V L A   U S E R   M A N U A L

April, 1977

Information in this manual applies only for the interval April-December, 1977. Several major changes are planned which will render this manual obsolete by early 1978.

This manual is written for observers and potential observers with a background in interferometry and does not pretend to be an introduction to interferometry or aperture synthesis.

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CHAPTER I. INTRODUCTION AND LOGISTICS

1. A VLA Overview

The VLA is a versatile and complex instrument. Moreover, much of its equipment was designed with state-of-the-art components, and represents an ambitious undertaking insofar as making many copies of these components work reliably from the outset. The complexity and advanced design concepts will become increasingly obvious as one proceeds through this manual. It is therefore helpful to begin this manual with a simplified system overview and to introduce some common terminology.

The telescopes are now situated on the southwest arm with separations up to 5 km. During 1977 additional spacings along this arm with separations up to 10 km will become available. The VLA can operate as several subarrays, and it is common to find at least two antennas in the "engineering test array" where new electronic components are being exercised. These antennas are not generally available for scientific use. The remaining telescopes (normally four at present, and six by September) will be configured as scientific and engineering needs dictate, but it is not likely that they will be moved often.

Communication between the control room and the antennas utilizes low-loss waveguide. For one milli-second out of approximately fifty-two, digital instructions generated by the on-line computer (a system of four Modcomp computers) and 5 and 600 MHz timing signals for alignment of the phase locked oscillators are sent to the antennas. During the rest of the cycle, analog IF and digital information concerning the actual performance of the electronic or other systems is returned to the control room. The general name given to the system sending digital data to and from the telescopes and receivers is the "monitor and control system". The returning digital data are known as "monitor data".

The monitor data are read by the on-line computer on a 1 to 10 second time scale. Monitor data are examined every 10 seconds for evidence of equipment malfunction. An indication of the overall system performance and a listing of the system problems are displayed in the control room enabling a crude assessment of data quality in real-time. The monitor data are "logged" on disk and tape at intervals between 80 seconds and 20 minutes, depending on their significance.

The analog IF signals are sampled, digitized, delayed, and correlated by the "digitizing samplers" and the "digital delay and multiplier" systems. The present digital system is designed to handle up to 12 antennas with two IF channels each. (More sophisticated electronics will arrive in 1978 to service 27 antennas with four IF channels each. This new equipment will also provide a spectral analysis capability, but it is not anticipated that scientifically useful line observations will be supported until 1979.)

The complex correlation coefficients are sent from the digital correlators to the on-line computer. The computer attempts to ascertain the quality of the present data by inspection of the current monitor data. "Data flags" are set accordingly. For convenience, the collection of information including the measured visibilities, the data flags, the source name and position, etc. are referred to as "visibility data". Visibility and monitor data are written onto separate magnetic tapes. Soon, these types of data will also be written onto a high-speed fixed-head disk readable by the off-line, or synonymously, the DEC-10 computer. Merging of monitor and visibility data is thereafter possible only in the DEC-10.

Data from the fixed-head disk are read every few minutes by the DEC-10 and stored (with an option to average) in a compact form known as the "visibility data-base". Alternately, data can similarly be added to the data-base from tape. For each observation an "index-record" is written which contains those parameters that are unchanged during the observation. These parameters include the source name, its given and precessed coordinates, the array configuration, various options selected, the synthesizer settings, etc. "Visibility records" containing the measured data, the data flags, weights, u, v, and w, etc. are recorded in a separate file. Finally a "gain table" is written for each observation in yet a third file. Stored in the gain table "entries" are the corrections to the measured data which have been or are to be applied. Corrections are stored for each IF channel of every antenna. A new gain table entry is generated at the beginning of an observation, periodically thereafter (typically every ten minutes), and again at the end of an observation. Actual corrections to the data are then calculated by linear interpolation between appropriate gain table entries.

Similarly, the monitor data can be stored into a "monitor data-base" for inspection. Post-observation use of the monitor data for automatically setting or resetting flags in the visibility data is not yet implemented.

The types of data alteration fall into three general categories, *to wit*, "selection" (where data are flagged as acceptable or unacceptable in quality), "*a priori* corrections" (i.e., corrections known *a priori* for atmospheric effects, baseline errors, synthesizer drifts, etc.), and "empirical corrections" (i.e., corrections for the calibration of gain, phase, and polarization). In the VLA, data are selected by the setting of flags as described earlier; measured data are never physically deleted and the flags can be reset or ignored by DEC-10 software as desired. Most *a priori* corrections are determined by the Modcomp computers. The remaining *a priori* corrections and all of the empirical corrections are computed by the DEC-10. The Modcomp computed corrections are applied to the data and the values recorded in a part of the gain table. DEC-10 correction values are stored elsewhere in the gain table, but unlike the Modcomp correction process, the data are not actually altered in the data-base. DEC-10 analysis programs will routinely apply the requisite corrections to the data whenever necessary.

Because of the present rapid evolution of the off-line DEC-10 software, no attempt will be made in this manual to provide detailed instructions on its execution. Program documentation is limited to an overall description of program objectives. More explicit instructions about program execution can be obtained by contacting the VLA computer group prior to scheduled observations.

2. Logistics At Socorro

a. VLA Operations Organization

A. R. Thompson, Acting Head for Operations Head, VLA Electronics Division	Control Building Rm 204 772-4240
B. G. Clark, Scientific Coordinator Head, VLA Computer Division	Control Building Rm 206 772-4268
V. Herrero, Head, Array Operations Division	Control Building Rm 220 772-4280
C. Bignell, VLA Scientific Staff	Control Building Rm 108 772-4305
E. B. Fomalont, VLA Scientific Staff	Control Building Rm 207 772-4242
N. Vandenberg, VLA Scientific Staff	Control Building Rm 208 772-4208
R. M. Hjellming, Scientific Staff	Control Building Rm 209 772-4274
J. P. Lagoyda, Visitor Services	Tech. Serv. Bldg. Rm 7 772-4276
D. L. Swann, Personnel Officer	Tech. Serv. Bldg. Rm 10 772-4206

For help or information in the following areas, contact the people given below:

Scientific programs, scheduling, computing	B. G. Clark
Array operations	V. Herrero
Array status, configuration, calibration	VLA Scientific Staff
Accommodations, meals	J. P. Lagoyda
Local transportation (cars and busses)	D. L. Swann
Electronics	A. R. Thompson
General problems or unresolved difficulties	A. R. Thompson

After your observing run, in order to make your experiences available to others, before leaving the site please give a brief verbal or written report on the general performance of the array, problem areas and comments to B. G. Clark, A. R. Thompson, or V. Herrero. If you find problems or have comments later, please let us know by telephone or letter.

b. Visiting Scientist Quarters

Reservations	FTS: 476-8210 Commercial: (505) 772-4210 On-Site Extension: 210
Key Pickup	Room Assignment Board in lower lobby of Control Building.
Registration	Please fill out the Registration Card accompanying your key and return to any secretary.
Rates	\$5.50 per night for single occupancy \$3.50 per night per person for double occupancy
Billing	Bill for lodging may be picked up from the secretary in the Technical Services Building or sent to your business address. If you wish, payment may be made at time of checkout.
Checkout	11:30 a.m. Please drop key in "Key Return Box" beneath the Room Assignment Board.
Bed and Bath Linen	Linen will be placed in your room prior to check-in. As daily maid service is not available, please make your own bed. Upon checkout you are requested to place the used linen in one of the pillow cases and leave it in the room.

Personal Laundry	A washer and dryer are available for your use and are located in the utility room on the east end of the Visiting Scientist Quarters.
Problems	If you have any problems connected with the Visiting Scientist Quarters, please call extension 276.

c. <u>Cafeteria</u>

Meals -	are on a cash basis.
Breakfast -	is available for those people staying at the site overnight between the hours of 8:30 to 9:30 a.m. Monday through Friday.
Lunch -	is served between the hours of 12:00 to 1:00 p.m. Monday through Friday.
After Hours Meals -	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 lunches picked up between 2:00 and 4:00 p.m.
Weekend Meals -	there is no provision for on-site weekend meal services. There is a restaurant in Datil, closed on Sunday, 15 miles to the west of the site on Highway 60. There are several restaurants in Magdalena, 25 miles east of the site on Highway 60, and also in Socorro, 50 miles east of the site.

d. Library

Present library facilities at the VLA are minimal. Major astronomical journals are available for recent years (mostly from 1975, but ApJ from 1962), catalogs of astronomical data and a few books. A set of National Geographic-Palomar Schmidt prints will shortly be available. However, do not rely on finding data critical to your observations in the library.

e. Telephone

The Federal Telecommunications System (FTS) is for official government business only. If you wish to make a personal call, please use the commercial facilities. You are requested to use either your telephone credit card or call collect for these calls. If that is not possible, then as soon as possible please advise the site operator, extension 0, of the number called and the date the call was made as these calls involve additional cost.

Emergency Numbers	Fire: Dial 9-772-5645
	State Police: Dial 9-772-5676
	Ambulance: Dial 75-835-0340

Special Site Extensions

	Extension	Location
Main number		505-772-4011
Food Service	235	Cafeteria Building
Administrative Service	276	Rm 7, Tech. Serv. Bldg.
Site Manager	240	Rm 204, Control Building
Project Manager		505-835-2921 Socorro
Plant Maintenance	261	Rm 4, Tech. Serv. Bldg.
Array Operations	280	Rm 220, Control Building
Observers' Office	281	Rm 221, Control Building
Guard	214	Rm 12, Tech. Serv. Bldg.
Control Console	251	Rm 225, Control Building

f. Transportation

Albuquerque-Socorro via Continental Trailways -

The current schedule (subject to change without notice) is:

LV Albuquerque	AV Socorro	LV Socorro	AV Albuquerque
0600	0745	0325	0455
1100	1235	0935	1115
1915	2050	1415	1555
2335	0115	2055	2230

Site buses - Buses run Monday through Friday except holidays. Buses leave Socorro Office, 1000 Bullock Avenue, at 7:30 a.m. and arrive at site at 8:30 a.m., after a stop at Magdalena to pick up Magdalena personnel.

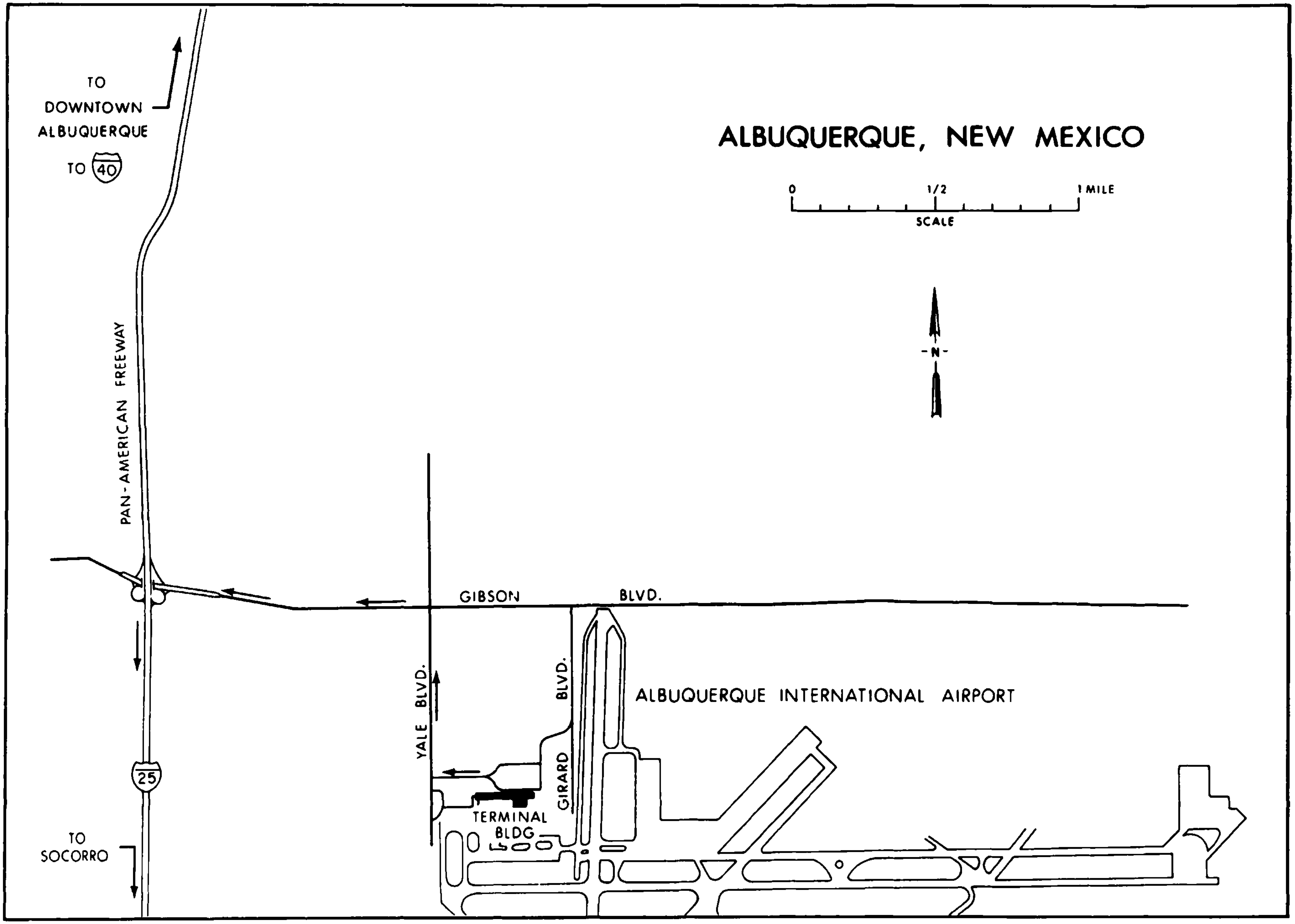
Buses leave site from Technical Services Building and Control Building at 4:30 p.m. and arrive in Socorro at 5:30 p.m.

Shuttle Service - There is usually a car from site to Socorro and Socorro to site, leaving both places at 12:00 noon, and arriving at 1:00 p.m. There is often a car leaving Socorro at 10:00 a.m. and returning to Socorro in the evening, leaving the site about 8:00 p.m. In either case, contact Florence Foster (Socorro), Cynthia Baca (Tech. Serv. Bldg.) or Doris Gill (Control Bldg.) the previous day, or as far in advance as possible (these car schedules are not guaranteed.)

Off Hour Transportation - Vehicles needed for obtaining meals over the weekend or holidays can be arranged.

They should be coordinated in advance with Don Swann, extension 206 at the site or 835-2924 at Socorro.

Travel Expense Claims -	The NRAO policy of covering all but $75 of transportation costs for U. S. astronomers applies to the VLA. See Doris Gill (Control Bldg.) for the appropriate voucher forms. For questions about the policy, see A. R. Thompson.



