b  b      .  b      b  b       b b       .  .
              .    .          .         .   b bb b .         .  .
              .   b.          .         .          .         .  .
              .    .          .         .          .         .  .
              ...................................................<0
              .    .          .         .          .         .  .
              .    .          .         .          .    a   !.  .
              .    . a  aa aa aa    a   .          .  a b! ! .  .
              ..a................aa..aa.a.........aa.a........!..<-100.
              .  a .a  a      .         .  aa  a a .         .  .
              .   a.          .         .     a    .         .  .
              .....!..........!.........!..........!.........!...
               141.3      141.4     141.5      141.6     141.7
1MAY21[14,]                       Time (IAT, day number within 1978)
1        Phase  ?:*       *      6.0cm   6-9   AA,CC       Cal:N
                TAve:None        BAve:N  PFig:2  Mode:
         Sources: 2005+403:*, BLLAC:*
   Distinguished IFpairs:  a AA; b CC

*fin                            # Exit from VISPLT #
```

From the previous plots, and supplemental LISTER information to help to identify IAT times more specifically, it was clear that from 10:56:10 to 11:58:40 IAT on May 21, antenna 8 underwent a phase jump of + 90 degrees. Similarly, antenna-IF 9C underwent a phase jump of 180 degrees from 15:18:10 to the end of the day.

As mentioned previously, we strongly recommend that the user prepare batch files to carry out any actual changes of the gain table. For our current example, focusing only on the May 21 data, the following is the first part of the batch file, which we will call GAINTB.CTL, that uses GTBCOR to apply phase corrections "fixing" the phase jumps:

```
.r gtbcor
setdef                               # Restore program default parameters #
db 1may21
band 6cm
go reset                             # Clear out the gain table #
ant 8                                # Correct antenna 8 phase jump first "
ifs a c                              # Both IFs for antenna 8 #
phase  +90d  +90d                    # Constant phase shift of 90d #
time 78may21 at 10:39:10 to 78may21 at 12:36:10 #Range of phase shift #
go phase                             # Put phase shift in gain table #
ant 9                                # Now switch to antenna 9 #
ifs c                                # Only 9C had a phase jump #
phase +180d  +180d                   # Linear phase shift of 180d #
time 78may21 at 15:18:20 to 78may21 at 17:14:50 # Shift time range #
go phase                             # Put phase shift in gain table #
fin                                  # Exit from GTBCOR #
```

Because the correction for T_{sys} variations was applied on-line, there was no need to use the GTTSYS program after this execution of GTBCOR. After the above corrections were applied to the data base, the following is the plot of the corrected phases for antenna 8:

```
                                                           Visibility Data
                                                                     Phase
              .....|..........|.........|..........|.........|b..
              .  bb.          .         .          .         .  .
              .    .          .         .          .         .  .
              ...................................................<100.
              .    .          .         .          .         .  .
              .    .          .         .          .         .  .
              .    .          .         .          .         .  .
              .    .          .         .     a    a    aa   .  .
              ..a...a...a..aa..a.aa.aaa.a..aa.a..aa..aa..........<0
              .    . a a a    a         .          .       aa.  .
              .  aa.          .         .          .         .a .
              .    .          .         .          .         .  .
              ...................................................<-100.
              .    .          .         .      b   b    bb  b.  .
              .    .b   b  bb .b bb b b b  bb b  bb. bb    b .  .
              ..b..|.b.b.b....b......b..|..........|.........|...
               141.3      141.4     141.5      141.6    141.7
1MAY21[14,]                          Time (IAT, day number within 1978)
1        Phase  ?:*           *         6.0cm   6-8   AA,CC       Cal:A
                      TAve:None       BAve:N  PFlg:2  Mode:
         Sources: 2005+403:*, BLLAC:*
    Distinguished IFpairs:  a AA; b CC
```

The first thing done in the GAINTB.CTL file, after running GTBCOR, is setting the defaults to those you expect from the program. This is to avoid unexpected transfer of parameters from a previous run of GTBCOR. After the data base is named, you then use the GO RESET command to reset the gain table to an initial state with no entries. This is because you will tend to execute GAINTB.CTL more than once, and you want to ensure that you never apply correction or calibration more than once.

The next step is to add to the GAINTB.CTL file the execution of ANTSOL and GTBCAL to determine and apply empirical calibration factors. One wants to execute ANTSOL, list the gain and phase calibration parameters it has obtained, and then use GTBCAL to apply them to the data base. The following is an example of what was obtained in the log of the batch file executing this part of the calibration process, where we delete entries where convenient to save space.

```
.r antsol                          # Run ANTSOL #

ANTSOL
======
Version 3.5  September 15, 1978
I solve for antenna gains and write out a temporary CAL file.

*setdefaults                       # Restore program default parameters #
*ant 11 3 1 13 12 6 2 8 9          # Specify antennas in solution #
*refant 6 2 1 8                    # Desired order of reference antennas#
*db 1may21
*band 6cm
*out tty:                          # Output results to terminal #
*inputs                            # Display current parameters #

ANTSOL INPUTS
====== ======
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . 1MAY21[14,]
sources . . . . . *:*
calcodes. . . . . CAL
antennas. . . . . 11, 3, 1, 13, 12, 6, 2, 8, 9
refants . . . . . 6, 2, 1, 8 (Physical IDs)
ifs . . . . . . . C
bands . . . . . .  6.0cm
passflag. . . . .  2
minamp. . . . .        .1000
uvlimits. . . . .      .0nsec, 70000.0nsec
outfile . . . . . TTY:
listoptions . . . PHASE
average . . . . . SCAN
amp/jy. . . . . . YES
closurelimit. . .   .05,  5.00d
xaxis . . . . . .  IAT.DAYS
yaxis . . . . . .   .000 TO 25.000 AMPLITUDE
*ifs *                             # include all IFs #
*go solve                          # Solve for antennas gains & phases #

ANTSOL EXECUTION    on    1978OCT21    at    14:51
====== =========

%antsolxx- Amp   closure error on  2-11 AA   5.8% at 78MAY21  6:22:45
%antsolxx- Phase closure error on  9-11 AA   -8d  at 78MAY21  6:22:45
```

```
%antsolxx- Phase closure error on  9-11 CC    5d  at 78MAY21   6:22:45
%antsolxx- Amp   closure error on  9-13 CC   5.4% at 78MAY21   6:22:45
%antsolxx- Amp   closure error on  1- 3 AA   5.1% at 78MAY21   6:38:40
%antsolxx- Phase closure error on  2- 3 AA    6d  at 78MAY21   6:38:40
%antsolxx- Phase closure error on  3- 8 AA   -7d  at 78MAY21   6:38:40
%antsolxx- Phase closure error on  8- 9 AA    6d  at 78MAY21   6:38:40
%antsolxx- Phase closure error on  9-11 AA   -6d  at 78MAY21   6:38:40
%antsolxx- Phase closure error on  9-11 CC    7d  at 78MAY21   6:38:40
%antsolxx- Amp   closure error on  2-11 AA   5.1% at 78MAY21   6:58:30
%antsolxx- Amp   closure error on  3- 6 AA   6.0% at 78MAY21   6:58:30
%antsolxx- Phase closure error on  3- 8 AA   -5d  at 78MAY21   6:58:30
%antsolxx- Amp   closure error on  3- 8 AA  -5.3% at 78MAY21   6:58:30
     .
     .
     .
%antsolxx- Amp   closure error on  8-11 AA   5.7% at 78MAY21  16:57:00
%antsolxx- Phase closure error on  9-11 AA   -7d  at 78MAY21  16:57:00
%antsolxx- Amp   closure error on  2- 9 CC   5.8% at 78MAY21  16:57:02
%antsolxx- Phase closure error on  9-11 CC    7d  at 78MAY21  16:57:02
*ant 3 1 13 12 6 2 8 9          # Shorten list to fit on screen #
*ifs a                          # IF A first to be listed #
*list ampl                      # Amplitudes only for now #
*go list                        # List IF A amplitudes   #

ANTSOL EXECUTION    on    1978OCT21    at    14:53
====== =========

LISTING OF ANTENNA VOLTAGE GAINS;  AMPLITUDES (*SQRT 1000)

  TIME    BAND  SOURCE      3A    1A    13A    12A    6A    2A    8A    9A
---------------------------------------------------------------------------
78MAY21
  6:22:45   6 2005+403   16.9  14.8          19.8  18.1  16.6  18.8  17.5
  6:38:40   6 BLLAC      15.8  14.4          18.6  17.2  15.8  18.0  16.6
  6:58:30   6 BLLAC      16.2  14.6          18.9  17.3  16.0  18.2  16.9
  7:18:34   6 BLLAC            14.7          18.9  17.7  16.2  18.3  16.7
  7:18:45   6 BLLAC      16.6
  7:38:30   6 BLLAC      16.4  14.7          19.4  17.8  16.1  18.3  16.5
  7:58:20   6 BLLAC      16.8  14.8          19.3  17.7  16.1  18.0  16.4
  8:18:45   6 2005+403   17.1  14.8          19.4  17.8  16.6  18.5  16.6
      .
      .
      .
 15:37:10   6 BLLAC      16.5  14.3          19.8  18.3  16.2  19.1  17.3
 15:57:25   6 BLLAC      16.4  14.2          19.7  18.5  16.4  19.6  17.9
 16:17:20   6 2005+403   16.5  14.3          19.7  18.4  16.2  19.3  17.9
 16:37:00   6 BLLAC      16.7  14.2          20.3  18.8  16.6  19.5  18.4
 16:57:00   6 BLLAC      17.2  14.4          20.3  18.7  16.5  19.4  18.3
*ifs c                          # Set up to list IF C now #
*go list                        # List IF C amplitudes #
```

```
ANTSOL EXECUTION    on    1978OCT21    at    14:53
====== =========

LISTING OF ANTENNA VOLTAGE GAINS:  AMPLITUDES (*SQRT 1000)

  TIME    BAND  SOURCE      3C     1C    13C    12C     6C     2C     8C     9C
----------------------------------------------------------------------------
78MAY21
  6:22:45    6 2005+403   20.1   19.1   20.0   20.7   18.3   17.9   20.8   17.3
  6:38:40    6 BLLAC      18.9   18.2   19.2   19.5   17.4   17.1   19.5   16.6
  6:58:30    6 BLLAC      19.3   18.4   19.4   19.8   17.4   17.3   19.9   17.0
  7:18:34    6 BLLAC             18.6   19.5   19.9   17.9   17.2   20.1   16.5
  7:18:45    6 BLLAC      19.5
  7:38:30    6 BLLAC      19.7   18.8   19.6   20.2   17.9   17.4   20.0   16.4
  7:58:20    6 BLLAC      19.8   18.9   19.5   20.1   17.9   17.5   19.7   16.3
  8:18:45    6 2005+403   20.3   19.4   20.4   20.4   17.9   17.8   20.2   16.5
        .
        .
        .
 15:37:10    6 BLLAC      20.0   19.0   19.9   20.5   18.3   17.6   21.2   17.5
 15:57:25    6 BLLAC      20.0   19.0   19.8   20.4   18.5   17.7   21.9   18.1
 16:17:20    6 2005+403   19.7   18.6   20.1   20.6   18.6   17.6   21.7   18.3
 16:37:00    6 BLLAC      20.6   19.1          21.2   19.0   17.9   22.1   18.3
 16:37:15    6 BLLAC                    20.6
 16:57:00    6 BLLAC      20.7   19.2          21.4   19.0   17.8   22.0   18.2
*ifs a                           # Switch back to IF A #
*list phas                       # Now we list phases #
*go list                         # List IF A phases #