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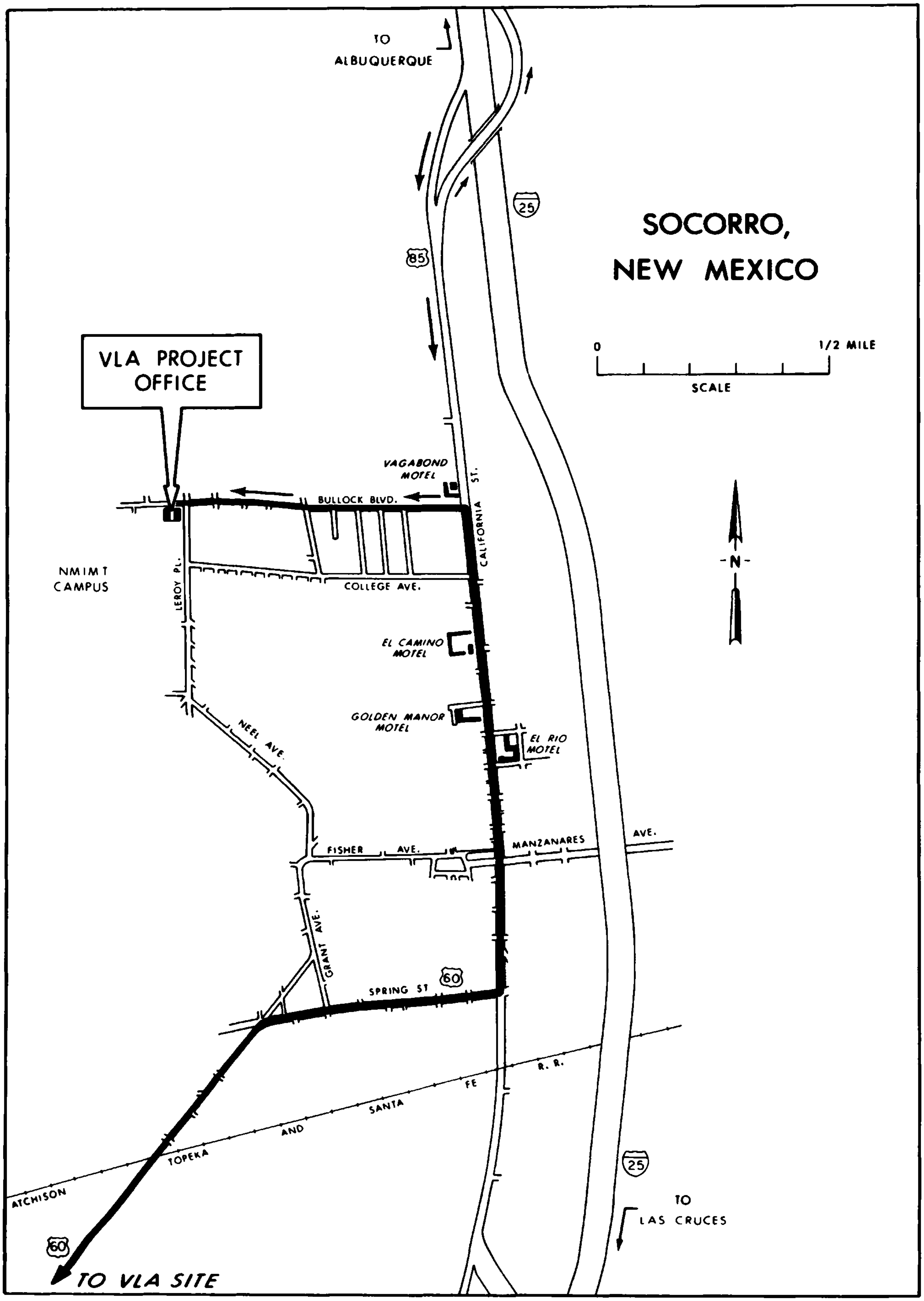
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GOLDEN MANOR MOTEL
EL RIO MOTEL
NEEL AVE.
FISHER AVE.
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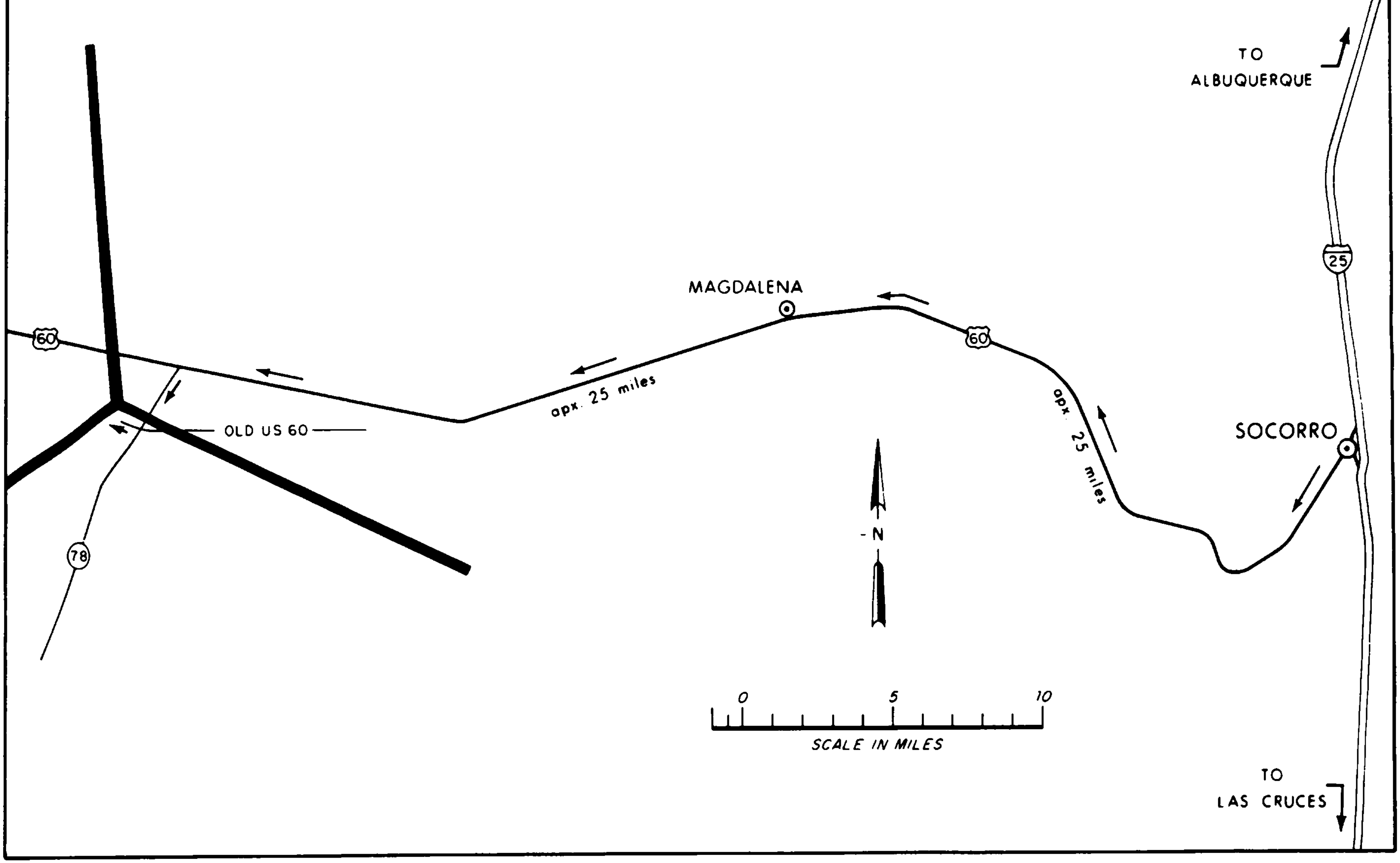

CHAPTER II - VLA SYSTEM DESCRIPTIONS

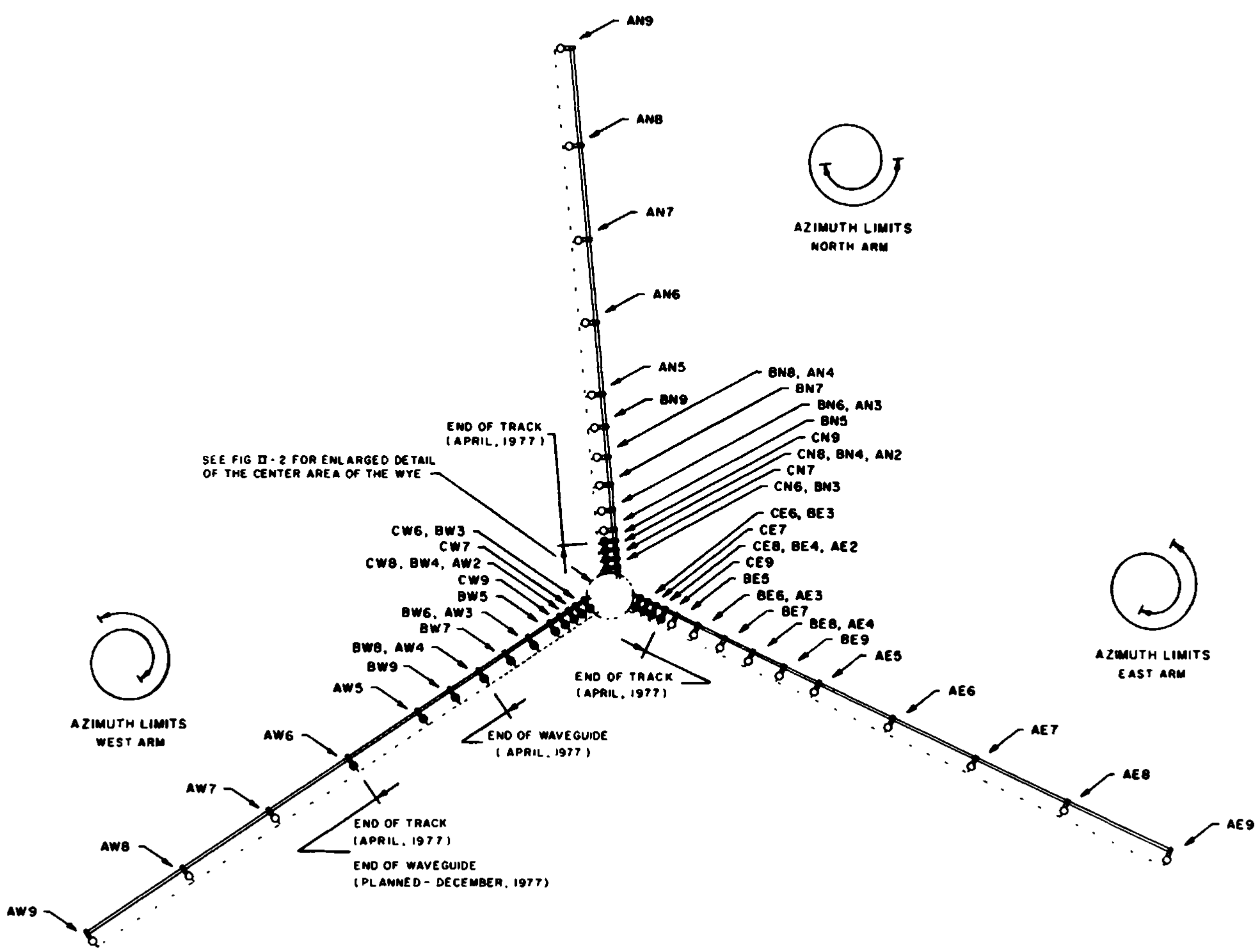

Figure II-1. WYE PLAN.

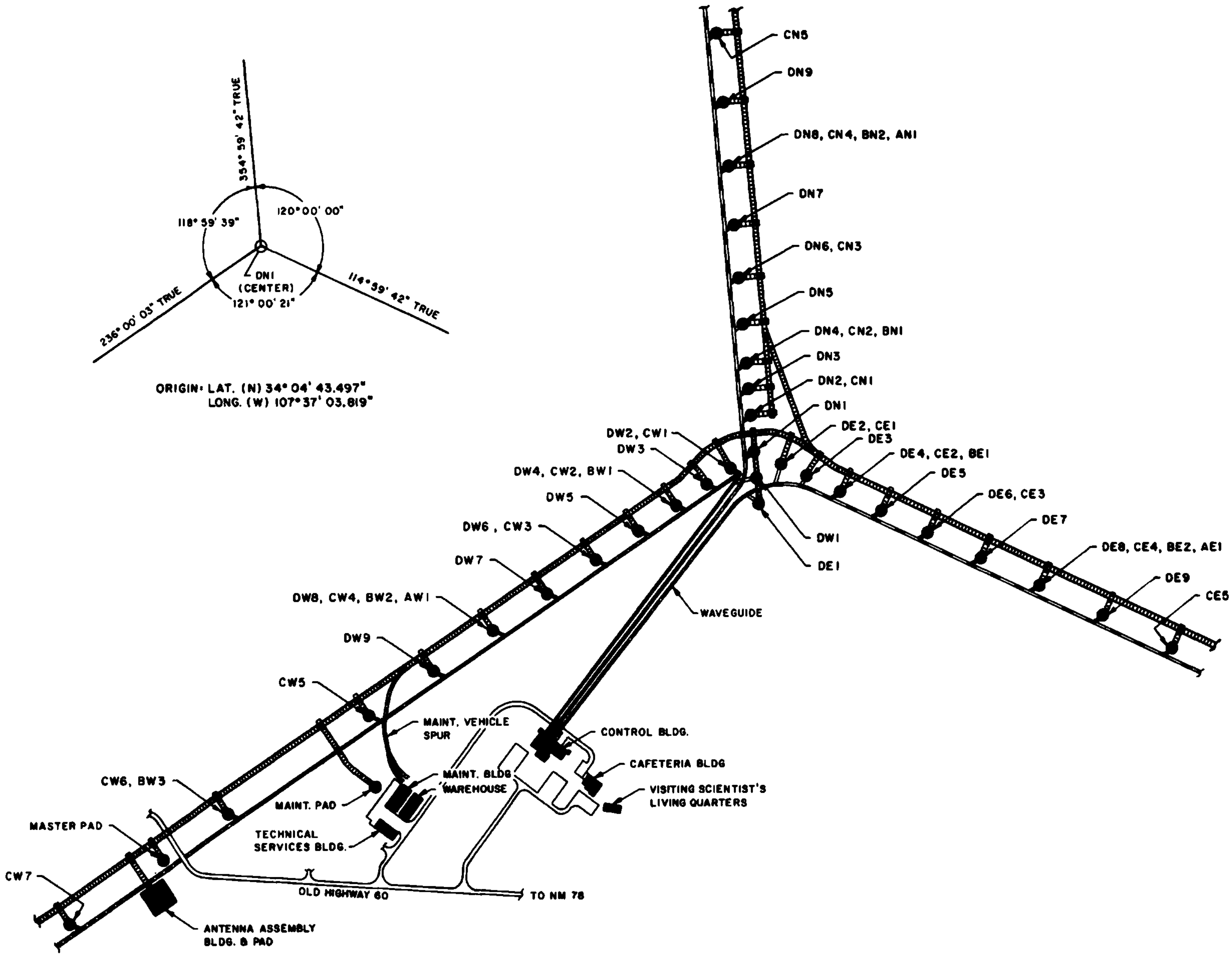

Figure II-2. CENTER OF WYE. (Enlarged detail).