ANTSOL EXECUTION    on    1978OCT21    at    14:53
====== =========

LISTING OF ANTENNA VOLTAGE GAINS:   PHASES (degrees)

  TIME    BAND  SOURCE      3A     1A    13A    12A     6A     2A     8A     9A
----------------------------------------------------------------------------
78MAY21
  6:22:45    6 2005+403    173    -33           -158     0     46     18    114
  6:38:40    6 BLLAC       147    -65           -165     0     44     48    132
  6:58:30    6 BLLAC      -179    -30           -147     0     52     64    163
  7:18:34    6 BLLAC              -12           -128     0     32      9    123
  7:18:45    6 BLLAC      -163
  7:38:30    6 BLLAC       155    -44            177     0     27     28     85
  7:58:20    6 BLLAC       179    -33            168     0     40     26     80
  8:18:45    6 2005+403    113    -76            126     0     45     11     76
  8:38:20    6 BLLAC       148    -49            171     0     50     24     95
        .
        .
        .
```

```
*ifs c                          # Switch to IF C #
*go list                        # List IF C phases #

ANTSOL EXECUTION    on    1978OCT21    at    14:53
====== =========

LISTING OF ANTENNA VOLTAGE GAINS:   PHASES (degrees)

  TIME    BAND  SOURCE      3C    1C   13C   12C    6C    2C    8C    9C
-------------------------------------------------------------------------
78MAY21
      .
      .
      .
 10:57:50   6 BLLAC        151   141    90   131     0   -30   167  -108
 11:17:45   6 BLLAC        140   134    73   126     0   -27   170   -99
 11:37:50   6 BLLAC        147   136    66   125     0   -35   157   -98
 11:57:45   6 BLLAC        146   143    68   134     0   -30   156   -92
 12:37:40   6 BLLAC        150   141    55   143     0   -34   153   -76
 12:57:40   6 BLLAC        155   150    62   151     0   -36   153   -61
 13:17:50   6 BLLAC        161   152    65   159     0   -40   147   -56
 13:37:45   6 BLLAC        156   146    59   156     0   -50   137   -67
 13:57:35   6 BLLAC        153   144    63   153     0   -44   154   -62
         .
         .
         .
*fin                            # Finished with ANTSOL #

.r gtbcal                       # Now run GTBCAL #

GTBCAL
======
Version 5.3  October 15, 1978 (<=27 Antennas)
I interpolate the results from ANTSOL into your gain table.

*setdefaults                    # Restore default program parameters #
*db 1may21
*ant 11 3 1 13 12 6 2 8 9
*band 6cm
*sources *:*                    # Calibrate all sources #
*calc *                         # Calibrators and non-calibrators #
*inputs                         # Display current parameters #

GTBCAL INPUTS
====== ======
jobname . . . . . GTBCAL
jobtime . . . . .  0:05:00
timerange . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . 1MAY21[14,]
sources . . . . . *:*
```

```
calcodes. . . . . . *
antennas. . . . . . 11, 3, 1, 13, 12, 6, 2, 8, 9
ifs . . . . . . . . *
band. . . . . . . .  6.0cm
calsources. . . . . *:*
outfile . . . . . . TTY:GTBCAL
average . . . . . .  2:00:00
caltype . . . . . . AMP, PHASE
pastonly. . . . . . NO
interpfunct . . . . BOXCAR
weight. . . . . . . UNIFORM
xaxis . . . . . . .  IAT.DAYS
yaxis . . . . . . .   .000 TO  2.000 AMPLITUDE
*go calib                     # Insert calibration in gain table #

GTBCAL EXECUTION    on    1978OCT21   at   14:54
====== =========

%gtbcalxx- Antenna  1A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  2A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  3A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  6A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  8A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  9A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna 11A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna 12A came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  1C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  2C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  3C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  6C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  8C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna  9C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna 11C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna 12C came on line during scan 78MAY21  6:21:00
%gtbcalxx- Antenna 13C came on line during scan 78MAY21  6:21:00
*fin
```

(d) Evaluation of Calibration

There are a number of ways of evaluating the adequacy of the calibration of a data base. One can use the ANTSOL complaints about closure error to edit data until an acceptable level is achieved, in which case the ANTSOL batch LOG file is important. In the previous example, since the run was basically just a detection experiment, the occasional 6% amplitude closure error and 8d phase closure error were deemed acceptable. One can look at the calibration tables themselves to find discrepancies and evaluate scatter. In the example just listed, there are significant drifts in phase that are acceptable for this program because we are doing a "local" calibration with a calibrator quite close to the program source. For other purposes, the phase drifts, in this case mainly due to antenna station errors, might need to be corrected for. One uses BASFIT to solve for corrections with respect to a selected reference antenna, and then uses the BASELINEERR and GO BASECORR commands in GTBCOR to add these corrections to GAINTB.CTL.

In the last analysis, however, one of the best ways to evaluate calibration is to look at calibrated AMPLITUDE/JY and PHASE for calibrators. If the calibration is good, the AMPLITUDE/JY should come out near 1000 and the phases should come out near zero. The following is an example where this has been done:

```
.r lister                          # Run LISTER #

LISTER
======
Version 5.8 September 30, 1978 (Antennas<=27)
I list visibility data in a large (but finite) number of formats
*db 1may21
*ant 11 3 1 13 12 6 2 8 9
*calc cal                          # List calibrators only #
*out tty:                          # Output listings to a terminal #
*list amp/                         # List AMPLITUDES/JY first #
*aver scan amps                    # AMPSCALAR SCAN averages #
*inputs                            # Display current parameters #
```

```
LISTER INPUTS
====== ======
jobname . . . . . . LISTER
jobtime . . . . . .  0:05:00
timerange . . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . . 1MAY21[14,11]
sources . . . . . . 2005+403:*
calcodes. . . . . . CAL
antennas. . . . . . 11,3,1,13,12,6,2,8,9 WITH 11,3,1,13,12,6,2,8,9
ifpairs . . . . . . AA, CC
bands . . . . . . . *
modes . . . . . . . '  '
passflag. . . . . .  2
outfiles. . . . . . TTY:1SEP16
listoptions . . . . AMP/JY
calibration . . . . APPLY
average . . . . . . SCAN AMPSCALAR
scalefactor . . . .   1.0E+00
*go m                          # Put out matrix type listing #

LISTER EXECUTION    on    1978OCT21    at    14:54
====== =========

***78MAY21***
2005+403:1
 x1.0E+03
Scale: x1.0E+03   AA upper right, CC lower left
  A--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11|                999        1013  1057  1024  1080   989
 3|               1057        1023   998  1001   962  1065
 1|  1011  1028               1034  1019  1012  1032  1044
13|   993   978   984
12|  1061  1038  1023   960         1019   977  1053  1043
 6|   983  1010  1036  1013   976         1002  1047   979
 2|  1003  1010  1028   986  1011  1009         1014  1013
 8|  1013  1023  1035   999  1018  1036  1025         1035
 9|  1071  1036  1024  1025  1054  1026  1010  1029
Average of above: 10:18:20 <amp>&rms= 1019+/- 26 <phi>=   5d  Navg=  62

          .
          .
          .
```

```
2005+403:1
 x1,0E+03
Scale: x1,0E+03   AA upper right, CC lower left
  A--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11!               932          967   939   940   999  1010
 3!              1010          944  1050  1020   960   936
 1!   972   962                984   995   998   982  1003
13!   947   952   957
12!   962   966   970   986          966   948  1007  1009
 6!   969   970   982   992   974         1001   985   947
 2!   936   964   962  1004   982   993          957   988
 8!  1003   979   977   978   985   995   983         1018
 9!   949   994   975  1028  1024  1003  1039  1080
Average of above: 16:17:20 <amp>&rms=  981+/- 26 <phi>= -20d  Navg=  62

*list ph                          # List phases next #
*go m                             # Put out matrix type phase listing #

LISTER EXECUTION    on    1978OCT21   at    14:54
====== =========

***78MAY21***
2005+403:1
AA upper right, CC lower left
  P--11---- 3---- 1----13----12---- 6---- 2---- 8---- 9--
11!                -6          13    -5    -3   -19   -31
 3!                 5           4    -2     9    13    12
 1!    -3     7                 9     2    -2    17    21
13!    10     5     7
12!     9     1     8     5           8    11    -6   -13
 6!    -7    -4     2     4     6           3    16    19
 2!    -2     6     1     5     9     2          17    26
 8!   -19    10    17     4    -9    15    17           6
 9!   -20    13    21    37   -12    18    18     3
Average of above:  6:22:45 <amp>&rms= 4680+/-109 <phi>=  10d  Navg=  62

     .
     .
     .
*fin                              # Finished with making listings #
```

The calibration shown above is not great, but was deemed temporarily adequate for one to proceed to the mapping of Cyg X-2.

(e) Mapping and Map Display

Once an acceptable calibration has been inserted in the gain table of a data base, one can proceed to map making and map display. We next show an example of the log of a batch control file which does the following: maps Cyg X-2 using all the data of May 21-22, 1978; calculates the corresponding synthesized beam; cleans a 20" X 20" area around the center of the Cyg X-2 map; displays the results of GO INDEX, GO PROFILE, GO FIT, and GO SHOW on a terminal using the SEEMAP program. For variety, we will run these programs under DANEEL control.

```
.r daneel                          # Run DANEEL #

DANEEL Version 1.0
====== ======= ===
I am the top level of a program calling many sub-programs.
DANEEL *go makmap                  # Run MAKMAP program #

DANEEL EXECUTION    on    1978OCT21    at    12:13
====== =========

MAKMAP Version 2.2 (September 15, 1978)
I make radio maps from visibility databases.
MAKMAP *   db 1may21               # Specify Data Base #
MAKMAP *   band 6cm                # Required specification of band #
MAKMAP *   source cygx-2:0         # Source name and requried qual #
MAKMAP *   ant 11 3 1 13 12 6 2 8 9      # Good antenna list #
MAKMAP *   remarks 'May 21-22, 1978 Data'
MAKMAP *   mapname dcygx2            # Assign map file name #
MAKMAP *   mapsize 256               # Make 256X256 map #
MAKMAP *   cell 0.2"                 # Specify cell size #
MAKMAP *   uvwe natural              # Natural weighting #
MAKMAP *   type map                  # Make map not beam #
MAKMAP *   inputs                    # Display current parameters #
```

```
MAKMAP INPUTS
====== ======
jobname . . . . . . MAKMAP
jobtime . . . . . .  0:05:00
timerange . . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . . 1MAY21[14,]
sources . . . . . . CYGX-2:0
antennas. . . . . . 11, 3, 1, 13, 12, 6, 2, 8, 9
stokes. . . . . . . I
bands . . . . . . .  6.0cm
passflag. . . . . .  2
category. . . . . . [no-map-category]
mapname . . . . . . DCYGX2[14,]
remarks . . . . . . 'May 21-22, 1978 Data'
cellsize. . . . . .   .200" by   .200"
mapsize . . . . . .  256 by  256 cells
uvweight. . . . . . NATURAL
uvtaper . . . . . . NONE      .000km
uvconvolve. . . . . BOX   1 cell(s)
gridcorr. . . . . . NO
subsources. . . . . NONE
shiftcenter . . . .    0    0 (both in cells)
addmaps . . . . . . NONE
typemap . . . . . . MAP
MAKMAP *   go make            # Go make specified map #

MAKMAP EXECUTION    on    1978OCT21   at   12:14
====== =========

Beginning data selection pass.


78MAY21
06:25:20  210   06:40:10  315   07:00:00  308   07:20:00  315
07:40:00  315   07:59:50  315   08:20:40  280   08:39:50  315
08:59:40  315   09:19:40  315   09:39:40  315   09:59:30  315
10:20:10  280   10:39:30  315   10:59:20  315   11:19:20  315
11:39:20  315   11:59:20  315   12:21:40  280   12:39:20  315
12:59:10  315   13:19:40  280   13:39:30  315   13:59:10  315
14:19:40  280   14:39:00  315   14:59:00  307   15:18:50  306
15:38:40  315   15:59:10  280
```

```
78MAY22
06:20:40  245   06:36:10  315   06:56:10  315   07:16:00  315
07:36:00  315   07:56:00  315   08:16:30  280   08:35:50  315
08:55:50  315   09:15:40  315   09:35:40  315   09:55:40  315
10:16:10  280   10:35:30  315   10:55:30  315   11:15:30  243
11:35:20  315   11:55:30  315   12:17:50  245   12:35:20  315
12:55:20  315   13:15:50  280   13:35:30  315   13:55:20  307
14:15:50  280   14:35:00  315   14:55:00  316
No change observed in gain codes.

Data selection pass/initial sort completed. 18028 records written.
Beginning merge pass 1
Beginning merge pass 2
Beginning merge pass 3
Merging complete on file 012SRT.TMP
Gridding for MAP.
Value of center cell:  2.521606
18028 records read; 18028 records used.
Total weight:  385248.0
Maximum amplitude:  .1103863    Jy
Now starting to calculate MAP.
Completed column transforms.
Transpose completed.
Grid correction suppressed.
Maximum  .6349025@-3 Jy at x = -4,  y = -3  (grid cells)
Minimum -.2239949@-3 Jy at x = -49,  y = -106  (grid cells)
Generating new map file: DSK:DCYGX2.I6[14,]
MAKMAP Version 2.2 (September 15, 1978)
I make radio maps from visibility databases.
MAKMAP *   type beam          # Now make a beam map #
MAKMAP *   inputs             # Display current parameters #
```

```
MAKMAP INPUTS
====== ======
jobname . . . . . . MAKMAP
jobtime . . . . . .  0:05:00
timerange . . . . . 76JAN01 at  0:00:00 to 85DEC31 at 24:00:00 IAT
dbname. . . . . . . 1MAY21[14,]
sources . . . . . . CYGX-2:0
antennas. . . . . . 11, 3, 1, 13, 12, 6, 2, 8, 9
stokes. . . . . . . I
bands . . . . . . .  6.0cm
passflag. . . . . .  2
category. . . . . . [no-map-category]
mapname . . . . . . DCYGX2[14,]
remarks . . . . . . 'May 21-22, 1978 Data'
cellsize. . . . .    .200" by   .200"
mapsize . . . . . .  256 by  256 cells
uvweight. . . . . . NATURAL
uvtaper . . . . . . NONE      .000km
uvconvolve. . . . . BOX   1 cell(s)
gridcorr. . . . . . NO
subsources. . . . . NONE
shiftcenter . . . .    0      0 (both in cells)
addmaps . . . . . . NONE
typemap . . . . . . BEAM
MAKMAP *   go make             # Go make synthesized beam #

MAKMAP EXECUTION    on    1978OCT21   at    12:24
====== =========

%makmap- Selection criteria same as last time.
         Bypassing data selection phase.
Gridding for BEAM.
Value of center cell:  3808.000
18028 records read; 18028 records used.
Total weight:  385248.0
Maximum amplitude:  1.000000    Jy
Now starting to calculate BEAM.
Completed column transforms.
Transpose completed.
Grid correction suppressed.
Maximum  .9998754    Jy at x = 0,  y = 0  (grid cells)
Minimum -.6097777e-1 Jy at x = -114,  y = -41  (grid cells)
Generating new map file: DSK:DCYGX2.BI6[14,]
MAKMAP Version 2.2 (September 15, 1978)
I make radio maps from visibility databases.
```

```
MAKMAP *   fin                             # Exit back to DANEEL #
DANEEL Version 1.0
====== ======= ===
I am the top level of a program calling many sub-programs.
DANEEL *go clnmap                          # Run CLNMAP program #

DANEEL EXECUTION    on    1978OCT21    at    12:27
====== =========

CLEANER PROGRAM,    VERSION 1.2    September 15, 1978
I clean up dirty maps.
Cleanliness is next to godliness!
                                 -- John Wesley
CLNMAP *   dmap dcygx2         # Name dirty map #
CLNMAP *   dbeam dcygx2        # Name dirty beam #
CLNMAP *   cmap ccygx2         # Name for cleaned map #
CLNMAP *   rmap rcygx2         # Name residual map file #
CLNMAP *   clnsize 128         # Make 128X128 cleaned map #
CLNMAP *   inputs              # Display current parameters #

CLNMAP INPUTS
====== ======
jobname . . . . . CLNMAP
jobtime . . . . .  0:05:00
stokes. . . . . . I
band. . . . . . .  6.0cm
clnsize . . . . .  128
nboxes. . . . . .    0
box . . . . . . .
subpercent. . . . 50.000
limpercent. . . .   5.00
maxiteration. . .  100
posclean. . . . .    0
fitbeam . . . . .  0d0'0.0"  0d0'0.0" 0d0'0.0"
restartsubtract . YES
dmap. . . . . . . DSK:DCYGX2[14,]
dbeam . . . . . . DSK:DCYGX2[14,]
cmap. . . . . . . DSK:CCYGX2[14,]
rmap. . . . . . . DSK:RCYGX2[14,
CLNMAP *   go subtract       # Do source subtraction step #
```

```
CLNMAP EXECUTION    on    1978OCT21   at   12:27
====== =========

DIRTY MAP FILE:  DSK:DCYGX2.I6[14,]
DIRTY BEAM FILE: DSK:DCYGX2.BI6[14,]
CLEAN FILE:      DSK:CCYGX2.I6[14,]
RESIDUE FILE:    DSK:RCYGX2.I6[14,]
COMPONENTS FILE: DSK:RCYGX2.CMP[14,]
component     1 subtracted from cell   -4,   -3, peak value =  5000
component     2 subtracted from cell   -4,   -3, peak value =  2500
component     3 subtracted from cell    3,    1, peak value =  1516
component     4 subtracted from cell  -13,    6, peak value =  1228
component     5 subtracted from cell   44,   -7, peak value = -1235
component     6 subtracted from cell   17,  -53, peak value =  1102
component     7 subtracted from cell   63,  -64, peak value =  1070
component     8 subtracted from cell   51,   31, peak value = -1065
component     9 subtracted from cell  -51,  -34, peak value = -1054
component    10 subtracted from cell  -28,  -30, peak value =  1058
component    11 subtracted from cell   49,  -46, peak value =   997
component    12 subtracted from cell   60,  -32, peak value = -1009
component    13 subtracted from cell   39,   13, peak value =  1000
component    14 subtracted from cell   42,   21, peak value = -1093
component    15 subtracted from cell  -49,    0, peak value =  -946
      .
      .
      .
component    94 subtracted from cell  -15,  -45, peak value =  -544
component    95 subtracted from cell   37,   63, peak value =  -540
component    96 subtracted from cell   14,  -64, peak value =   553
component    97 subtracted from cell  -27,   12, peak value =  -546
component    98 subtracted from cell  -59,   -2, peak value =   532
component    99 subtracted from cell   63,  -46, peak value =   527
component   100 subtracted from cell   60,  -33, peak value =  -576
SUBTRACTION TERMINATING AFTER MAXCOMP COMPONENTS

CLNMAP *   go restore                  # Restore cleaned components #

CLNMAP EXECUTION    on    1978OCT21   at   12:31
====== =========

DIRTY MAP FILE:  DSK:DCYGX2.I6[14,]
DIRTY BEAM FILE: DSK:DCYGX2.BI6[14,]
CLEAN FILE:      DSK:CCYGX2.I6[14,]
RESIDUE FILE:    DSK:RCYGX2.I6[14,]
COMPONENTS FILE: DSK:RCYGX2.CMP[14,]
```

```
fitted beam: (first, second, final windows)
     major axis   2.30", minor axis    .80", pos. angle -56.09 deg
     major axis   2.22", minor axis   1.06", pos. angle -38.25 deg
     major axis   2.80", minor axis   1.17", pos. angle -56.11 deg
               DIRTY BEAM                                      CLEAN BEAM
 2 2 2 2 2 3 3 4 4 4 5 5 5 4 3 3 2 2 2    0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1
 2 2 2 2 2 3 3 4 4 5 5 5 5 4 4 3 2 2 2    0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
 1 1 2 2 2 3 3 4 4 5 5 6 5 5 4 3 3 2 2    0 0 0 0 0 0 0 0 0 1 1 1 1 2 2 2 2 2 2
 1 1 2 2 2 3 3 4 4 5 6 6 6 5 4 3 2 2 2    0 0 0 0 0 0 0 0 1 1 2 2 3 3 3 3 3 3 2
 1 1 2 2 2 3 3 4 5 6 7 7 6 5 4 3 2 2 2    0 0 0 0 0 0 1 1 2 2 3 4 4 5 5 4 4 3 2
 1 1 2 2 2 2 3 4 5 7 8 8 7 5 4 3 2 2 2    0 0 0 0 0 1 1 2 3 4 5 6 6 6 6 5 4 3 2
 1 1 2 2 2 2 3 4 6 8 9 8 7 5 4 3 2 2 2    0 0 0 1 1 2 2 4 5 6 7 7 8 7 6 5 4 3 2
 1 1 2 2 2 2 3 5 7 9 9 9 7 5 3 2 2 2 2    0 0 1 1 2 3 4 5 7 8 9 9 8 7 6 5 4 2 2
 1 1 2 2 2 3 4 6 81010 8 6 4 3 2 2 2 1    0 1 1 2 3 4 6 7 9 910 9 8 7 5 4 3 2 1
 1 2 2 2 2 3 5 8 910 9 8 5 3 2 2 2 2 1    1 1 2 3 4 6 7 9101010 9 7 6 4 3 2 1 1
 1 2 2 2 3 4 6 81010 8 6 4 3 2 2 2 1 1    1 2 3 4 5 7 8 910 9 9 7 6 4 3 2 1 1 0
 2 2 2 2 3 5 7 9 9 9 7 5 3 2 2 2 2 1 1    2 2 4 5 6 7 8 9 9 8 7 5 4 3 2 1 1 0 0
 2 2 2 3 4 5 7 8 9 8 6 4 3 2 2 2 2 1 1    2 3 4 5 6 7 8 7 7 6 5 4 2 2 1 1 0 0 0
 2 2 2 3 4 5 7 8 8 7 5 4 3 2 2 2 2 1 1    2 3 4 5 6 6 6 6 5 4 3 2 1 1 0 0 0 0 0
 2 2 2 3 4 5 6 7 7 6 5 4 3 3 2 2 2 1 1    2 3 4 4 5 5 4 4 3 2 2 1 1 0 0 0 0 0 0
 2 2 2 3 4 5 6 6 6 5 4 4 3 3 2 2 2 1 1    2 3 3 3 3 3 3 2 2 1 1 0 0 0 0 0 0 0 0
 2 2 3 3 4 5 5 6 5 5 4 4 3 3 2 2 2 1 1    2 2 2 2 2 2 1 1 1 1 0 0 0 0 0 0 0 0 0
 2 2 2 3 4 4 5 5 5 5 4 4 3 3 2 2 2 2 2    1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0
 2 2 2 3 3 4 5 5 5 4 4 4 3 3 2 2 2 2 2    1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0

flux of restored components:
     uncorrected for box convolution =     1 mJy
       corrected for box convolution =     1 mJy

NEW MAXIMUM:  .547930-3 Jy at x = -.80000    "  y = -.60000     "

NEW MINIMUM: -.113550-3 Jy at x =  0.8000    "  y = -1.4000     "
CLNMAP *   go seemap                   # Now run SEEMAP #

SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   band 6cm
SEEMAP *   mapn dcygx2
SEEMAP *   type map                    # Display dirty map info #
```

```
SEEMAP *   go index                        # Display map header info #

SEEMAP EXECUTION    on    1978OCT21   at   12:33
====== =========

 TYPE OF MAP: MAP
 Map name: DSK:DCYGX2.I6[14,]
 Source: CYGX-2  Qual: 0  Cal:   Polariz: I
 Band: 6cm    freq:  4.8851GHz   Bandw:  50.000MHz
 May 21-22, 1978 Data
 RA50:  21h42m36.88s dec50:  38d05'27.87"
 RA:  21h43m47.96s dec:  38d13'07.88"
 Pass flag: 2  avgtime: 00:02:00   Observer: 0
 Date/time intervals selected:

 76JAN01 at 00:00:00  to  85DEC31 at 24:00:00
 Corrected gain table was applied.  Nominal gains were retained.