CHAPTER II. VLA SYSTEM DESCRIPTIONS

1. Physical and Mechanical

a. Positions of antenna stations

Four configurations of antennas are available with the array, and these are referred to as A, B, C and D; A being the most extended. In each configuration the distance of the antenna stations from the center of the wye is proportional to n^{α} where n is the antenna number counting outwards along each arm. Chow[1] has shown that such a power law arrangement gives good coverage in the (u,v)-plane for a three armed array. With hour angle coverage of eight hours or more, the array performance is broadly optimized over a wide range of declinations if the value of α lies in the vicinity of 1·6. For the VLA, $\alpha = 1{\cdot}716$ which is equal to the logarithm to base 2 of the scale factor between adjacent configurations (3.28). With this scheme the n^{th} station on any configuration coincides with the $2n^{th}$ station on the next smaller configuration. The total number of stations for all configurations is thereby reduced from 108, which would be required with no coincidences, to 72. This reduction results in significant savings both in construction costs and reconfiguration time.

The relative positions of antennas corresponding to the power law configuration is shown in Figures II-1 and II-2. The D configuration is 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.

Table II-1 gives the positions of all antenna stations in terms of their distance from the center of the array. Stations are designated by A, B, C or D for the configuration, N, E or W for the arm, and 1 to 9 for the station number along the arm. The position angles of the arms are as follows:

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[1]Chow, Y. L., in preparation.

STATION	DISTANCE (M)	STATION	DISTANCE (M)	STATION	DISTANCE (M)
DW1	-40.00	DE1	-80.00	DN1	0.00
DW2-CW1	44.85	DE2-CE1	44.85	DN2-CN1	54.86
DW3	89.93	DE3	89.93	DN3	94.86
DW4-CW2-BW1	147.33	DE4-CE2-BE1	147.33	DN4-CN2-BN1	134.86
DW5	216.07	DE5	216.07	DN5	194.82
DW6-CW3	295.43	DE6-CE3	295.43	DN6-CN3	266.38
DW7	384.89	DE7	384.89	DN7	347.04
DW8-CW4-BW2-AW1	484.00	DE8-CE4-BE2-AE1	484.00	DN8-CN4-BN2-AN1	436.40
DW9	592.40	DE9	592.40	DN9	534.15
CW5	709.79	CE5	709.79	CN5	639.99
CW6-BW3	970.50	CE6-BE3	970.50	CN6-BN3	875.07
CW7	1,264.35	CE7	1,264.35	CN7	1,140.03
CW8-BW4-AW2	1,589.92	CE8-BE4-AE2	1,589.92	CN8-BN4-AN2	1,433.58
CW9	1,946.03	CE9	1,946.03	CN9	1,754.67
BW5	2,331.65	BE5	2,331.65	BN5	2,102.37
BW6-AW3	3,188.09	BE6-AE3	3,188.09	BN6-AN3	2,874.59
BW7	4,153.40	BE7	4,153.40	BN7	3,744.98
BW8-AW4	5,222.90	BE8-AE4	5,222.90	BN8-AN4	4,709.31
BW9	6,392.69	BE9	6,392.69	BN9	5,764.08
AW5	7,659.48	AE5	7,659.48	AN5	6,906.29
AW6	10,472.87	AE6	10,472.87	AN6	9,443.03
AW7	13,643.92	AE7	13,643.92	AN7	12,302.27
AW8	17,157.23	AE8	17,157.23	AN8	15,470.10
AW9	21,000.00	AE9	21,000.00	AN9	18,935.00

Table II-1. DISTANCES IN METERS OF ANTENNA STATIONS FROM THE ARRAY CENTER. DW1 and DE1 are on a southern extension of the north arm and the distances of DN2, DN3 and DN4 have been slightly modified from the power law values to allow rail tracks to pass through.

north 354° 59' 42"

southeast 114° 59' 42"

southwest 236° 00' 03"

The geodetic coordinates of the center of the array are:

latitude 34° 04' 43·497" north

longitude 107° 37' 03·819" west

The height of the center point is 2,124 m above sea level and the height variations along the arms lie with ±32 m.

b. Antennas

The antennas have 25 meter diameter main reflectors which are shaped to optimize the gain when used in the Cassegrain mode. The mounts are altazimuth and fully steerable. The base of the antenna structure is triangular with sides of length 9.75 meters, and each corner is supported by a concrete foundation pedestal. The antennas are manufactured by E-Systems, Inc., of Dallas, Texas. Some details of design and performance are listed below.

Reflector diameter, 25 m (82 feet)

Total geometrical aperture, 421 m^2

Focal length of main reflectors, 9 m

Maximum width of subreflector (asymmetric), 1·83 m (6 feet)

Effective magnification, 8·8

Total blockage (subreflector and support legs) gives aperture efficiency reduction factor 0·85

Surface accuracy,	panels,	<0·038 cm rms
	panel setting,	<0·046 cm rms
	gravity, wind, thermal,	0·036 cm rms
	Total	<0·070 cm rms

Azimuth and elevation positions readouts, Inductosyn, 20 bits for 360°

Non-repeatable pointing errors, <15 arcsec (combined az.

and el. for wind <15 mph and temperature differences of structure $<5^{\circ}$ F)[1]

Slew rates, azimuth 40° per minute
elevation 20° per minute

Drive, servo controlled 5 H.P. electronic motors, 2 per axis

Minimum elevation, 8°; Maximum elevation, 125°

Stow position, zenith

Azimuth limits, $\pm 270^{\circ}$ relative to track azimuth

Total weight of antenna, 419,000 pounds (~210 tons)

Resonant frequency, torsional 2·2 Hz
rocking 2·3 Hz

Wind speed specifications,	precision operation	<15 mph
	normal operation,	<40 mph
	survival at stow,	110 mph with snow load of 20 lbs. per sq. ft.

c. Feed system

The VLA antenna uses a Cassegrain feed system in which the feeds are off-axis but the beam is aligned on the boresight axis of the antenna. In this geometry, the phase gradient across the aperture of the primary reflector due to the feeds being off-axis is exactly cancelled by a phase gradient introduced by tilting the subreflector. The feeds are arranged on a circle (the feed circle) with radius 98 cm around the main reflector axis. The relative locations of the feeds around the feed circle are defined by the angles 6°, 25°, 135°, 335° for the 1·3, 2, 21 and 6 cm feeds respectively. Looking into the dish at the horizon these angles are measured anti-clockwise from the up direction.

The main reflector is a surface of revolution with a modified parabolic profile shaped for high efficiency. The shaping is small

[1]Specification, not currently achieved.

enough to allow prime focus operation at frequencies below 1·3 GHz. Nominal antenna efficiencies are shown in Table II-3.

The antenna beamwidth in arcminutes is given closely by $1{\cdot}43\lambda$, where λ is the wavelength in cm. The observing frequency 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 taken by the subreflector to rotate from the 6 cm feed to the 18-21 cm feed, which is the greatest distance it must travel, is 25 seconds. The time for rotating between other feeds is proportional to the angle between the feeds measured around the feed circle.

The 18-21 cm feed is a corrugated horn illuminating a hybrid lens of dielectric and waveguide elements. The 6 cm feed is a lens corrected corrugated horn. The 2 and 1·3 cm feeds are multimode horns.

All feeds can provide either dual orthogonal linear polarization or left and right hand circular polarization. The normal observing mode is circular polarization. Changing between linear and circular polarization is accomplished by manually changing the polarizer at each feed output. This process takes approximately twenty minutes per feed per antenna.

Measurements of the polarization properties of the antenna show that the left and right hand circularly polarized beams are separated by 0·06 ± .005 beamwidths. The direction of the beam separation is perpendicular to the plane containing the feed and the main reflector axis.

Simultaneous operation at 6 cm and 2 cm is made possible by placing a dichroic (frequency sensitive) reflector over the 2 cm feed and an ellipsoidal reflector over the 6 cm feed. The use of the dual frequency system increases the system temperatures by 4° K and reduces the antenna efficiency by a factor of 0·97 at both 6 cm and 2 cm. The dual reflector system is installed manually and takes

45 minutes to install per antenna. It is currently available on antennas 1 and 2 only.

2. The Electronic Receiving System

a. Introduction

The electronic receiving system of the VLA is basically similar to that of other synthesis arrays in its overall function. Signals received at the antennas are amplified in low noise front ends, undergo various conversions to intermediate frequencies, and are transmitted to a central location. There, compensating delays are introduced to equalize the time delays from the source through the various antennas and electronic paths to the correlators, and finally a set of multipliers is used to measure the correlation between the signals received from all pairs of antennas. The overall electronics can be regarded as an assembly of smaller systems: the front end, the local oscillator system, the IF system, the signal transmission system, the delay and multiplier system. The signal transmission system is based on the use of a single trunk line of TE_{01} mode waveguide on each arm of the array with a coupler at each antenna station. Phase shifting for fringe rotation and phase switching is included within the local oscillator system. There is also a monitor and control system through which all parts of the electronics are interfaced with the synchronous computer. A basic block diagram of the electronics is shown in Figure II-3.

The physical layout of the electronics is shown in Figure II-4. There are two racks in the vertex room of each antenna, rack A containing the front end and rack B containing local oscillator and IF equipment and the waveguide interfacing units which are referred to as modems. Rack C in the pedestal room contains antenna control equipment. In the electronics room of the Control Building there is one type D rack for each antenna. Equipment in this rack communicates with the corresponding B rack through the waveguide system, and local oscillator, IF, control and monitor signals are

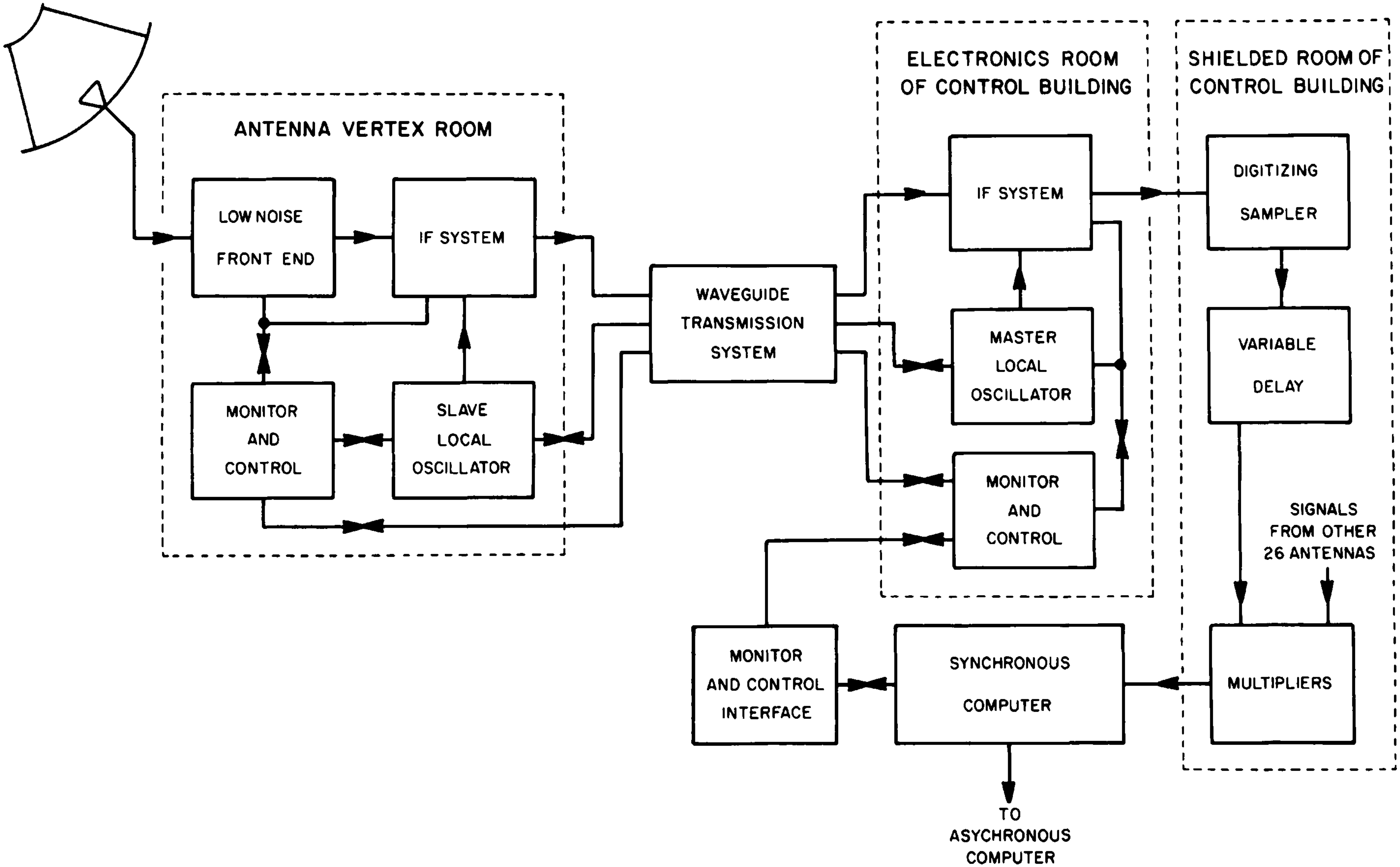

Figure II-3. Basic block diagram of the electronic receiving system. One device per antenna is required for all blocks shown except the master local oscillator, the synchronous computer and the monitor and control interface.