 Natural weighting applied to (u,v) data.
 No tapering in (u,v) plane.  Box conv., width:  1.0000 cells.
 No shift was applied to the phase center.
 No sources subtracted.
 Cell size (map domain): 00'00.20"    00'00.20"    Ncells: 256    256
 Binary scaling factor: -11    Total weight: 385248
 Maximum  .634900-3Jy  at -00d00'00.80"   -00d00'00.60"
 Minimum -.223990-3Jy  at -00d00'09.80"   -00d00'21.20"
 Maximum fringe amplitude:  .11039 Jy
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   fit -4  -3  6  6               # Fit around central peak #
SEEMAP *   go fit                         # Fit guassian to peak in map #

SEEMAP EXECUTION    on    1978OCT21   at   12:33
====== =========

 GAUSSIAN OF BEST FIT:
Region fitted (Rx,Ry): 9.2000"  by 24.400"
         Center (x,y): -.53459" -.80417"
  Amplitude at center: .639690-3Jy
   Widths at half max: 13.685" 5.4214"
      Major axis P.A.: 178.32d
 Equation of best fit: .639690-3 . exp -[.942960-1 . (x - -.53459)^2
                          + .148780-1 . (y - -.80417)^2
                          + -.466400-2 . (x - -.53459)(y - -.80417)]
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   prof -4 -3 90d                 # Horizontal profile of source #
SEEMAP *   go prof                        # Plot profile through center #

SEEMAP EXECUTION    on    1978OCT21   at   12:33
====== =========
```

```
I mJy  --------|-------------------|-------------------|-------
       |                           X                          |
   0.6 -                          X X                         -
       |                                                      |
       |                         X   X                        |
       |                                                      |
       |                                                      |
   0.4 -                        X     X                       -
       |                                                      |
       |                                                      |
       |                       X       X                      |
   0.2 -                      X         X XX                  -
       |                     X           X  XXXXX             |
       |                   XX                    X            |
       |       XXXX    XXXX                       X      XX   |
       |XXX   X    XXXX                                 X  X  |
     0 -   XXX                                     X   X    XX-
       |                                            X X       |
       |                                             X        |
       --------|-------------------|-------------------|------- rho "
              -20                  0                   20
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   out tty:dcygx2                 # Terminal output #
SEEMAP *   go show                        # Display map center on TTY #

SEEMAP EXECUTION    on    1978OCT21   at   12:34
====== =========

y, "   --|-----------------------|------------------------|---
       |111111111  11222112233344444434444432234443l  11111    |
       |211111111 1122211122333444443344554333344321  11111  1|
       |21111111111222111122333344433344554433444431   11111111|
     1 -111111111122211 1122233344433345555444444321  112111112-
       |1111111111112211    122223344433345665444444321  112211122|
       |1111111111112221    1222234444334566654444321  1122222222|
       |111111 11221 aa  122234444333467765544432111122222222|
       |11111  11221 aa 11223344433335678765444321111222222221|
     0 -11111  1121 aaa 12223344432346888765443321112222222211-
       |1111  11221 aaa 222333443223579987654332211122112221l |
       |1111  1121 aaa 122333333333579TT875433221111111112211 |
       |2211  1121 aaa 223333333334689T98643322211111111211  |
       |2211  1111 aa 12333333333344579TT87532222111111111111  |
    -1 -2211 11111 aa 12333333344456799975422111111111112111 1-
       |2211 1111  a 1233333344455678876432111222211111221111|
       |221  1111    133333334444566776532111222221111222111111|
       |221  1111   12333333344444556654321222332211122222111111|
       |211  1111   12333223333333445665432222333221112222111111|
       --|-----------------------|------------------------|---  x, "
         5                       0                       -5
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
```

```
SEEMAP *   type beam                      # Now switch to the beam #
SEEMAP *   go index                       # Map header info for beam #

SEEMAP EXECUTION    on    1978OCT21    at    12:35
====== =========

 TYPE OF MAP: BEAM
 Map name: DSK:DCYGX2.BI6[14,]
 Source: CYGX-2  Qual: 0  Cal:   Polariz: I
 Band: 6cm    freq:  4.8851GHz   Bandw:  50.000MHz
 May 21-22, 1978 Data
 RA50:  21h42m36.88s dec50:  38d05'27.87"
 RA:  21h43m47.96s dec:  38d13'07.88"
 Pass flag: 2  avgtime: 00:02:00   Observer: 0
 Date/time intervals selected:

 76JAN01 at 00:00:00  to  85DEC31 at 24:00:00
 Corrected gain table was applied.  Nominal gains were retained.

 Natural weighting applied to (u,v) data.
 No tapering in (u,v) plane.  Box conv., width:  1.0000 cells.
 No shift was applied to the phase center.
 No sources subtracted.
 Cell size (map domain): 00'00.20"    00'00.20"    Ncells: 256    256
 Binary scaling factor: -1    Total weight: 385248
 Maximum  .99988Jy  at  00d00'00.00"    00d00'00.00"
 Minimum -.609780-1Jy  at -00d00'22.00"   -00d00'08.20"
 Maximum fringe amplitude:  1.0000 Jy
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   fit 0 0 6 6                    # Fit around beam center #
SEEMAP *   go fit                         # Fit to a gaussian #

SEEMAP EXECUTION    on    1978OCT21    at    12:35
====== =========

 GAUSSIAN OF BEST FIT:
Region fitted (Rx,Ry): 15.200"  by 51.000"
         Center (x,y): .425660-5" -.237030-4"
  Amplitude at center: .99987Jy
   Widths at half max: 26.528" 7.9695"
      Major axis P.A.: 174.37d
 Equation of best fit: .99987 . exp -[.432860-1 . (x - .425660-5)^2
                       + .432310-2 . (y - -.237030-4)^2
                       + -.775360-2 . (x - .425660-5)(y - -.237030-4)]
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   prof 0 0 90d                   # Profile beam center #
SEEMAP *   go prof                        # Plot profile through beam #

SEEMAP EXECUTION    on    1978OCT21    at    12:36
====== =========
```

```
I mJy  --------|-------------------|-------------------|-------
       |                           X                          |
       |                          X X                         |
       |                                                      |
   800 -                                                      -
       |                         X   X                        |
       |                                                      |
       |                                                      |
       |                                                      |
       |                        X     X                       |
       |                                                      |
   400 -                                                      -
       |                       X       X                      |
       |                                                      |
       |                      X         X                     |
       |                   XXX           XXX                  |
       |                 XX                 XX                |
       |X   XXXXXXXXXXXXX                     XXXXXXXXXXXXX   |
       | XXX                                              XXX|
       --------|-------------------|-------------------|-------  rho "
              -20                  0                   20
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   out tty:bcygx2               # Out display to terminal #
SEEMAP *   go show                      # Display center part of beam #

SEEMAP EXECUTION    on    1978OCT21   at   12:36
====== =========

y, "   --|------------------------|------------------------|---
       |111    1111111112222223344555544322222211111111111111  |
       |111   11111111111112223344556554332222111111111111111  |
       |11    111111111111122233445666543222221111111111111111 |
     1 -11    11111111111112223345677654322221111111111111    -
       |1    11111 11111111222345788754322221111111111111      |
       |1    1111  1111111222234689875432222111111111111       |
       |     111   11111111222235799975322221111111  1111      |
       |    1111  111111111223468TT86432222111111  1111        |
     0 -    111   111111112222358 9T985322221111111   111      -
       |   1111  11111111222234 68TT8643222111111111  1111     |
       |   1111  11111111222235799975322221111111   111     11|
       |  1111111111111112222345789864322221111111  1111    111|
       |  1111111111111112222345788754322221111111 11111    111|
    -1 -  11111111111111122223456776543322211111111111      111-
       | 111111111111111122223456665443322211111111111      1111|
       | 111111111111111122223345565544332221111111111     11111|
       | 1111111111111112222223445555443322222211111111    11111|
       |111111111111111122222233455544433222222111111111  111111|
       --|-----------------------|------------------------|---  x, "
         5                       0                       -5
```

```
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   mapn ccygx2                    # Display clean map info #
SEEMAP *   type map                       # Map not beam #
SEEMAP *   go index                       # Clean map header info #

SEEMAP EXECUTION    on    1978OCT21    at    12:37
====== =========

 TYPE OF MAP: MAP
 Map name: DSK:CCYGX2.I6[14,]
 Source: CYGX-2  Qual: 0  Cal:   Polariz: I
 Band: 6cm    freq:  4.8851GHz   Bandw:  50.000MHz
 May 21-22, 1978 Data
 RA50:  21h42m36.88s dec50:  38d05'27.87"
 RA:  21h43m47.96s dec:  38d13'07.88"
 Pass flag: 2  avgtime: 00:02:00   Observer: 0
 Date/time intervals selected:

 76JAN01 at 00:00:00  to  85DEC31 at 24:00:00
 Corrected gain table was applied.  Nominal gains were retained.