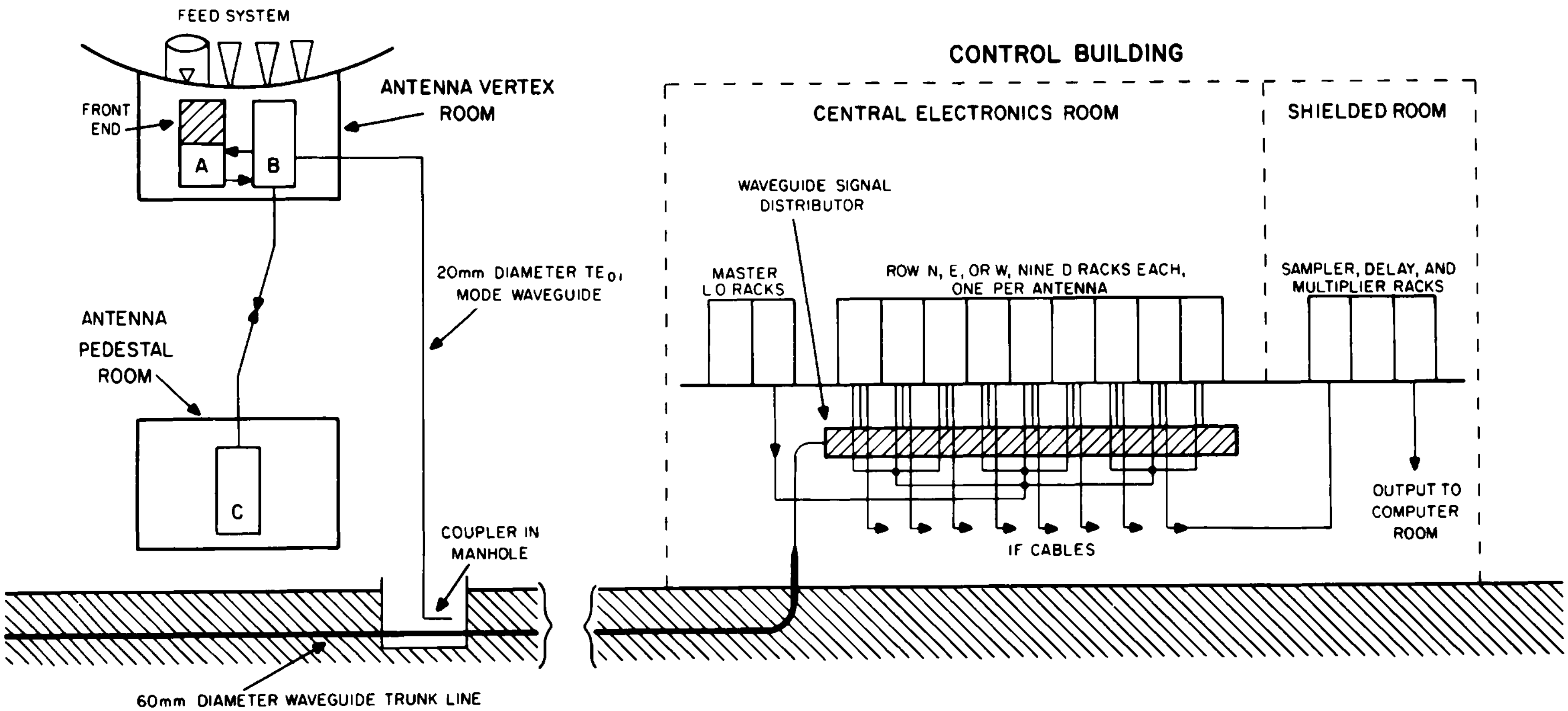

Figure II-4. Schematic diagram showing main locations of electronic equipment.

transmitted back and forth. The delay and multiplier equipment involves high speed digital circuitry and is located in a shielded room to eliminate possible radiation. Most of the electronics is built in modules designed for easy replacement for servicing.

Detailed documentation of the electronics is found in a series of VLA Technical Reports. Amongst these is a manual on each module which includes lists of all relevant drawings. Report No. 29 contains a description of the overall system, and sections (b) to (i) which follow are adapted from parts of it. There is also a series of VLA Electronics Memoranda which covers a range of subjects including performance requirements and related design specifications.

b. The front end

The front end is designed to cover four frequency bands of interest to radio astronomers and to achieve high sensitivity at a reasonable cost. A block diagram is shown in Figure II-5, and details of the input frequency bands are given in Table II-2. The four bands span a range of over four octaves from 1·34 to 24 GHz, and each one contains one of the frequency bands assigned to radio astronomy research.

VLA BAND	WAVELENGTH	RADIO ASTRONOMY BAND	ATOMIC AND MOLECULAR LINES
1340-1730 MHz (L)[1]	18-21 cm	1400-1427 MHz	Neutral Hydrogen 1420·4 MHz $HCONH_2$ (Formamide) 1538-1542 MHz OH 1612, 1665, 1667, 1721 MHz HCOOH (Formic Acid) 1639 MHz
4500-5000 MHz (C)	6 cm	4990-5000 MHz	$HCONH_2$ (Formamide) 4617-4620 MHz OH 4660, 4751, 4766 MHz H_2CO (Formaldehyde) 4830 MHz
14·4-15·4 GHz (U)	2 cm	15·35-15·40 GHz	H_2CO (Formaldehyde) 14·489 GHz
22·0-24·0 GHz (K)	1·3 cm	23·6-24·0 GHz	H_2O 22·235 GHz NH_3 (Amonia) 22·834-23·870 GHz

[1]Band designation letter used in the VLA

TABLE II-2: VLA OBSERVING BANDS

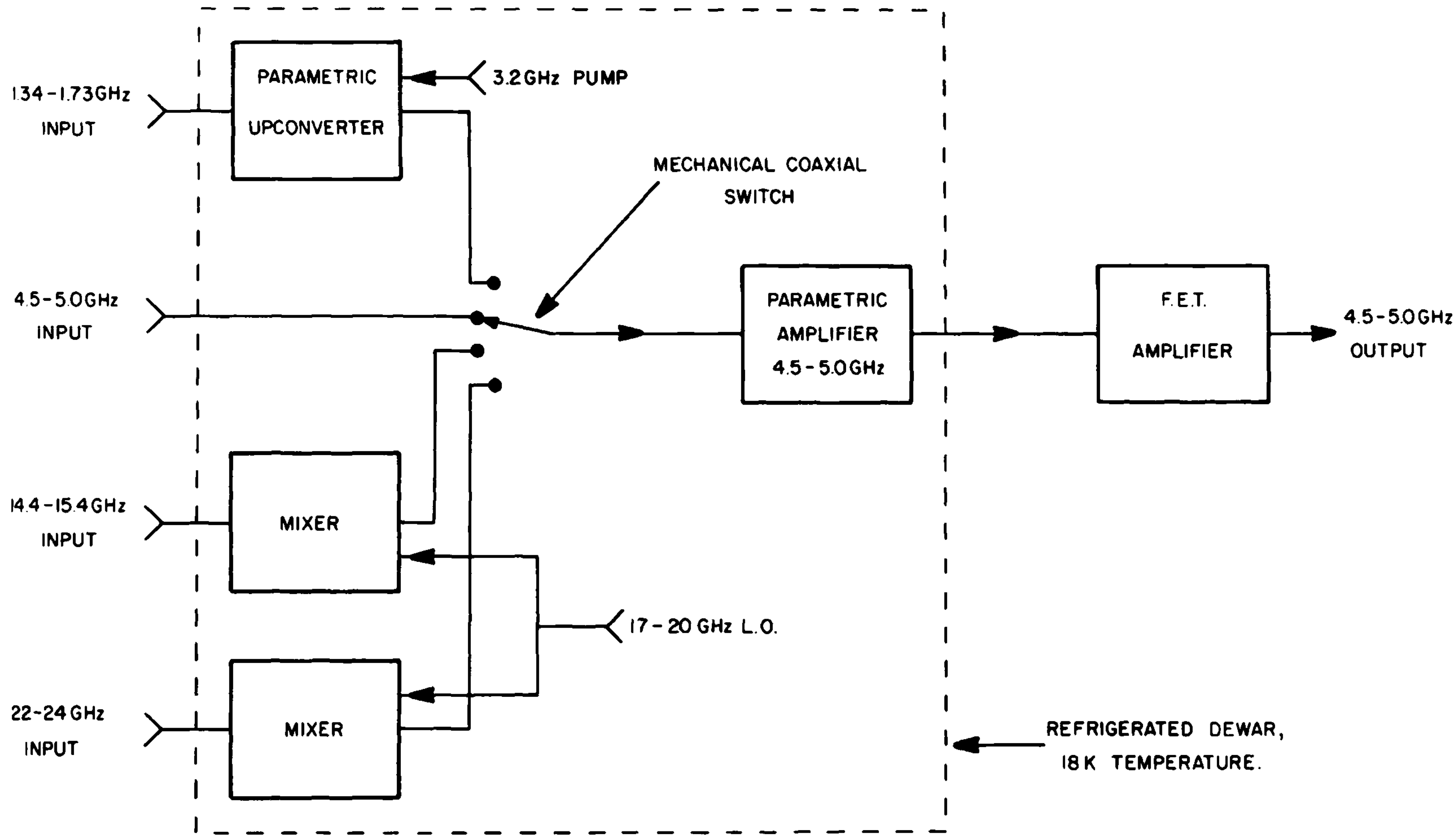

Figure II-5. Block diagram of the Front End. Two systems of the type shown, combined in the same Dewar, are used at each antenna to provide for two oppositely polarized outputs from each feed.

The basic component of the front end is a parametric amplifier with a frequency response of 4·5-5 GHz. When cooled to 18K it has an input noise temperature of about 25 K. The prototype amplifier used three cooled stages, but the third is being replaced by a room-temperature transistor amplifier with a Ga As F.E.T. input stage.

A latching coaxial switch allows the input of the parametric amplifier to be connected directly to the 4·5-5 GHz feed, through a parametric upconverter to the 1·34-1·73 GHz feed, or through cooled mixers to the 14·4-15·4 or 22-24 GHz feeds. The upconverter and the mixers are in the same 18K environment as the parametric amplifier. The parametric upconverter has a gain of approximately 3 dB and is an inherently low noise device. The upconverter uses a fixed frequency pump at 3·2 GHz and covers a 400 MHz band, with some tuning adjustment of the varactor bias and pump power. With the parametric amplifier as a second stage the input noise temperature of the upconverter is about 20K. The mixers for the 2 and 1·3 cm bands have input noise temperatures of 200 and 240K respectively. These figures apply to optimum performance at the band center and all of the noise temperature values given above increase by about 20% at the band edges except for the 1·3 cm band where the increase is nearer 40%. Details of the antenna performance and system temperatures are given in Table II-3.

WAVELENGTH	APERTURE EFFICIENCY	SYSTEM TEMPERATURE[1]
18-21 cm	50%	60K
6 cm	65%	60K
2 cm	54%	280K
1·3 cm	46%	320K

[1]Values given apply to the band center and increase at the band edges (see text).

TABLE II-3: ANTENNA EFFICIENCIES AND SYSTEM TEMPERATURES

Two systems of the type described above are used in each front end to accept the two oppositely polarized outputs from each feed. The polarization modes can be opposite circular or crossed linear, as described in Section 1-c.

The two sets of front end circuitry are both mounted in a single rectangular Dewar of exterior dimensions 12"x18"x18". They are cooled by a closed cycle helium refrigerator with a cold-station at approximately 18K and an intermediate temperature station at 60K which is used to cool a radiation shield around the cold-station components. A mechanical pump capable of reducing the pressure down to 10^{-4} mm of mercury is mounted with the Dewar. Cooldown, including pumping, takes about 8 hours, and repairs which involve opening a Dewar require at least 12 hours of down time. The Dewar is mounted in the upper part of the front end rack in the vertex room of the antenna, just below the feed mounting ring. The helium compressor for the refrigerator is located on the alidade platform of the antenna.

A description of the VLA front end has been published by Weinreb, Balister, Maas and Napier (1977)[1]. The outputs from the front end at 4·5-5·0 GHz go to the IF system.

c. <u>The waveguide transmission system</u>

The use of TE_{01} mode waveguide for the transmission between the antennas and the control building is an innovation which has a considerable impact upon the overall electronic design. To achieve sufficient bandwidth with cable for the VLA, frequencies up to one or two gigahertz would have to be used, and even with low-loss cable the attenuation would necessitate the use of repeater amplifiers about every km. These would add considerably to the cost and complexity of the system, especially since signals must be transmitted in both directions. A waveguide system using the TE_{01} mode is therefore a very attractive alternative since a bandwidth of

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[1]Weinreb, S., Balister, M., Maas, S. A., and Napier, P. J., <u>IEEE Trans. Microwave Theory Tech.</u>, to be published 1977 (April).

over 50 GHz is available with an attenuation of less than 1·5 dB per km and repeaters should not be necessary.

The TE_{01} mode waveguide takes the form of a circular pipe, and that used on the VLA has an internal diameter of 60 mm, far larger than the wavelength of the signals propagated down it. The very low loss depends on this large size to reduce wall conductivity losses. The low loss also depends upon the straightness of the waveguide as bends cause power to be converted to unwanted modes and absorbed. The waveguide must be pressurized with dry nitrogen to avoid the attenuation due to oxygen at frequencies above 50 GHz. A general description of TE_{01} mode waveguide is given by Miller (1954)[1].

In the VLA one trunk line of 60 mm diameter waveguide runs down each arm of the array. It is given a protective coating and directly buried at a depth of four to ten feet depending upon the level of the ground surface. The waveguide passes through a manhole at each antenna station and couplers are inserted at these points. For connection from the coupler to the vertex room of the antenna, waveguide of 20 mm internal diameter is used, since tighter bends can be tolerated in smaller waveguide. Flexible sections which can be bent to one meter radius and rotating joints are used in the 20 mm runs.

The signals transmitted along the waveguide lie in the 27-53 GHz range. Local oscillator and IF signals are amplitude modulated onto microwave carriers in modem units which incorporate Gunn diode oscillators and diode mixers working as modulators and demodulators. The same modems are used in both transmit and receive modes, and in the latter case the Gunn diode acts as a local oscillator. A different carrier frequency is used for each antenna on any given arm of the wye. At each antenna the modem connects to the TE_{01} mode waveguide by a rectangular to circular transition. At the control building the three trunk lines each terminate in a signal distributor unit which performs a demultiplexing function and

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[1]Miller, S. E., Bell System Tech. J., 33, 1209, 1954.

provides a separate output in rectangular waveguide for each of the channels. For every antenna there is a modem in the central building connected to one of these outputs.

The frequency band of the signals that must be transmitted in any one channel is sufficiently large that if both modulation sidebands were used the velocity dispersion between them would cause distortion in signals received after traversing a few kilometers of waveguide. Because of this, only one sideband is used in the signal transmission. To make the sidebands easily separable by filtering, all modulation signals lie in the range 1-2 GHz, and both the lower sideband and the carrier are removed by a filter in the output of the modem.

The spectrum of the signals which are modulated onto each carrier of the waveguide transmission system is shown in Figure II-6. Signals transmitted out to the antennas are oscillator reference signals at 1200 and 1800 MHz, with 5 MHz reference amplitude modulated onto the former and digital control signals modulated onto the latter. The same signals are transmitted back from the antennas with monitor data replacing the control signals and with the addition of four 50 MHz-wide IF bands centered at 1325, 1425, 1575 and 1675 MHz. The 1200 and 1800 MHz signals are used in converting the required IF signals to base band, and the phases of the transmitted signals are therefore independent of the phase stability of the carrier-frequency oscillators in the modems. The power levels transmitted from the modems are -2 or -8 dBm for the 1200 and 1800 MHz signals, depending on the direction, and -6 dBm for each IF band. The total loss between the modem at each antenna and the corresponding one in the control building is adjusted to be 40-56 dB in all cases.