 Natural weighting applied to (u,v) data.
 No tapering in (u,v) plane.  Box conv., width:  1.0000 cells.
 No shift was applied to the phase center.
 No sources subtracted.
 Cell size (map domain): 00'00.20"    00'00.20"    Ncells: 256    256
 Binary scaling factor: -11    Total weight: 385248
 Maximum  .547930-3Jy  at -00d00'00.80"   -00d00'00.60"
 Minimum -.113550-3Jy  at  00d00'08.80"   -00d00'01.40"
 Maximum fringe amplitude:  .11039 Jy
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   type map                       # Map not beam #
SEEMAP *   fit -4  -3  6  6               # Fit to center of map #
SEEMAP *   go fit                         # Fit to a gaussian #

SEEMAP EXECUTION    on    1978OCT21    at    12:37
====== =========

 GAUSSIAN OF BEST FIT:
Region fitted (Rx,Ry): 5.0000"  by 5.0000"
        Center (x,y): -.64393" -.46821"
  Amplitude at center: .604190-3Jy
   Widths at half max: 3.0597" 1.8798"
      Major axis P.A.: 124.14d
 Equation of best fit: .604190-3 . exp -[.45016 . (x - -.64393)^2
                          + .63099 . (y - -.46821)^2
                          + -.45394 . (x - -.64393)(y - -.46821)]
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   prof -4 -3 90d                 # Profile through source #
SEEMAP *   go prof                        # Plot profile #
```

```
SEEMAP EXECUTION    on    1978OCT21   at   12:37
====== =========

I mJy  --------|-------------------|-------------------|-------
   0.6 -                           XX                         -
       |                          X  X                        |
       |                         X                            |
       |                              X                       |
       |                        X                             |
   0.4 -                               X                      -
       |                       X                              |
       |                                X                     |
       |                      X                               |
   0.2 -                                 X                    -
       |                     X            X                   |
       |                                   XXX                |
       |                    X                 XXX             |
       |                   X                     X            |
     0 -XXX   XXXXXXXXXXXXX                       X      XXXXX-
       |   XXX                                     X    X     |
       |                                            X  X      |
       |                                             XX       |
       --------|-------------------|-------------------|-------  rho "
              -20                 0                   20
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   out tty:ccygx2                # Output to terminal #
SEEMAP *   go show                       # Display clean map center #

SEEMAP EXECUTION    on    1978OCT21   at   12:38
====== =========

y, "   --|------------------------|------------------------|---
       |111          1         111111   11    12221  aa   aaaa|
       |11          11         11111         122221 aa    aa  |
       |11        111   a      1111     1111122321  aa        |
     1 -1         111 aaaaa    1111    11112233321 aaa        -
       |1        111 aaaaaaaa  1111   112223334321 aa       11|
       |         11 aabbbaaa  11111  12233344432   a      1111|
       |           aabbbbaaa 1122111234455555431         1111 |
       |           abccbba  11222112355666665421         111  |
     0 -          abcccba  11222222345778887765321       11   -
       |         aabccbba 1122222234679999876431             a|
       |         abbccba 11222234568TTTT976431              aa|
       |         abbcba 122222234579TTTT986431       a      aa|
       |11      aabbba 122222234578TTTT976421  aa  aaa     aaa|
    -1 -111     aabbaa12222222345789TT9875321 aaa  aaa     aa -
       |111      aaaa 1222223456788876431  aaaa    aa   1 a   |
       |211      aaa 1223222345666654321  aaaa     a   11 a   |
       |211      aa  1233222344554443221 aaaa 111     11  a 11|
       |21      aaa 122222223333332211  aaaa 1111    111  a 11|
       --|------------------------|------------------------|---  x, "
        5                        0                        -5
```

```
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   mapn rcygx2                  # Display residual map #
SEEMAP *   out tty:rcygx2               # Output to terminal #
SEEMAP *   go show                      # Display residual map #