To eliminate phase errors resulting from variation in the electrical path length of the waveguide, the 600 MHz signal transmitted back from the antenna (as the difference between the 1200 MHz and 1800 MHz signals) is compared in phase with the 600 MHz that is transmitted out. Variations in the round-trip path length to each antenna are thereby monitored and can be allowed for. The outgoing and incoming signals for any antenna must travel at the same frequency in the waveguide to avoid errors in the round-trip measurement that could result from small reflections in the transmission system. It is therefore not possible to separate incoming and outgoing signals by a frequency difference, and a time multiplexing scheme is used. The received signals are transmitted back from the antennas for 51 ms out of every 52 ms and the local oscillator reference signals are transmitted out to the antennas during the remaining 1 ms. These figures are approximate and the exact frequency of the transmit-receive cycles is 19·2 Hz. This timing sequence has widespread effects on the design of the electronics system.

A description of the waveguide system has been published by Weinreb, Predmore, Ogai and Parrish (1976)[1].

d. The oscillator system

The oscillator system provides a series of frequencies at each antenna that are phase locked to a master oscillator at the control building. From these the various local oscillator signals required for frequency conversion of the received signals are synthesized. The system also contains provision for measuring the phase variation resulting from changes in the electrical path length of the waveguide so that compensation for this can be made in the computer. The system is designed to give an rms phase error of not more than one degree per gigahertz at the observing frequency between corresponding signals at any pair of antennas[2]. With this criterion, atmospheric effects should dominate the phase stability of the array except at

[1] Weinreb, S., Predmore, C. R., Ogai, M., and Parrish, A., Proc. of the IEE Conference on Millimetric Waveguide Systems, London, Nov. 9-12, 1976, p. 245. Also published in Microwave Journal, 20, 49, 1977 (March).

[2] This design goal is not achieved by the electronics available for observations during 1977, but will be after changes that are implemented in early 1978.

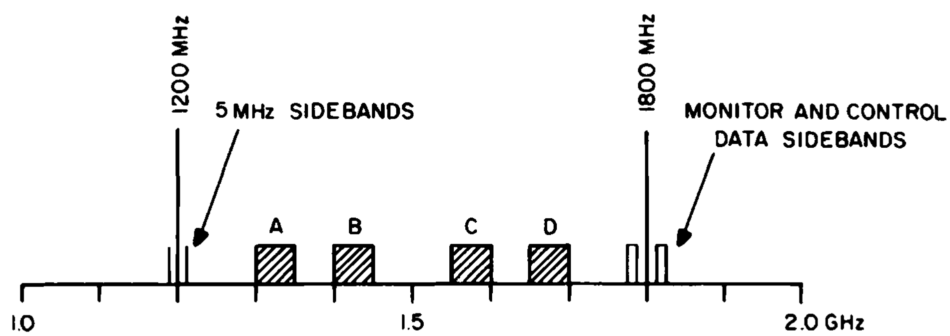

Figure II-6. The spectrum of the modulation in the waveguide transmission system. The IF signals A, B, C and D are present in transmission from the antennas only, but the other signals travel in both directions.

the shortest spacings.

It is necessary to phase lock an oscillator at the antenna to a reference signal at the same frequency received over the waveguide transmission system. The reference signal appears for intervals of approximately 1 ms at a 19·2 Hz rate, and because of this a conventional phase lock circuit can lock the oscillator not only at the desired reference frequency but also at integral multiples of 19·2 Hz away from it. The unwanted lock frequencies occur because the relative phase of the oscillator and the reference changes by an integral multiple of 2π radians between reference samples, and thus to the phase detector the two signals appear to remain in phase. To avoid such undesirable offsets the oscillator at the antenna is a high stability crystal that cannot depart from its nominal value of 5 MHz by more than a fraction of one Hz. The required local oscillator frequencies are then generated by synthesis techniques, but to prevent phase ambiguities frequency division is generally avoided and most frequencies are multiples of 5 MHz. This permits a fine enough tuning interval at the antennas.

The accuracy with which the phase of the 5 MHz oscillator can be controlled depends upon the signal to noise ratio of the reference frequency. An effective improvement of almost 42 dB can be obtained by using a reference of 600 MHz instead of 5 MHz, and comparing this with 600 MHz generated by frequency multiplication from the 5 MHz oscillator. This is the adopted scheme, as shown in the block diagram of the oscillator system in Figure II-7. At the antennas signals are received at both 5 and 600 MHz, the former from the modulation on the 1200 MHz signal and the latter from the frequency difference between the 1200 and 1800 MHz signals. Locking only on the 600 MHz signal would result in phase ambiguities at intervals of 3° in the 5 MHz oscillator. A phase comparison is therefore made at 5 MHz also, and the loop is first closed using the output of the 5 MHz phase detector. When the 5 MHz phase error

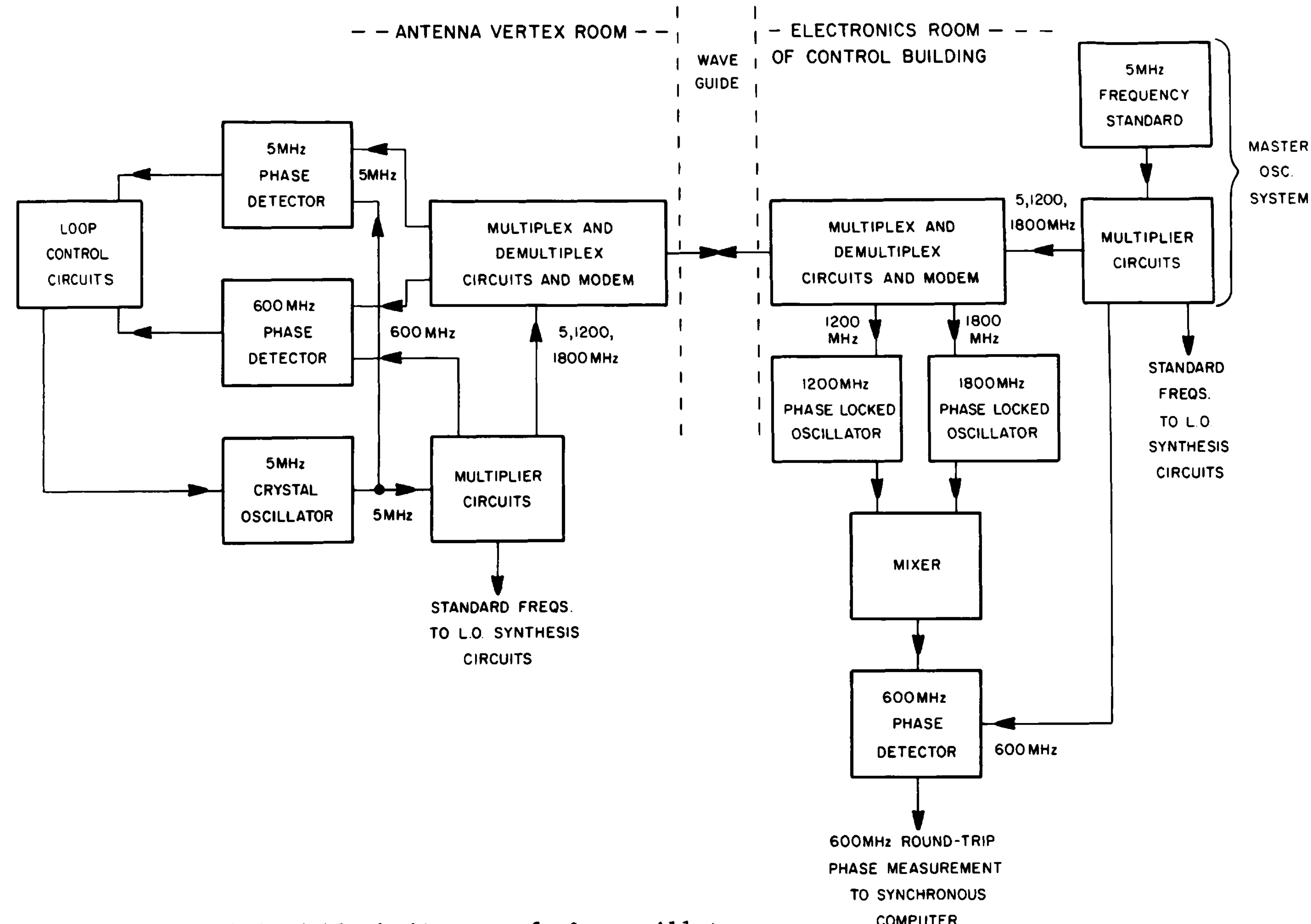

Figure II-7. Simplified block diagram of the oscillator system. Except for the two Master Oscillator blocks, each antenna requires a separate system of the type shown.

is less than 1°, control is switched over to the 600 MHz phase detector, and can be returned if the 5 MHz phase error becomes too large.

To monitor the effects of variations in the electrical length of the waveguide the 5 and 600 MHz signals are transmitted back to the control building in the same way in which they are sent out. At the control building locked oscillators at 1200 and 1800 MHz remove the noise and sidebands on the received signals, and the 600 MHz difference frequency is derived and compared with 600 MHz from the master oscillator in a phase detector. The output of the phase detector goes to the synchronous computer.

To receive signals at any frequency within the front end passbands using 50 MHz-wide IF bands the local oscillator must be tunable in steps of 50 MHz or less. This is achieved by the use of a 2-4 GHz YIG-tuned oscillator that is phase locked to harmonics of 50 MHz with a 10·1 MHz IF offset in the loop. This allows tuning steps at alternate intervals of 20·2 and 29·8 MHz. In addition the local oscillator that converts signals in the 2 and 1·3 cm bands to the input frequency of the parametric amplifier is tunable in alternate 100 MHz and 200 MHz increments. At the control building, local oscillator signals for the final frequency conversions are tunable in 2 Hz steps. These are derived from frequency synthesizers in the master oscillator system and are distributed through a branching cable network to each of the 27 racks that receive the signals from the antennas.

The transmit/receive cycle at each antenna is synchronized to that at the control building by detecting the rising edge of the received 1200 MHz reference signal.

Units known as Fringe Generators introduce continuous phase changes in the phase lock loop of the 2-4 GHz oscillators mentioned earlier; the initial phase and rate of change of phase are set by commands from the computer, which updates them every 1.25 seconds.

The Fringe Generator also introduces 180° phase reversals so that phase switching can be used to eliminate offsets in the outputs of the signal multipliers. The switching sequences take the form of Walsh functions generated by the synchronous computer, and with this scheme orthogonal switching functions are obtained for all antenna pairs without the requirement of very high switching rates.

e. The IF system

For signals received in the 18-21, 2 and 1·3 cm bands the parametric amplifier acts as the first IF amplifier, but this section is concerned with the IF channels from the output of the front ends to the digital samplers. Four signal bands[1], each 50 MHz wide, are selected from the front end outputs at each antenna. They are converted several times to different intermediate frequencies before arriving at the digital samplers. Fifty megahertz is the maximum bandwidth of each channel, and additional filters to decrease the bandwidth can be switched in at the final IF amplifiers in the control building. The narrower bandwidths are used to match the system response to the assigned radio astronomy bands, to improve the selectivity when working outside these bands, to increase the field of view at long spacings, and for spectral line observations. A block diagram showing all of the IF stages and frequency conversions is shown in Figure II-8.

The four channels are designated A, B, C and D, and channels A and B come from the parametric amplifier for one polarization and channels C and D from the other[1]. The two polarization outputs can be interchanged between the AB and CD channel pairs by a transfer switch, and this facility is helpful in testing and in reducing instrumental effects. The four channels are then converted to center frequencies of 1325, 1425, 1575 and 1675 MHz respectively. Filters at these frequencies pass the full 50 MHz bandwidth. The signals then go to the modems and travel down the waveguide at

[1]During 1977 and 1978 only 2 channels, A and C, will be available.

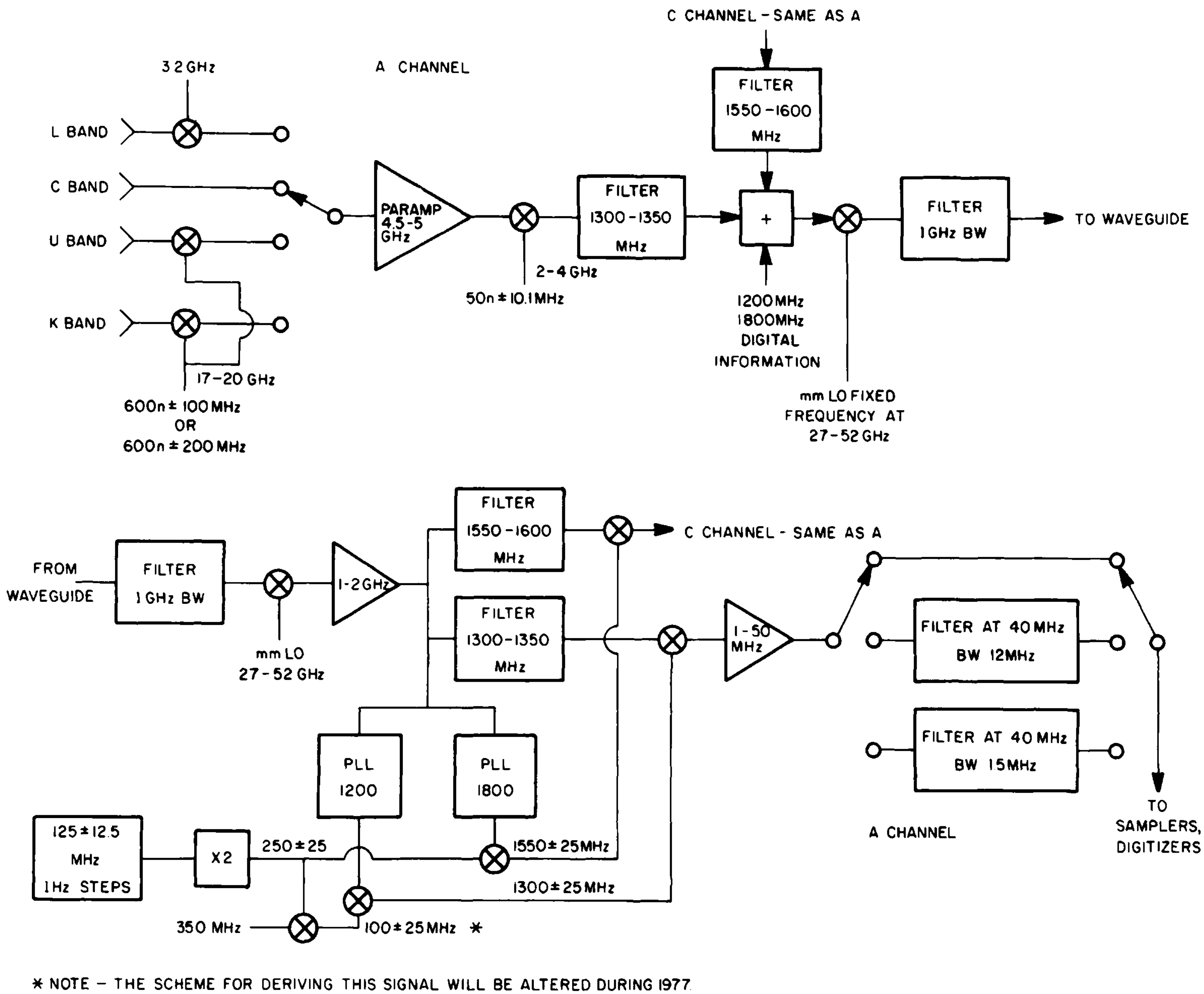

Figure II-8. Block diagram showing signal paths through the system and local oscillator signals used in frequency conversions (1977 system).

frequencies equal to the intermediate frequency (1325 MHz, etc.) plus the carrier frequency for the particular waveguide channel. From the modems at the control building the signals emerge at 1325, 1425, 1575 and 1675 MHz again. They are then converted to a base band of 1-50 MHz by local oscillators tunable in 2 Hz steps. A series of narrow band filters can be inserted under computer control into the 1-50 MHz IF amplifiers. Details of bandwidths and center frequencies are given in Table II-4.