SEEMAP EXECUTION    on    1978OCT21    at   12:38
====== =========

y, "   --|------------------------|-------------------------|---
       |111          1         11111        aa  11  aa         |
       |11          11         1111  a       a 11  aa          |
       |11         111          11  aaa        11  aa          |
     1 -1         111               aa        11  aaa          -
       |1        111               aaa        11  aa        111|
       |         111  aa           aa        111  aa    1  111 |
       |         11  aaa       11            11    a   11 1111 |
       |        111  aaa      11   a        111           111  |
     0 -        11  aaa       1             111           11   -
       |        11  aaa   1           1    1111               a|
       |       111  aaa  11          111  1111                a|
       |       11  aaa  111        111111111                 aa|
       |       1   aaa  11      1111111             aa       a |
    -1 -11        aaa  111     111111       aa     aaa         -
       |11        aaa  111    11111       aaaa    aaa          |
       |11        aa  1111   1111        aaaa     aaa   1      |
       |11       aaa  1111    1   aa    aaaa      aa   11    11|
       |1        aaa  111        aaa     aa   11   a 111   a 11|
       --|------------------------|-------------------------|---  x, "
         5                        0                        -5
SEEMAP Version 2.2  (September 15, 1978) I display maps made by MAKMAP
SEEMAP *   fin                          # Finished with map display #
DANEEL * fin                            # Finished with DANEEL #
```

From the above mapping and map display, we conclude that on May 21-22, 1978 the radio counterpart of Cyg X-2 was present at a level of about 600 μJy. Maps made on separate days indicated it was present at the same average level on both days. The noise bumps in the maps were about at the level of 100 μJy. In practice, the phase calibration of the data for this example was not sufficient for a final result, and recalibration following more careful phase correction will occur before publication. This calibration was carried out immediately after the observing run on each day was completed, so it constitutes an example of the results that can be attained within a couple of hours after VLA observing is completed.

(f) Archiving or Carrying Away Results on Magnetic Tape

When an observer arrives at the VLA site, one of the first things he receives is a form asking for, amongst other things, how he wishes to dispose of his data when he leaves the VLA site. There are four possibilities that he can choose:

1. Storing edited, corrected, and calibrated visibility data bases on magnetic tape. This saves them for further processing if and when the observer returns to the VLA site.

2. Storing map data bases on magnetic tape. Also saved for further processing if and when the user returns to the VLA site.

3. Writing the data on a so-called export tape that can be read by programs in the NRAO Charlottesville system for VLA data reduction.

4. Copying the VLA archive tapes which contain the visibility data written on tape in real time during observing.

In late 1978 a more generalized system of transporting data to other computer systems has not yet evolved.

Storing visibility and map data bases on tape, and putting them back on disk, is an activity for which users can receive any help they need just by asking.

10. The Interactive Map Processing System - IMPS

(a) Introduction to IMPS and Associated Hardware

Once maps are produced in the DEC-10 or the PDP 11/70 map-making system, the user normally begins map processing. In addition to the map processing possible with programs running in the DEC-10, there is a separate hardware and software system used solely for this purpose. Map processing in this dedicated system is carried out by running a program called IMPS (Interactive Map Processing System) in a PDP 11/40 that: (1) controls image display hardware; (2) handles communications with the user; (3) formulates requests for the off-line computer system hardware to produce input maps; and (4) processes map data. Map processing can be broadly described as consisting of a mixture of map display, map analysis, and formulation of new maps by remapping, combining maps arithmetically, source subtraction, map cleaning, and model fitting.

IMPS is a single program controlling a large number of possible functions. The program is oriented towards selection of menu items representing functions, options, or parameters of map processing requests. Once the user becomes familiar with the simple input mechanisms of IMPS, the menus are self-documentation for the function and parameter control available to the user. IMPS can have one function in execution as an interactive foreground task, and another function in execution on a longer time scale as a background task.

The hardware controlled by IMPS is schematically shown in Figure VI-2, and Figure VI-3 shows a picture of some of this hardware being used to display VLA radio and optical "maps" of an object. As we see (Pages VI-10 and VI-13), the hardware controlled by the IMPS program is extensive. This hardware includes: color and black/white TV monitors for displays of 256X256 arrays of image data with or without overlays; 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 is moved 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 data input. A separate terminal is used to initiate the running of IMPS (and to carry out software development), after which all 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 the image being displayed, and so-called function memories for dynamically altering the mapping of map pixel values into displayed intensity values. Each point in the map, or pixel, is stored in the COMTAL memory as an 8-bit number. The control of the COMTAL hardware, the refresh terminal, the data tablet, and the keyboard is carried out by the PDP 11/40, which has 90 million words of disk storage and 64K words (16 bit) of core memory. Additional hardware controlled by this system consists of a DICOMED film recorder with up to 4096X4096 pixels of black/white or color image display, and a VERSATEC electrostatic printer-plotter with 2000 dots per line. Since the latter is a dot matrix printer, hard copy of gray scale images with 32 distinguishable levels can be obtained in addition to listings or plots.

The user initiates execution of IMPS by typing

run IMPS

on the terminal shown on the right-hand side of the pictures shown in Figure VI-3. The program then asks for the user's number, which is the same as the programmer number (PN) in the DEC-10. The user's map files are organized under this number on disk. Once this is done, the IMPS top level menu appears on the VT11 refresh terminal screen, and the user can proceed.

The basic control of IMPS occurs through user selection of items out of lists of options called menus, which are displayed on the VT11 refresh line drawing terminal. 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 on the data tablet cause the displayed cursor to move on the VT11 screen. The user then pushes down on the pen to indicate to IMPS that the cursor is pointing at the desired item. IMPS then intensifies the selected item on the screen and turns off the cursor. If the user is sure that the desired item has been selected, he then pushes down on the pen again. If he doesn't want that item, the user types a key on the keyboard (any key will do). In this case 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 acknowledgment or a "yes" answer; typing a key on the keyboard indicates cancellation or a "no" answer. After the user selects a category of functions out of the top level menu, IMPS will display the corresponding second level menu. This may be a list of subcategories or it may be another list of functions. After a function has been executed, IMPS returns to the menu that initiated the function. If the user then wants to exit to a higher level menu, he types a key on the keyboard.

Experience has shown that, with no more than 5-15 minutes of a "hands on" introduction to IMPS, the user will be able to proceed on his own. Only after some initial use of the system will the user be able to fully appreciate the reasons for the use of data tablet, keyboard, refresh terminal, and menus by IMPS.

(b) Producing Maps for IMPS

The initial input maps for IMPS in the PDP 11/40 are produced by the DEC-10 and the PDP 11/70 map making system. As far as the user is concerned, the result of running a DEC-10 program requesting a map display output to the PDP 11/40, as an alternative to DEC-10 terminal (TTY) or line printer (LPT), is the immediate or only slightly delayed appearance of the map in IMPS-oriented format on the disk of the PDP

11/40. At this point the map can be accessed by the user running IMPS. One of the IMPS utility functions is the display of a summary of available maps on disk in the user's area. The display of such a list of maps as a menu is used by the COMTAL image loading functions to let the user choose a particular map on disk.

One of the available data processing functions of IMPS is the capability to formulate mapping and map cleaning requests that are communicated to the DEC-10 and the PDP 11/70 map maker for execution. This capability, when paired with a utility function which can ask for a particular map to be brought over to the PDP 11/40, means that the user can carry out the complete process of requesting map making, and transfer of maps to the PDP 11/40, from IMPS. One uses this capability when one learns, in the course of map processing, that other maps are needed.

(c) The IMPS Menu Structure and IMPS Functions

(1) The Evolving Nature of IMPS Menus

As this is being written in October 1978, the system aspects of IMPS are essentially finished, and the first group of map processing functions have been implemented. However, a large fraction of the applications functions are still to be coded and linked to IMPS. This means that all we can describe here are the general top level menus of IMPS and the functions that are already implemented or planned for immediate implementation. For this reason, the user is likely to encounter a different and more extensive menu of IMPS functions than we will describe here. However, we will describe some of the major top level menus so the user can get some initial idea about the IMPS functions. In the last analysis, the menus available to IMPS at any one time are best learned by running IMPS and seeing what is available. Menu items that are not yet implemented will generally have an asterisk preceding the text of the menu item.

(2) The IMPS Top Level Menu

The following is the current top level menu for IMPS. This menu is displayed when IMPS is first run and whenever the user returns to the top level menu:

1. Utility Functions
2. COMTAL Image Loading Functions
3. COMTAL Image Display Modification Functions
4. Data Plotting Functions
5. Data Processing Functions
6. DICOMED Output Functions
7. VERSATEC Output Functions
8. Execute User Coded Function
9. Exit from IMPS

Most of the top level menu items, when selected, lead to more extensive menu items. They are basically broad categories of map processing functions.

(3) 1. Utility Functions

Utility functions are miscellaneous in nature and best described by listing the menu you will see if you choose to select the utility functions category:

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 IMPS Parameters

1.9 Transfer Map From DEC-10 and PDP 11/70 to PDP 11/40

1.10 Log on to the DEC-10 to Run DEC-10 Programs

The map category, under which groups of maps can be organized, is one of the parameters specified when a map is made. One can choose to deal only with maps of a specific category.

The user can display, on the refresh terminal screen, a summary of either all the maps available to the user on disk or all the maps under a preselected category. This function is used only to inform the user about what is available.

If the user wishes a more complete display of information about a particular map, he can request such a display by asking for a display of map "header" information. Once this menu item is selected, the map summary appears as a menu, and selection of a particular menu item will result in a display of information about that map on the refresh terminal screen.

The user can request a change of map category. Once this is initiated, a map is chosen from a menu of maps, and the user is prompted to type a new category name for the selected map. A carriage return, typed after the category name, initiates the change of category and returns the user to the utility function menu.

Maps can be deleted from disk. Once this function is selected, a menu of available maps is displayed and choosing one of these results in its deletion.