Two automatic level control loops are included in each signal path. One at the antenna controls the level at the modem and one at the control building controls the level in the sampler. At the antenna there is also a square law detector and a synchronous detector for each channel, for use in single-antenna observations and calibration measurements with switched noise sources.

f. The digitizing samplers and the delay and multiplier system

The signals from the IF system are converted to digital form with three level quantization in the sampler modules, so that they can be processed by a digital delay and multiplier system. The sampling rate used for the 50 MHz bandwidth is 100 MHz which is close to the maximum frequency that can be comfortably handled by e.c.l. (emitter coupled logic) circuitry. This last point was a consideration in choosing the 50 MHz IF bandwidths.

Cooper (1970)[1] has shown that the signal to noise ratio obtainable in multiplication of three level quantized signals is 81% of that for a corresponding analog system, compared with 88% for full two-bit quantization and 64% for one-bit quantization. Three level quantization can also be regarded, as Cooper did, as two-bit quantization with a modified multiplication table in which all but the high level products are replaced by zero. This scheme is used in the VLA because the multiplication and integration logic is then much less complicated than that required for two-bit, four level quantization.

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[1]Cooper, B. F. C., Aust. J. Phys., 23, 521, 1970.

Bandwidth	Center Frequency
50 MHz	25 MHz (low pass)
12 "	40 " (band pass)
1·5 "	40 " "

TABLE II-4: BANDWIDTHS AND CENTER FREQUENCIES OF THE FINAL IF STAGES (PROTOTYPE SYSTEM)

A block diagram of the sampler is shown in Figure II-9(a). A quadrature network which is accurate over the full 1-50 MHz frequency response is used to generate two versions of the signal in which all frequencies differ by $\pi/2$ in phase. These are referred to as the cosine and sine components, and they go to separate sampling circuits. In the sampling the signals are compared with d.c. levels of $\pm 0.612\sigma$ where σ is the rms signal level. Two bits are then generated, as indicated in Figure II-9(b). The rms signal level must be maintained at the required value relative to the reference levels, and an a.l.c. loop is used in which the signal level is measured in the sampler unit and a control voltage is fed back to an attenuator in the final IF amplifier.

A simplified block diagram of the delay and multiplier system is shown in Figure II-9(c). The delay system operates in 10 ns increments controlled by the 100 MHz clock. To provide for smaller increments in the delay the phase of the clock in each sampler module can be shifted in increments of 625 ps which is 1/16 of a clock period.[1] The output bit streams from the samplers are then resynchronized with the standard 100 MHz clock before going on to the main part of the delay system.

The synchronous detection for the phase switching scheme is also implemented in the sampler modules. The same Walsh functions that control the phase switching at the antennas are also fed to the samplers and used to reverse the sign information in the output bits. Note that in systems with analog multipliers the synchronous detection must be done at the multiplier outputs, but, being digital, the delay and multiplier circuitry used here does not generate spurious offsets.

The output of each sampler module consists of four bit streams with a 100 MHz clock rate. These data go to the delay system where they are initially processed by e.c.l. circuitry and then, for economy, each 100 MHz stream is translated into sixteen 6·25 MHz

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[1]The delay increment is 1/32 of the reciprocal of the maximum signal bandwidth. This is more than sufficient to prevent significant loss of correlation, but the minimization of phase errors provides a more stringent criterion.

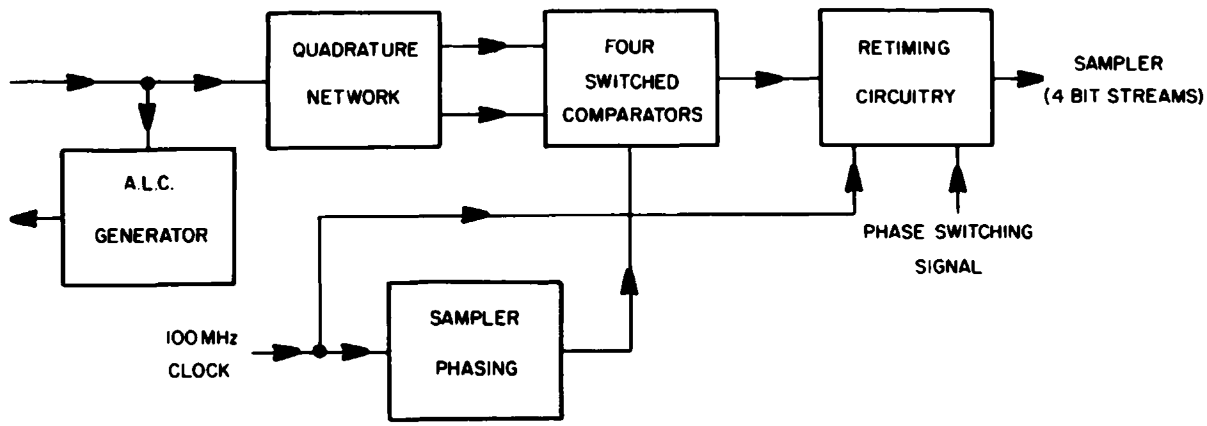

Figure II-9(a). A sampler unit.

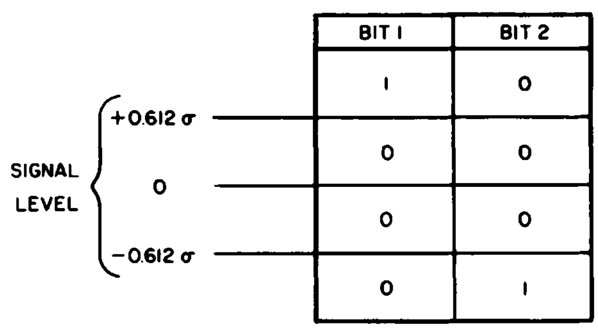

Figure II-9(b). Bit coding for signal levels in the samplers. σ is the r.m.s. signal level.

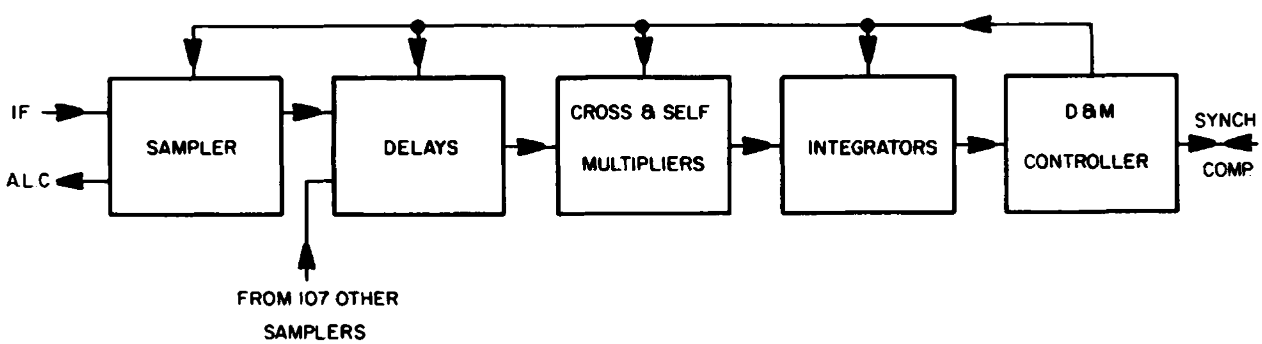

Figure II-9(c). The Delay and Multiplier system. Communication with the synchronous computer is through a special controller as data rates are too high for the general Monitor and Control system.

and 512 bit capacity. The range of variability of the delay is 164μs and the bit streams emerge from the delay system combined to their original state with a clock frequency back at 100 MHz. The delay values are set by the synchronous computer through an interface unit, the delay and multiplier controller, which also displays monitor data on the delay and multiplier system.

The multipliers operate at the 100 MHz frequency and the products have values -1, 0 or +1 but are counted as 0, 1 or 2 respectively. This enables unidirectional counters to be used for integration, and correction is made in the delay and multiplier controller by subtracting the number of multiplications involved. The integrated products are transferred to the controller every 52 ms (the cycle period of the waveguide transmission) and can then be further integrated for periods up to 312 ms before being transferred to the computer.

Sixteen multipliers are used for each antenna pair. For any two signals both sine x sine and sine x cosine products are formed, and these represent the real and imaginary parts of the visibility[1]. For polarization measurements four signal products are required: LL, RR, LR and RL, where L and R represent two signals at the same frequency but with opposite polarizations such as left and right circular. Finally, four IF channels allow polarization measurements to be made at two frequencies. For 27 antennas a total 16 x 351 = 5616 multipliers would be required, but the system described here is being implemented for preliminary operation with a maximum of 12 antennas only, and will be replaced by a more complex system with spectral line capability for operation with the full array.

In addition to the multipliers described above, which perform cross multiplication between two signals, the system includes eight multipliers per antenna which are referred to as self multipliers. Each sine or cosine signal component is fed to both inputs of one of these and the output gives a measure of the accuracy with which the

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[1] Some people prefer to count the two multipliers for sine x sine and sine x cosine as one complex multiplier.

signal level is set relative to the reference levels in the corresponding sampler. The output of each cross multiplier is divided in the computer by the mean of the outputs of the corresponding self multipliers. This reduces by a factor of approximately 10 the sensitivity of the visibility data to the signal levels in the samplers, and with the aid of this procedure the a.l.c. loops provide adequate level control.

g. The monitor and control system

The monitor and control system distributes control signals from the synchronous computer to all parts of the array and gathers monitor data which are fed to the computer. Examples of control data are antenna pointing commands, fringe generator parameters, and synthesizer frequency-selection commands. Examples of monitor data are power supply voltages, signal levels, and readback of some commands to check for correct transmission. Most of the monitor data are concerned with how the electronics is operating, but some, such as the detector outputs described in Section 2-i, are directly required in the visibility data reduction. The monitor and control system is sometimes referred to as the digital communication system (d.c.s.).

Commands from the synchronous computer system are accepted by the monitor and control system, which adds parity bits, distributes the command to the appropriate antenna, encodes it for transmission through the waveguide, and sends it to the device specified by the address. Data are handled in the form of 45 bit words which contain 24 bits of command or monitor data, 16 bits of address information and 5 parity bits. The parts of the monitor and control system that interface with other units of the electronics are called data sets. Two data sets are located in the vertex room, one in each equipment rack there. In the pedestal room there is a third data set used for the subreflector control, and the antenna control unit which is much the same sort of device. There is another data set in each D rack, for each antenna, in the control building.

The flow of monitor data is essentially similar to that described above, but in the reverse direction. For each antenna the five data sets provide the capacity for up to 240 different 24-bit digital commands, 320 24-bit monitor words and 640 analog monitor voltages, not including the antenna pointing commands. Only about 25% of this capacity is used by the present receiving system.

For transmission down the waveguide, data are converted to a biphase M code and amplitude modulated onto the 1800 MHz signal. Transmission in the two directions in the waveguide follows the 19·2 Hz sequence described in Section c.

h. <u>Determining observing frequencies and bandwidths</u>

Because of the number of frequency changes in the IF transmission path, and the fact that three of the local oscillator signals are tunable in discrete steps, determination of the center frequency of the signal band is rather complicated. The sequence of frequency conversions and bandwidth limiting elements is shown in Figure II-8 and in simplified form in Figure II-10. The frequency response of the system is limited at two points. The first is at the antennas where filters of bandwidth 60 MHz[1] centered on 1325, 1425, 1575 and 1675 MHz are introduced. The second point is in the final IF stages in the control building. Generally the final IF response will dominate, but in some cases it may be necessary to consider the combined response.

The center frequency of the signal band, as limited at the antennas, is given by

$$f_{signal} = \pm f_1 \pm \left[f_2 + f_{filter}\right] \qquad (1)$$

[1]60 MHz at -3 dB points gives 50 MHz at -1 dB.

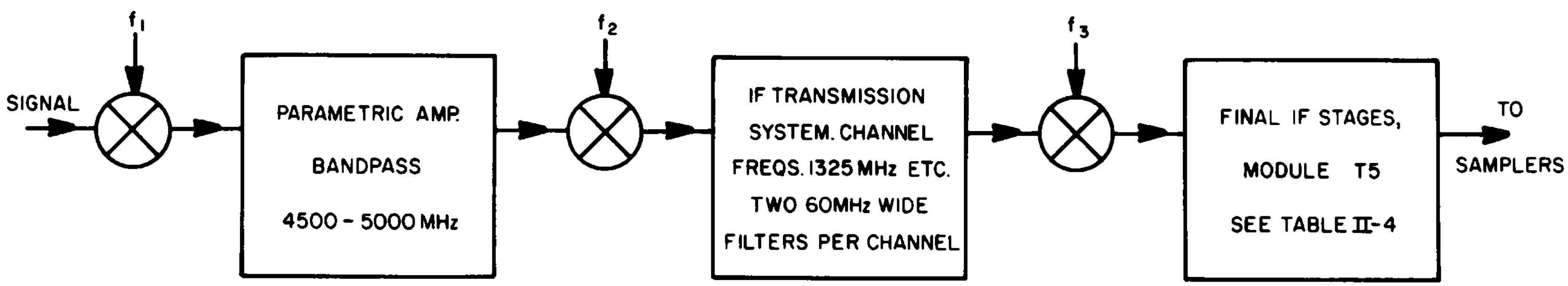

Figure II-10. Schematic diagram of a signal showing frequency conversions and bandpass limiting elements.

where f_1 and f_2 are defined below and f_{filter} is 1325, 1425, 1575 or 1675 MHz depending on the IF band.

The center frequency of the signal band, as limited by the final IF stages, is given by

$$f_{signal} = \pm f_1 \pm [f_2 - f_3 + f_{IF}] \tag{2}$$

<u>First ± sign</u> The first ± sign in equations (1) and (2) is - for the 18-21 cm band and + for all other cases.

<u>f_1</u> f_1 is the frequency of the first local oscillator. For the 18-21 cm band it is the upconverter pump frequency of 3200 MHz. For the 6 cm band it is zero since there is no frequency conversion in front of the parametric amplifier. For the 2 and 1·3 cm bands it is the frequency of the 17-20 GHz local oscillator which is discretely tunable as follows:

$$f_1 = m \times 600 \pm n \times 100 \text{ MHz},$$

where m is an integer and n is 1 or 2.

<u>Second ± sign</u> The second ± sign in equations (1) and (2) is - for the 2 cm band and + for all other cases.

<u>f_2</u> f_2 is the frequency of the 2-4 GHz synthesizer module. It is given by

$$f_2 = 2400 + N \times 50 \pm 10{\cdot}1 \text{ MHz},$$

N being an integer. For details see the manual on L6. Two of these units, which are independently tunable, are used at each antenna. One is for channels A and C, and one for B and D.

$\underline{f_3}$ f_3 represents the frequencies used to convert the bands at 1325 MHz, etc., down to the 0-50 MHz band. Tunability in 2 Hz steps is possible using four frequency synthesizers (Fluke model No. 6160B) in the master local oscillator. Two modes of operation are provided.

<u>Independent Tuning Mode</u>

$$f_3 = 1200 + f_{SA} \text{ MHz, channel A}$$
$$= 1200 + 2\, f_{SB} \text{ MHz, channel B}$$
$$= 1800 - 2\, f_{SC} \text{ MHz, channel C}$$
$$= 1800 - f_{SD} \text{ MHz, channel D}$$

f_{SA}, f_{SB}, f_{SC}, f_{SD} are the frequencies of the four synthesizers, which are independently tunable in 1 Hz steps.

<u>Polarization Mode</u>

For polarization observations correlation must be preserved between channels A and C and between channels B and D. In this case the synthesizers for channels A and C and for channels B and D are phase locked to maintain the following conditions:

$$f_{SA} + 2\, f_{SC} = 350 \text{ MHz}$$
$$2\, f_{SB} + f_{SD} = 350 \text{ MHz}$$

$\underline{f_{IF}}$ f_{IF} is the center frequency of the IF amplifier at the control building. The center frequency for each bandwidth is given in Table II-4.

Local oscillator frequencies must, of course, be chosen so that the signal band falls within all the pass bands shown in Figure II-10 Selection of oscillator frequencies and bandwidths is accomplished through the synchronous computer and the monitor and control system.

i. Built-in calibration

A gain calibration scheme using switched noise sources is incorporated into the electronic system. The noise sources are usually gated on and off during alternate cycles of the 19·2 Hz transmission system; i.e., they are modulated with a squarewave of frequency 9·6 Hz. Noise sources are provided for all four wavelength bands, and separate sources are used for the two opposite polarization inputs. The noise power is injected through directional couplers and levels are generally set to be 2-10% of the system temperature.

A power law detector in the frequency converter module provides measurements of power levels which are recorded by the synchronous computer through the monitor and control system. Two measurements are provided for each channel. The first uses a synchronous detector to measure the difference in levels between the on and off conditions of the noise source, and is referred to as the synchronous detector output. The second uses a gating circuit to measure the power level when the noise source is off, and is referred to as the gated total power output. The synchronous detector output is proportional to the injected noise level (which can be assumed to be constant) and the channel gain. The gated total power output is proportional to the system noise temperature and the channel gain. The two levels thus provide a means of calibrating changes in system temperature, which varies with antenna elevation, etc., and the corresponding gain changes produced by the a.l.c. circuits. The synchronous detector and gating circuits are also located in the frequency converter and further details on them can be found in the manual on that module.

3. The Modcomp Computer System

a. Distribution of tasks in CPU's

The Modcomp computer system consists of four computers. The computer which does all of the source list management, decides the antenna configuration, and generally manages the observing has the nickname 'Boss'. His peripheral devices are the magnetic tapes and disk units. In addition, two of the CRT terminals are logically, but not physically, connected to Boss. In addition to his management functions (which include the 'ten second' tasks described below), Boss also runs some informational services -- the real-time lister and scan averager reside in him.

The computer which runs the array communications is called 'Monty' (because he runs the monitor services). He handles the digital communication system. He generates commands and sees that they are sent at the proper time. He receives data from the monitor system and interprets its address to generate a digital image of the VLA; any point monitored in the electronics is represented by a number in the computer core, giving its current voltage. Monty also generates averages or max/min values for any monitor point, if asked to do so (by a recompilation of a program). The flagging program, CHK, which sets a flag word in the data to an error level of zero to four (depending on the seriousness of the condition -- see the operators for current definitions) according to values reported by the monitor system, also runs in Monty. Monty's peripherals are the unit record devices -- the terminals, the printer, and the card reader.

Eventually there will be two computers to handle correlator data. With the relatively small number of antennas presently operating, only one is needed. Her name is 'Cora'. The second correlator handling computer is now used for program development and source list preparation when the main system is observing or otherwise engaged. His name is 'Corbin'.

There are several programs that run in the Modcomp computers to process the command information to be sent to the receivers. There are three which will concern us here. They are NEW, G10, and GEORGE. NEW is the new-source program, and is called once for each observation request, typically every few minutes. It currently requires about 20 seconds to run, mostly waiting for completion of data transmission of commands to antennas. It is anticipated that this run-time will remain constant -- the addition of antennas to the system will be offset by efficiencies which we shall introduce into the program. NEW is responsible for the setting of local oscillator frequencies, setting the front-end control switches, precession of the source coordinates, and lookup of phase and gain settings appropriate for the band and antenna.

G10 runs every 10 seconds and calculates initial values and rates for phases, delays, and pointing commands. It also takes the data which has been reduced by the correlator computer and writes it on magnetic tape and on a disk data area.

GEORGE runs every 52 1/12 milliseconds, that is, every waveguide transmit/receive cycle. It takes the initial values and rates calculated by G10 and makes up the actual commands which are sent, via the digital communication system, to the antennas. A pointing command, either azimuth or elevation, is sent to each antenna each cycle, so that the commanded position is updated about every 0.1 second. A new phase, phase rate, and phase reversal command is sent to each antenna each 1.25 seconds. A new set of delays and phase reversal commands are sent to the delay multiplier system every 52 milliseconds.

b. <u>Ephemeris calculations</u>

The operations generally grouped under this heading include general precession, nutation, aberration, and gravitational light bending. The last named effect is not included at this writing, but probably will be during 1977. In addition to these calculations, we shall discuss, in this section calculations of a similar nature for sidereal time, corrections to baselines, and the calculation of refraction. Those interested in greater detail about the precession process may refer to VLA Computer Memorandum 105.

General precession is implemented by the formula given in the Explanatory Supplement to the American Ephemeris (hereafter called ES). It is presumed that the epoch given is in Besselian years. Nutation is calculated from the table of constants given in the ES. Aberration is calculated for the Ephemeris by numerical differentiation of the position of the sun, a procedure impractical for an online program. The program instead takes a sufficient number of terms from Newcomb's Tables of the Sun, and calculates the velocity by summing algebraic derivitives.[1]

Coordinates may be entered in 1950 coordinates, coordinates of date, or coordinates of any integer Besselian year. Solar system objects may be tracked by specifying an initial position and rate of change (the rate of change is assumed to be in RA, DEC of date). The program does not currently calculate parallax corrections.

It is anticipated that we shall implement precession, etc., using the constants adopted by the IAU General Assembly of 1976. It is our intention to utilize these constants for equator and equinox 2000 positions only. We shall expect to implement these changes only as the elucidations appear in the Papers of the American Ephemeris, so it is unlikely that they will be implemented in 1977.

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

The positions calculated by these programs have, for the standard case of 1950 initial epoch, been carefully compared with positions derived by means of the tabulated Besselian day numbers, with agreement to about 0.002 seconds of arc.

The sidereal time is calculated from UT1 by the formulae in

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[1]Atkinson, R. d'E., AJ 77, 518, 1972

the ES, with an assumed longitude of the array center of $107^{\circ}37'03''.800$. Derivation of UT1 is somewhat more difficult. To avoid difficulties with the leap second, the fundamental time of the VLA is IAT, which is a continuous time incremented at the rate of one second per SI second. When we receive a new copy of the publications of the USNO, Series 7, we 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. NEW proceeds to apply this formula for the estimation of UT1. These extrapolations frequently differ from the BIH quick service post facto evaluations of time by 10 ms. Only if the observer is interested in astrometry, proper motions, or combination of maps at different epochs need he apply further corrections to the extrapolated time. No correction is applied for the forced nutation of the earth (about 1 ms). It is expected that this correction will be implemented when the other recommendations of the IAU General Assembly of 1976 are incorporated.

The baselines are taken from input card images. Eventually these will be generated in a semiautomatic fashion by the DEC-10 computer system. However, the expectation for 1977 is that the solution must be made on demand and that the resulting numbers must be entered in the Modcomp system card images through a computer terminal. The 'baseline parameters' are not really baselines, but are really antenna locations. They are entered in nanoseconds in a topocentric coordinate system with the z axis pointing to the NCP, the x axis to the meridian and equator, and the y axis east. Provision is also made for entering a term arising from the fact that the azimuth and elevation axes of the telescope do not precisely intersect. The axis intersection defect has not yet been determined because of the various elevation dependent phase terms which will probably be controlled during 1977. It is believed to be quite small.

Baselines as read are corrected for the effects of Earth tides by the formulae of VLA Computer Memorandum 105. They, also, are not corrected for the forced nutation term. It is anticipated that during 1977, this program section will be revised to use a more lucid, and probably more correct, derivation by C. Wade.

NEW also handles some elementary refraction calculations. Atmospheric refractivity enters in three places. First, the pointing of the antenna must be corrected; the antenna must be pointed higher than it would be in the absence of an atmosphere by (N-1)*tan z radians, where N is the index of refraction and z is the zenith distance. The third order term, proportional to the cube of tan z, can become important (>6") at elevations below 10 degrees, but is not taken into account in the calculations as implemented. Second, there is a correction to the phase of a wave arriving at any antenna proportional to (N-1)*H*sec z, where H is the height of the antenna above a reference datum. Third, there is a correction to be made for the sphericity of the earth's atmosphere. The approximation made to this term is that it arises entirely from the effect that the source is higher in elevation at one antenna than at the other. If we make the further assumption that the gross contribution of the atmosphere to the phase path is proportional to the zenith phase path times secant of zenith distance, and expand the Taylor series, this gives rise to an additional phase 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 scale height. The coefficients for these three terms -- refractivity and atmospheric contribution to zenith phase path -- are calculated by NEW, and the actual application of these terms, involving secant z, is done every ten seconds by G10.

Refractivity may be calculated from the temperature, dewpoint, and barometric pressure measured with a weather station, which will shortly be moved to a location about 100 meters north of the control building, near the center of the array. In order to take into account the possible breakdown of the weather station, provision is made to use, instead, typical values for the weather variables. The latter mode has, until now been the standard one. Changeover to the actual weather station is expected by April, 1977. The 'typical values' include a mean temperature of 8 degrees C, a sinusoidal seasonal variation in temperature of amplitude 12 C, with maximum about August 1, and a sinusoidal daily variation with amplitude 12 C, and a maximum at about 1300 MST. Dewpoint is taken to be 10 C less than ambient temperature (about 35% relative humidity), and pressure 750 mBars.

c. Calculation of phase commands

The Modcomp programs are written so that the existing antennas may be subdivided into subarrays, which operate quite independently, and may be observing different sources at different bands and different bandwidths, within the restrictions imposed by hardware used in common. At the moment, there is provision for two independent subarrays. The number can be expanded up to five by recompilation of a single program. All correlator information from baselines between antennas in different subarrays is discarded at a very early stage of processing. It should be construed in the following (and preceding) material that all source-dependent calculations are repeated for each subarray as appropriate.

The task G10 takes information provided by NEW and proceeds to develop starting values of phase and rate for each fringe rotator. It takes a 'sidereal time at midnight IAT' developed by NEW and a rate of change of sidereal time, and calculates the sidereal time for the beginning of the next ten second interval. Then, it takes the source position (referenced to midnight) and applies the correction for the motion of the source, either as specified by the observer or as due to the change in nutation and aberration since midnight. A further correction is made for diurnal aberration. The correction for retarded baseline[1] is not currently applied but will probably be installed in 1977. (The retarded baseline correction is identical to the diurnal aberration correction if the antenna positions are transformed relativistically into a geocentric coordinate system, but an additional term dependent on square of baseline length is required in the topocentric development used here.)

Having developed the source position, and in particular, the source position in the rectangular topocentric coordinate system in which the antenna positions are expressed, G10 calculates, for each antenna, the geometric delay of the waves falling on it. This is further modified by the refraction corrections discussed above. This, then, is the starting phase for the next ten second interval. The phase rate is calculated (u*cos dec), and is modified for the rate induced by the motion of the source. The second derivative of phase is also calculated. These numbers are, at this point converted from delay to wavelengths by multiplication by the L.O. frequencies, kept separately 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 by G10. A 'peculiar phase', different for each synthesizer, is added (the intention is to use this card specified number to make the output phases zero in real time, so that the observer will eventually see calibrated phases as output from the Modcomp computer system). The phase is further corrected according to the measured 600 MHz round-trip phase to the antenna. These phases and rates are then formulated into commands suitable for the fringe rotators, and are dispatched to the antenna. Also going with them 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 for one 52 millisecond waveguide cycle. Because of the

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[1]Cohen, M. H. and Shaffer, D. B., AJ 76, 91, 1971

orthogonality of the walsh functions, any DC offsets in the system -- self interference or digitizer offsets -- will be canceled out on integration times of multiples of 32 waveguide cycles -- 3 1/3 seconds. This also suppresses any other instrumental effects which vary on time scales much greater than 3 seconds.

Using the starting delay and delay rate, GEORGE also calculates, every 52 ms, the geometric delay for a particular antenna, adds to it a 'peculiar delay' for each IF, comprised of the differences in line lengths and propagation rates for that IF path, and sends it to the delay/multiplier system to be applied to the data.

d. Derivation of pointing commands

The azimuth and elevation of the source as seen from the center of the array (longitude 107°37'04", latitude 34°04'44") are calculated every 10 seconds, including refraction corrections. The telescope stations are leveled so that all the azimuth axes are parallel to 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 local vertical. Then the antenna pointing parameters are applied to each antenna. Provision for 12 pointing parameters for each antenna are allowed in the program as follows:

N-S tilt for elevation	N-S tilt for azimuth
E-W tilt for elevation	E-W tilt for azimuth
El encoder first harmonic term amplitude and phase	Az encoder first harmonic term amplitude and phase
	Axis perpendicularity error
El collimation error	Az collimation error
	Antenna base rotation

In practice, the pointing is not improved by the addition of pointing parameters beyond tilt (taken the same for pointing both axes), collimation errors, and azimuth rotation. There is provision for making the collimation errors band dependent.

e. Observing modes

Standard interferometer observations are implemented in blank mode, that is, the mode columns on the observation request card are left blank. For special purposes, two other modes are implemented -- D, which steps through the delay pattern, for finding the center, and IA, which steps to the half power points of the antenna beam for measuring the antenna pointing. (There is also a mode PA, used for single dish pointing, and a mode TF, test front end, which most observers need not be aware of.) In these special modes, some parameter is stepped through a cycle; the position in the cycle is called the submode. In both modes odd submode data is invalid because the parameter is in the process of changing (antenna in actual motion in IA mode). The significance of the even submode data is given below.