Completely analogous to the SAVECOMMANDS, GETCOMMANDS, and SETDEFAULTS standard commands in the DEC-10 are the utility menu items to Save, Restore, and Initialize IMPS Parameters.

A map that has been prepared in the DEC-10 and PDP 11/70 map making system can be brought over to the PDP 11/40 and stored on disk in IMPS format. When this menu item of the Utility Functions is selected, the user is asked to supply the map name, and the map transfer is then initiated.

Starting from IMPS, the user can initiate the capability to log on the DEC-10 to run DEC-10 programs. Once this Utility Function menu item is chosen, the user is talking to the DEC-10 just like any other DEC-10 terminal at monitor level and must log on in the same manner, using the

login P,PN

command and then supplying the appropriate password as discussed earlier in this chapter. When the user logs off the DEC-10 with the usual

k/f

the user is returned to IMPS control and the menu of possible utility functions is displayed on the screen. As usual, hitting a keyboard key will return the user to the IMPS top level menu.

(4) 2. COMTAL Image Loading Functions

The general category of functions which will load different types of images into COMTAL memory, and hence display images on the COMTAL screens, are called Image Loading Functions. Normally a pixel value is represented by an 8-bit number when loaded into COMTAL memory, corresponding to 256 different gray scale levels, or 64 different colors. Selection of the COMTAL image loading function of IMPS gives you access to a variety of ways in which one or more maps can be displayed on the COMTAL screens. The following is a sample menu of Image Loading Functions that are available:

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 an Image
2.7 Load Graphic Overlay Image into Entire Screen
2.8 Clear Graphic Overlay in Entire Screen
2.9 Load Graphic Overlay Image into Quadrant of Screen
2.10 Clear Graphic Overlay in Quadrant of Screen

If the user chooses to load an image into the entire 256X256 screen of the COMTAL TV monitor, the immediate result is to show a menu of maps that could be displayed. Once a map is selected, if its size is greater than 256X256, the refresh terminal screen will show a 256X256 box outlining the region of the map to be displayed, inside a box showing the full limits of the map. By moving the tablet pen, the box on the VT11 screen showing the portion of the map to be displayed on the full COMTAL screen can be changed, and, when it corresponds to what the user wants, pressing the pen on data tablet initiates the loading of that portion of the map into COMTAL memory. If the map is 256X256, it is directly loaded into COMTAL memory and appears on the TV screens. If the map is smaller, it is loaded in the center of the TV screen. As the image is loaded, it appears on the TV monitors.

The entire COMTAL screen can be cleared of an image by selecting the menu item for clearing the entire screen. This clearing is optional; it need not be done before loading another image.

Up to four 128X128 images can be loaded into the four quadrants of the COMTAL memory and TV monitor screens. This function behaves just like the loading of the entire memory and screen except that, after selecting a map for display, one is shown an image of the four quadrants of the memory and screen so that one of the four can be selected for loading of a 128X128 portion of the appropriate map. Once the quadrant is chosen, loading of image into memory and screen proceeds. Four executions of loading into a quadrant of the screen will fill the entire screen. Frequently, the loading of images into quadrants of the screen is preceded by use of the utility Data Processing Functions to produce new maps by decreasing the number of pixels per map by averaging or picking out the highest points in subsections of the map.

Quadrants of the COMTAL screen can be cleared one at a time by selecting the appropriate menu item to clear quadrants and then selecting the quadrant to be cleared.

Two different images can be selected for blink comparison on the COMTAL screens. After the two map images have been selected from the menu of available maps, the first map image is loaded in four bits of COMTAL memory and is displayed on the COMTAL screens. The second map image is loaded in the other four bits of COMTAL memory. Once the two images are loaded, one proceeds to one of the COMTAL image modification functions which allows the user to control the alternate display of the two images on the screens.

One of the image loading functions that can be used to get a quick look at an entire map which is larger than 256X256 is the scroll load of an image. Once this is selected, one chooses the 256 columns that are to be scrolled through and then motion of the tablet pen will control which 256X256 portion of an N_x X N_y map will appear on the TV screens. As the cursor changes the displayed portion of the map, the refresh screen will show which subset of the entire map is on the screen at the time. Because of practical limitations of the COMTAL hardware, one can scroll through rows but not through columns of an image.

(5) 3. COMTAL Image Display Modification Functions

There are many different ways to modify the way a map image, previously loaded into COMTAL memory, appears on the COMTAL screens. Examples of menu items under this category are:

3.1 Modify Image Display Parameters
3.2 Blink Compare Two Images
3.3 Blink Graphic Overlay
3.4 Insert/Remove Linear Wedge in Image

Selection of the menu item to Modify Image Display Parameters transfers the user to control of a third level menu. This lists a menu of available types of modification and displays a plot of the transfer function used in the function memory for transferring stored map pixel values into displayed intensities. Also shown is a list of the current display status parameters. Types of image modification available in this menu are: switching from positive to negative images and vice versa; color contouring with control of the number of contours and their width; display of intensity values shown in a color spectrum; inserting black contours of varying number and width into a gray scale or color image; inserting or removing a strip wedge from the top of the COMTAL screens showing how the range of image intensities is mapped into gray scale or color values; and different ways of altering the transfer function.

If two images have been loaded for blink comparison, selecting the menu item to Blink Compare Two Images results in a mode of operation so that, with the tablet pen up, the first image is displayed, and with the tablet pen pressed down on the data tablet, the other image appears. By altering the pace at which the tablet pen makes contact, the user can control the blinking process as desired.

If a graphic overlay has been loaded, one can blink this overlay on and off with alternate contact of pen and data tablet.

Without getting into the modification of image display parameters, one can choose to insert or remove the linear wedge at the top of the COMTAL display screens which shows how map values are represented on a black/white or color scale.

(6) 4. Data Plotting Functions

Both cross-section plots and contour plots can be generated from a map or a combination of maps. The following are sample menu items initiating functions of this type:

4.1 Plot Horizontal Cross Section of Displayed Image

4.2 Plot Arbitrary Cross Section of Displayed Map

4.3 Plot Contour Map of Displayed Image

The selection of the menu item for plotting horizontal cross sections of a displayed image results in a plot of the cross section through the cursor on the COMTAL screen. Vertical changes in the location of the cursor result in a dynamically changing plot on the refresh terminal screen.

Choice of the menu item for plotting an arbitrary cross section of a map results in the usual two-box display of displayed image inside original map. The cursor can be moved to a point in the displayed image defining one point in the cross section, then, once this is chosen by pressing the pen down on the data tablet, the cursor can be moved to select another point to finish definition of the cross section. The selected cross section is then shown on the refresh terminal screen. The initial plot shows the cross section through the entire map. The user can then change which portion of the cross section is plotted.

Selection of the menu item for generation of contour maps will result in a display of contour display parameters that can be changed at will. Contour plots can be put on the refresh terminal screen, they can be turned into overlay images that can then be superimposed on maps, or they can be output to hard copy devices.

(7) 5. Data Processing Functions

The data processing functions represent the most expandable category of map processing. The following sample menu shows a sample of what is or will be implemented:

5.1 Utility

- 5.1.1 Change Map Pixel Storage Format
- 5.1.2 Decrease Number of Pixels by Averaging
- 5.1.3 Select Subsection of a Map
- 5.1.4 Decrease Number of Pixels by Selecting Largest Intensity
- 5.1.5 Increase Number of Pixels by Duplicating Pixels
- 5.1.6 Increase Number of Pixels by Interpolating Pixels

The utility data processing functions involve simple modifications of maps. Maps are stored on disk in three formats: real numbers, scaled integers, and 8-bit pixel values. Changing a stored map from any one of these formats to any other is a utility function. The 8-bit pixel format is the form for which fastest image loading is possible.

Map arithmetic consists of any of the reasonable ways in which maps can be generated from other maps by operations on corresponding pixels. This includes weighted addition of maps, generation of polarization maps, spectral index maps, etc.

Selection of the menu item for Gaussian Source Fitting gets one into a mode where map subsections are selected for a two-dimensional gaussian fitting procedure. The fitted sources are identified by numbers and the fitted parameters are stored on disk where they may be listed on the terminal screen and used for subsequent processing.

Map images from which previously fitted gaussians are subtracted, after selection from a menu of fitted gaussian parameters, may be generated.

Given point source parameters, either supplied by the user or obtained from a menu of gaussian fit parameters, one can carry out source subtraction by subtracting a dirty beam with a single flux and a single position.

Sources can be subtracted by cleaning of small selected areas in a map.

Remapping of sources in the DEC-10 and PDP 11/70 may be initiated by selecting the appropriate data processing function which allows the user to formulate mapping requests. This is equivalent to submitting a batch job to the DEC-10 and is an alternative to temporarily leaving IMPS to run mapping programs.

Extensive cleaning of maps may be initiated in the DEC-10 and PDP 11/70 by formulating the map cleaning request in IMPS. This is a batch-like equivalent of running the map cleaning program from a DEC-10 terminal, or using IMPS to establish such a connection with the DEC-10.

(8) 6. DICOMED Output Functions

Access to programs for generating DICOMED film recorder output of maps and COMTAL images may be obtained by selecting this top level item from the IMPS menu.

(9) 7. VERSATEC Output Functions

Output of hard copy images of plots, maps, and COMTAL images can be obtained by selecting this item from the top level menu of IMPS.

(10) 8. Execute User Coded Function

Users who have learned to code FORTRAN programs in the PDP 11/40, with a few standard lines of code beginning and ending each program, can run these programs under IMPS control by selecting the top level menu item of IMPS for Executing User Code Function. The user is then asked to type the name of the user coded function. The function or program is then run, and, when completed, control is returned to IMPS.

(11) 9. Exit from IMPS

At the end of a map processing session with IMPS the user exits from IMPS by selecting the appropriate item from the top level IMPS menu.

11. VLA Data Reduction at NRAO in Charlottesville

The processing of aperture synthesis data after completely edited, corrected, and calibrated data are obtained is well known to be both iterative and extensive in nature. The facilities and support for such iterative and extensive map processing at the VLA site is very limited. For this reason the VLA user without his own map processing facilities has the option of continuing his VLA data reduction at NRAO in Charlottesville.

The major package of programs available at the end of 1978 in Charlottesville is a group of programs evolved from Green Bank Interferometer Programs but oriented towards the processing of VLA data.

Calibrated data that are to be processed further in Charlottesville are transferred to Export tapes in the DEC-10. A system of map processing programs that run on the IBM 360/65 in Charlottesville is designed to process fully calibrated VLA data. Additional calibration of these data may be applied through format conversion to a second system of programs, which is a modified version of the Green Bank interferometer off-line data reduction system. Direct input of data, on the magnetic tapes written by the on-line computer system, is possible with the latter system.

The map processing programs in Charlottesville provide extensive facilities for: (1) editing, display, and model-fitting in the u-v plane; (2) mapping, (3) map cleaning, and (4) map display.

A manual describing the VLA data reduction facilities in Charlottesville is available. Copies may be perused at the VLA site library and the observers offices.

APPENDIX 1

THE LOGISTICS OF TRAVEL AND STAYING AT THE VLA SITE

Traveling to the VLA site and using the facilities at the VLA site involve a number of details that the user should be aware of.

1. Transportation

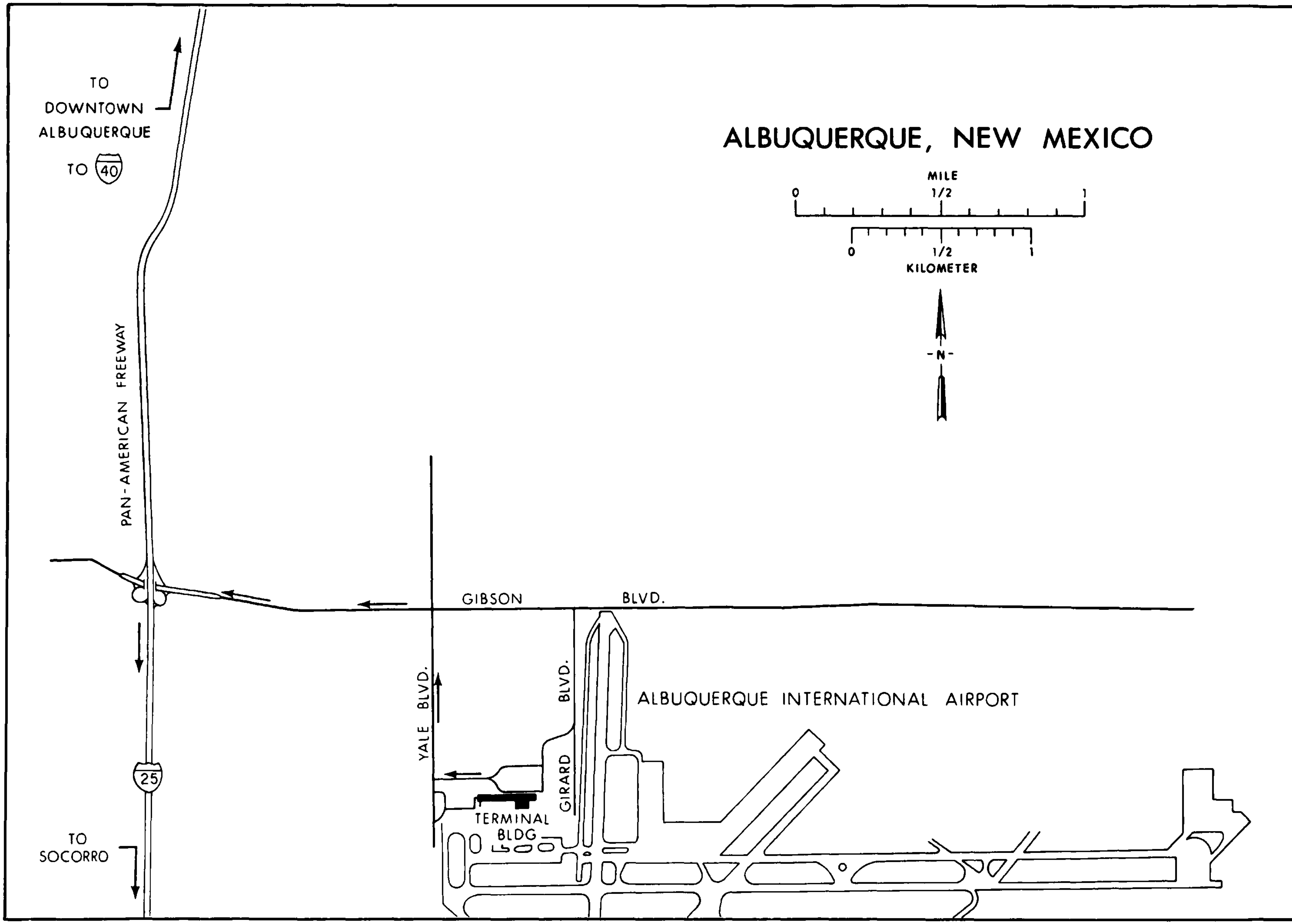
The primary means of access to the VLA site begins with an airline flight to the Albuquerque airport. From there one travels to Socorro via either the Continental Trailways bus or by driving a car. The maps on pages A-2, A-3, and A-4 show the route from the airport to Socorro and then to the VLA site.

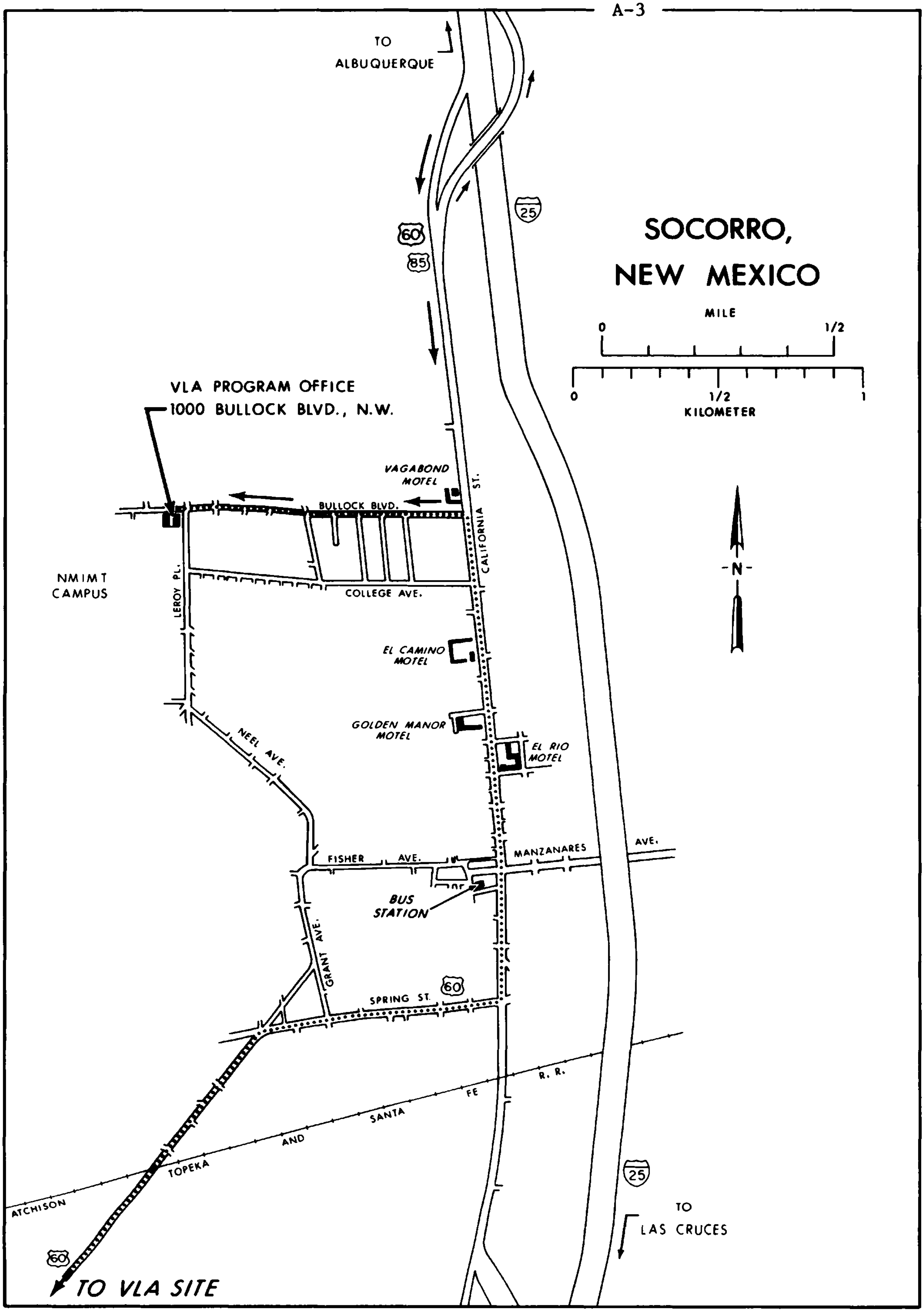
For those who use the Continental Trailways bus, it is first necessary to get from the airport to the Trailways bus station. Since there is considerable distance involved, it will be necessary to take a taxi or to travel via the Albuquerque bus system, which has an airport route, stopping at the east end of the airport terminal road and near the bus station. The current bus schedule (subject to change without notice) is:

LV Albuquerque	AV Socorro	LV Socorro	AV Albuquerque
0600	0745	0325	0455
1100	1245	0925	1115
1915	2100	1440	1620
2330	0115	2045	2230

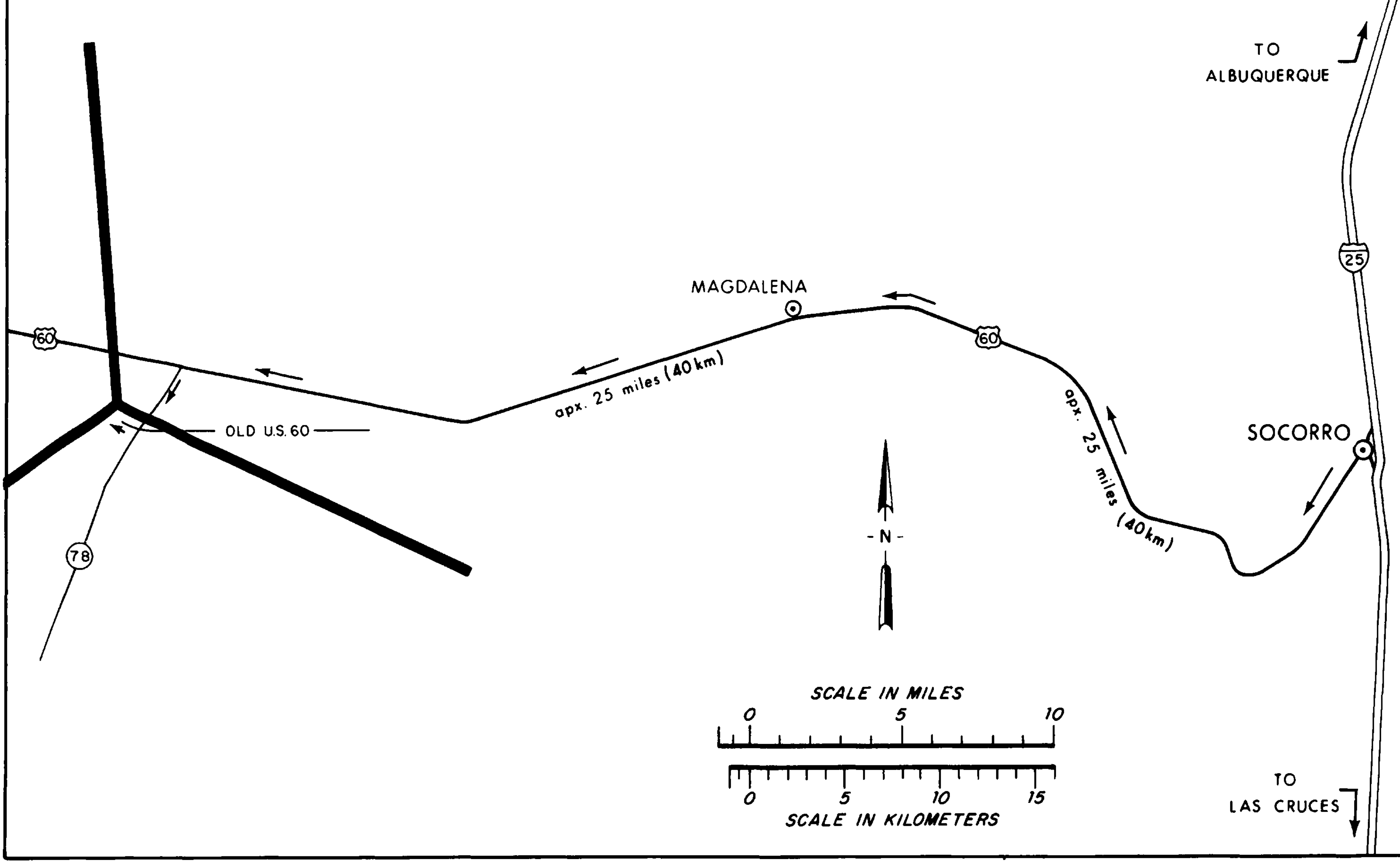
The Socorro bus station is about 1½ miles from the NRAO offices in Socorro. Travel from Socorro to the airport is only a matter of reversing the route.

The normal method of travel from the Albuquerque airport to the VLA site and back is with a GSA car. At least a week in advance, the user should call one of the Socorro office numbers to arrange for a GSA car. At the Albuquerque airport the Dollar-Rent-A-Car Agency


ALBUQUERQUE, NEW MEXICO
MILE
0
1/2
1
0
1/2
1
KILOMETER
N
TO
DOWNTOWN
ALBUQUERQUE
TO 40
PAN-AMERICAN FREEWAY
GIBSON BLVD.
YALE BLVD.
GIRARD BLVD.
ALBUQUERQUE INTERNATIONAL AIRPORT
TERMINAL
BLDG
25
TO
SOCORRO


SOCORRO,
NEW MEXICO
MILE
0
1/2
0
1/2
1
KILOMETER
N
TO
ALBUQUERQUE
25
60
85
VLA PROGRAM OFFICE
1000 BULLOCK BLVD., N.W.
VAGABOND
MOTEL
BULLOCK BLVD.
CALIFORNIA ST.
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



will provide you with the keys and form. This car may be kept at the site as long as needed, then returned to Dollar-Rent-A-Car at the Albuquerque airport. If a GSA car is not available, arrangements for a National rental car may be made; however, it must be dropped off at the Socorro office. Return from Socorro to Albuquerque will then be by another National rental car. As with the GSA car, it is best to let the Socorro VLA office arrange the needed rental. Since only National has an office in Socorro, rental of any other cars will be at the expense of the visitor, as will be extra expenses due to a National car not dropped off in Socorro on the way to the site.

The drive between Socorro and the Albuquerque airport is about 77 miles, taking roughly an hour and thirty minutes. The drive between the NRAO office in Socorro and the VLA site is about 54 miles, taking an hour.

There are a number of ways of traveling between Socorro and the VLA site.

(1) Monday - Friday Bus: Two buses run Monday through Friday, except holidays. The buses leave the Socorro office, 1000 Bullock Blvd., at 7:30 a.m., stop in Magdalena for a pickup at about 8:00 a.m., and arrive at the site at about 8:30 a.m. Buses leave the site from the Technical Services building and the Control building at 4:30 p.m., drop people off in Magdalena at about 5:00 p.m., and stop in the parking lot near the Socorro office at about 5:30 p.m.

(2) Shuttle Service: There is usually a car from site to Socorro and Socorro to site, leaving both places at about 12:00 noon and arriving at the other end at about 1:00 p.m. There is often a car leaving Socorro at about 10:00 a.m. and returning to Socorro

in early evening. In either case, contact any site or Socorro secretary the previous day, or as far in advance as possible, since these car schedules, while almost always occurring, are not guaranteed.

(3) Arranged Vehicles: Vehicles needed for obtaining meals over the weekend and holidays can be arranged. These should be coordinated in advance with the secretary in the upper lobby of the Control building (Extension 201).

The NRAO policy of covering all but $75 of transportation costs for qualified U. S. astronomers applies to the VLA. See the secretary in the upper lobby of the Control building (Extension 201) for the appropriate voucher forms.

2. Telephone Use and Special Telephone Numbers

The VLA site and the Socorro office both have commercial telephone numbers and Federal Telecommunications System (FTS) numbers. Use of the FTS system is for official government business only. When calling from site or Socorro office telephones or commercial lines, you are requested to use either your telephone credit card number or call collect. If this is not possible, then, as soon as possible, please advise the site telephone operator, Extension 0, about the number called, the extension used, and the date the call was made.

The following are general numbers for reaching personnel at the VLA site (during Monday-Friday working hours) and at the Socorro office.

Place	Commercial	FTS Direct
Socorro Office	505-835-2924	474-3671, 474-3653, 474-3647, 474-3654
Control Building	505-772-4011 505-772-4 + Ext.	476-8011 476-8 + Ext.

Place	Commercial	FTS Direct
Technical Building	505-772-4210 505-772-4 + Ext.	476-8210 476-8 + Ext.

The following are special site extensions:

	Extension	Location
Food Service	235	Cafeteria Building
Site Manager	011	Reach through site switchboard
Plant Maintenance	261	Room 4, Technical Services building
Guard	276	Room 7, Technical Services building
Observers Room 1	281	Room 221, Control building
Ovservers Room 2	238	Room 203, Control building
C.B. Terminal Room	298	Room 204, Control building
O.B. Terminal Room	226	Room 3, Scientific office building
Array Operators	251	Room 225 (Control Room), Control building

3. Living Quarters at the Site

There are two buildings with quarters for visiting scientists, with both double and single rooms. Reservations for use of these rooms must be made in advance and visitors observing at any particular time have priority.

Reservations:	Call 505-772-4011 (Commercial), 476-8011 (FTS), or on-site Extension 0.
Key pickup:	Room assignment board in lower lobby of Control building.
Building access:	If arrival is outside normal working hours, there is a telephone outside the east door of the Control building where you can call either the array operator (Ext. 251) or the guard (Ext. 276) to let you in.
Registration:	Please fill out the Registration Card and Observer's Information Sheet next to your key on the assignment board, and return with your key to any site secretary at time of departure.

Billing:	Bill for lodging may be picked up from the secretary in the lower lobby of the Control building, or it may be sent to your business address. Costs are $5.50 per night for single occupancy and $3.50 per night per person for double occupancy. If you wish, payment may be made at time of checkout.
Checkout:	Eleven a.m. checkout time. Later checkout time must be cleared with the secretary in the lower lobby of the Control building. Please return key and registration forms to any secretary.
Bed and Bath Linen:	Linen will be placed in your room prior to check in. As daily maid service is not supplied, please make your own bed. For extended stays, a request for new bed and bath linens may be directed to any site secretary.
Personal Laundry:	A washer and a dryer are available for your use. They are located in the utility room on the east end of one of the Visiting Scientist Quarters.
Problems:	If you have problems connected with the Visiting Scientist Quarters, please call Extension 261.

4. Meals

During Monday through Friday, with the exception of holidays, meals may be obtained from the VLA site cafeteria. All meals are on a cash basis. For those people staying at the site overnight, breakfast is available between the hours of 8:30 and 9:30 a.m. Lunch is served between the hours of 12:00 and 1:00 p.m. Since the cooks leave on the 4:30 p.m. bus, after-hours meals in the form of box lunches may be obtained by filling out an order form available at the cafeteria. Orders should be placed with the cooks before 1:00 p.m. and picked up between 2:00 and 4:00 p.m. Informal cooking service in the cafeteria is also provided on weekends.

In addition to the on-site meal service, the user has two options: (1) food may be purchased from Socorro or Magdalena grocery stores and used with the refrigerator and stove facilities in the Control building; and (2) one can eat at restaurants in Magdalena or Datil. There are two restaurants, one of which is closed on Sunday, in Datil, 25 miles to the west of the site on U.S. 60. There are several restaurants in Magdalena, 25 miles east of the site on U.S. 60, and also in Socorro, 54 miles east of the site on U.S. 60.

5. Library Facilities

Present library facilities at the VLA site are not too extensive. The library is located in the Scientific office building west of the Control building. Major astronomical journals are available from recent years (mostly from 1975 on, but the Astrophysical Journal from 1962). A set of National Geographic-Palomar Schmidt prints is available, but, as of the end of 1978, there are no special facilities for determining positions, etc. In general, you should not rely on finding data critical to your observations in the VLA library.

APPENDIX 2

PROCEDURES FOR PUBLICATIONS INVOLVING NRAO INSTRUMENTS

Because NRAO is a national facility funded by the National Science Foundation, the use of NRAO instruments places a few simple 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 where a portion of the work was done at NRAO, are being prepared for publication, three formal responsibilities must be met: (1) proper acknowledgment to NRAO and NSF must be included in such publications; (2) preprints of such publications should be sent to the NRAO librarian in Charlottesville; and (3) arrangements for the Observatory to pay one-half the publication page charges, if this is desired, and order reprints for its reprint series should be made. The Observatory will pay one-half the page charges for visitor publications and will distribute about 250 copies in its reprint mailing. The NRAO will not normally provide the authors with reprints, on the assumption that the home institution will do so; however, if requested at the time of submittal, the NRAO will provide fifty reprints to the authors.

Proper acknowledgment to NRAO and NSF is achieved by including a footnote where the 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 acknowledgments. The footnote or acknowledgment should read as follows:

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

or, as would be required for publication in journals published outside the United States, "The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the U. S. National Science Foundation".

The other two obligations are to provide preprints which serve the purpose of allowing the Director of NRAO and his staff to keep up-to-date about results obtained at the NRAO or with NRAO instruments and to arrange for the ordering of reprints for NRAO's reprint series. The following steps should be followed for all papers submitted for publication, excluding abstracts of papers presented at meetings:

1. At the time of submission or acceptance, send three prepublication copies of the paper to the NRAO librarian in Charlottesville, indicating the journal to which the paper is submitted. One copy is for the Director's office and two copies are for the NRAO libraries. The Observatory does not desire to referee visitors' publications.
2. At the time of acceptance for publication, please notify the librarian in Charlottesville of the proposed date of publication and apportionment of page charges so that necessary purchase orders can be initiated.
3. A copy of the journal's order form for reprints and the approximate number of journal pages should be sent to the librarian in Charlottesville. Please do not order reprints for NRAO at the time you order your reprints. The NRAO will order reprints separately.
4. All other scientific and administrative communications should be kept between the authors and the journals.