SM	IA	SM	D
2	On source	2	+14 ns
4	+El half power	4	-14 ns
6	-El "	6	-7 ns
8	+Az "	8	On delay
A	-Az "	A	+7 ns

Eventually other modes must be added for support of line observing and other curious options. It is not anticipated that this will occur in 1977.

The observer may also wish to indicate that some of his sources are calibrators. A column is allocated on the observation request card for a calibrator code. We request the use of the following codes:

A	Strong, unresolved flux calibrator
B	Weak, unresolved flux calibrator
C	Strong, unresolved, possibly variable calibrator
D	Weak, unresolved, possibly variable calibrator
E	Strong, slightly resolved flux calibrator
F	Weak, slightly resolved flux calibrator

There will be two effects from using these codes. In the Modcomp system, for codes A and C, the relative gain and phase of each antenna will be calculated, and if one antenna differs seriously from the mean, an on-line message will be produced (we expect to implement this feature in May, 1977). The second effect is that the data from these sources will be automatically made available to other observers using the array at about the same time, to help their calibration efforts, and, if appropriate, for baseline solutions.

f. Correlator data handling

The multiplier system controller has internal memory which is dumped to the computer system at 0.3125 second intervals. The computer system may ask for any set of correlators; in particular, it asks only for the correlators involving the antennas it knows about, and which are connected to the same subarray. This information is sent to Cora (the name is used ambiguously for the computer and for the only program that runs in it), where it is accumulated for ten seconds, and an rms is developed. In ten seconds there are one billion attempted correlations at a 100 MHz clock rate, requiring 31 bits (including sign) to express. The seven least significant bits are discarded in the correlator hardware, leaving 24 bits to express the remaining range of correlation. In practice, however, 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 used is the number of bits to be discarded from the right end of the 24 bit word. If too small a gain code is requested, the significant data may extend into the discarded bits on the left, and Cora will protest vigorously. 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, and perhaps 4, may be used without fear of unduly promoting the 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 occur for the extragalactic sources, but may on galactic HII regions, or the galactic center source.

Cora will apply gain corrections to convert the correlations to flux units, using calibration information provided on card images. This feature is not yet implemented, and its implementation will wait until a satisfactory system for doing this is demonstrated. A date is difficult to predict, but it is expected in 1977.

The correlator data, along with the circumstances of the observation, are written on magnetic tape, for permanent storage or transport, and on a disk file. It is our intention to make this disk file accessible from both the Modcomp and DEC-10 systems, so that observers may use the DEC-10 display and analysis programs on data freshly taken. This will be implemented in April or May, 1977.

A separate disk file (later copied to tape) is written containing the information collected by the monitor system. These are mostly voltages measured at various test points throughout the system, and are eventually expected to be of interest only to the engineers involved with the device in question (hence the separate recording), but, during this shakedown time, they are often of interest to the observer.

CHAPTER III - OBSERVING WITH THE VLA

CHAPTER III. OBSERVING WITH THE VLA

1. Organizing Your Observing

a. Before you submit a proposal

Before submitting a proposal you need some information concerning the capabilities of the VLA in 1977. The number of telescopes available, computer software and hardware development and receiver capabilities are discussed in other sections and these limit the astronomical programs which may be fruitfully done this year. In the following discussion we shall assume five antennas, all located on the South-west arm, operating at four frequency bands. The five antennas will be located at the stations AW1, AW2, AW3, AW4, AW5 (the last expected in July 1977) with a minimum spacing of about 1 kilometer and a maximum spacing of 6.5 kilometers. There will also be a sixth antenna giving an 0.22 kilometer spacing. It is unlikely that this configuration will significantly change during 1977.

In Table III-1 we have listed some of the properties of the VLA which should be useful in planning observations which can be implemented at the present time. The sensitivity of the VLA is impressive and it can detect small-diameter sources less than 1 mJy at 21 and 6 cm and about 10 mJy at 2 and 1.3 cm. In the above configuration of the antennas, the synthesized beamwidth is about 6 arcsecond at 21 cm to 0.5 arcseconds at 1.3 cm. Because of the lack of short baselines it will be difficult to map very extended sources and approximate limits at each frequency to the source size is shown in Table III-1. It is still possible to map a larger area of the antenna beam as long as the beam does not contain more than a few well-isolated regions of emission.

At 21 cm, and to a lesser extent at 6 cm, confusion is a problem. At 21 cm the flux density from sources in the antenna beam will be about 100 mJy and sidelobes from confusion may limit the sensitivity

TABLE III-1

SENSITIVITY AND RESOLUTION OF THE VLA IN 1977

	BAND				
	L	C	U	K	
frequency wavelength	1.34-1.73 20	4.5-5.0 6	14.4-15.4 2	22.0-24.0 1.3	GHz cm
rms sensitivity in 10 minutes	2.5	2.0	20.0	25.0	mJy
rms sensitivity in 12 hours	0.30	0.35	5.0?	10.0?	mJy
synthesized beam	6.0	2.0	0.7	0.4	arcsec
antennas half-power beam size	1800	540	220	120	arcsec
field of view with 50 MHz bandwidth	300	300	220	120	arcsec
largest mappable source	100	30	10	6	arcsec
confusion in antenna beam	100	2.3	<0.1	<0.01	mJy
confusion in field of view with 50 MHz bandwidth	2	0.6	<0.1	<0.01	mJy

of a radio map. At 21 cm and 6 cm the field of view; that is, the area in the sky from which radio emission adds coherently, is smaller than the beam of the antennas when the largest bandwidth of 50 MHz is used. Thus the effect of confusion will be decreased.

The amplitude, phase and pointing stability of the VLA is steadily improving with better understanding of the system and improvement of the electronics, but it is still far below the expectations of the original design. These instabilities may severely limit the dynamic range of the radio maps obtained in the coming year.

In terms of the basic synthesis properties of the VLA in 1977 its capabilities will be similar to the NRAO interferometer in Green Bank, W. Va. The baseline orientation of the South-west arm is 36^{o} north of east (within 10 degrees of that at Green Bank) so the (u-v) coverage for sources south of declination 30 degrees is restricted to certain portions of the (u-v) plane. In Figure III-1 the (u-v) tracks for the South-west arm of the VLA are given for various declinations.

The sidelobe levels for all but the very northern declinations will not be very pleasant, so detailed mapping of complex sources will not be possible. Special map restoration techniques like CLEAN may be necessary to improve the maps. However, the VLA antennas are alt-azimuth mounted and can track a source to about eight degrees elevation. This tracking improves (u-v) coverage of sources north of declination 30 degrees. An example of the response to a point source at declination 40 degrees with -6^{h} to $+6^{h}$ hour angle coverage is shown in Figure III-2.

The measurement of the linearly polarized radiation of extended sources and small-diameter sources should be possible in the latter half of the year. However, the sidelobe levels of the circularly polarized response of the antennas are poor and measurements of small degrees of circular polarization will be difficult or impossible in 1977.

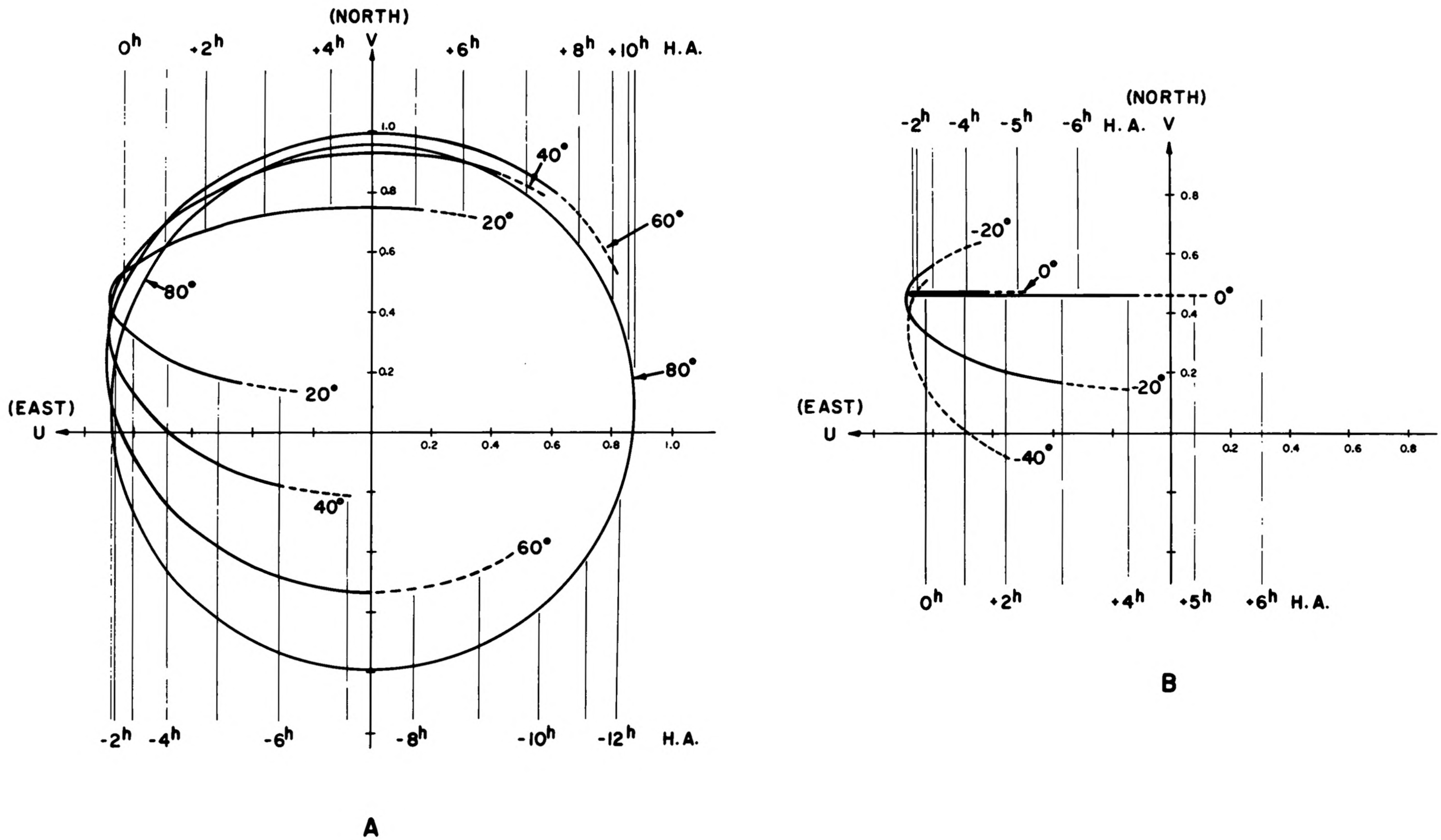

Figure III-1. (U-V) TRACKS FOR THE VLA. Curves dashed for elevations between 20° and 10°.

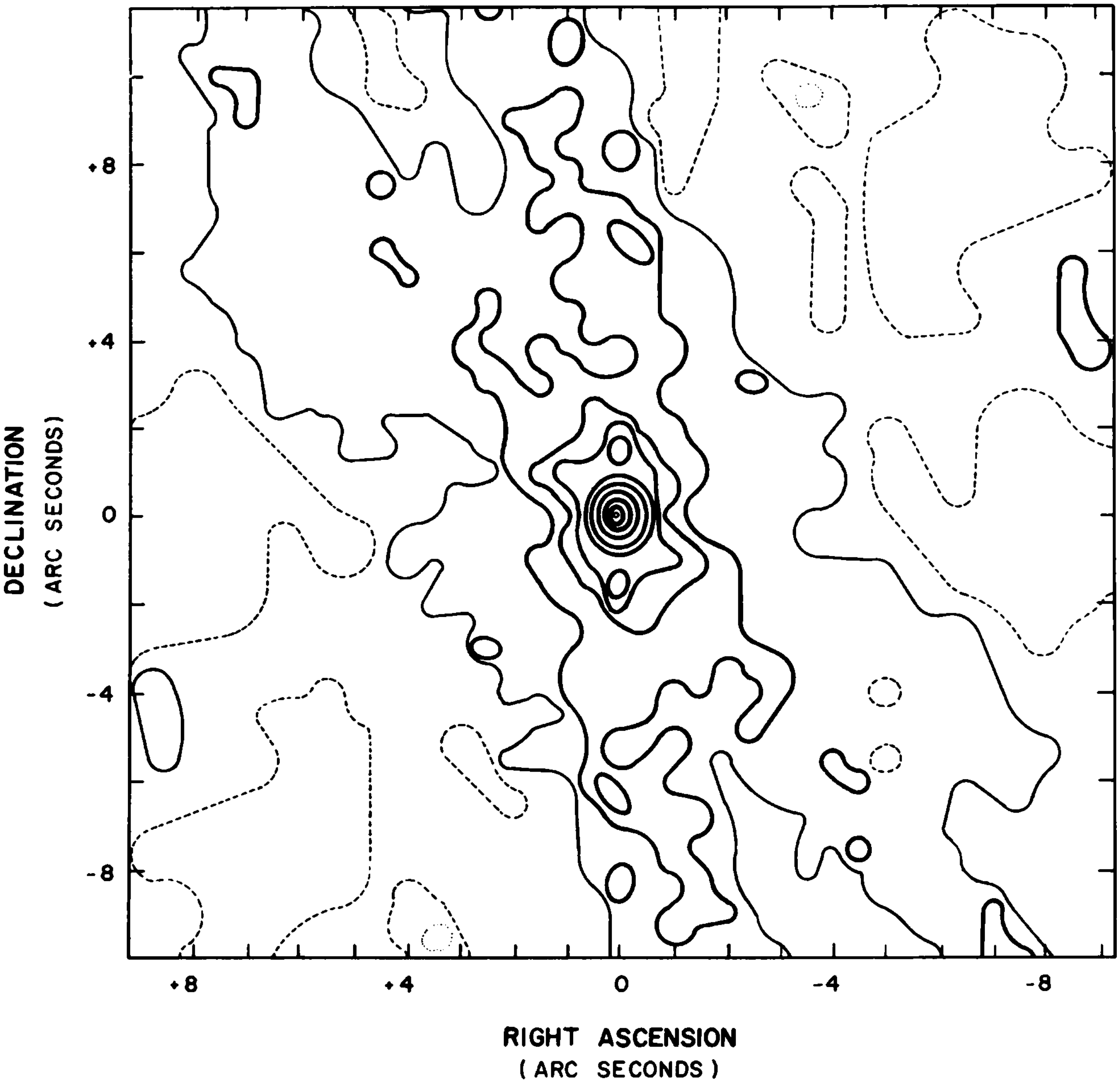

Figure III-2. RESPONSE TO A POINT-SOURCE. Synthesized beam of the 1977 VLA. Declination 40°, hour angle coverage -6 to +6 hours. Contour levels are at intervals of 10% of the peak response. 10% contour is shown faint, zero contour is omitted, negative contours are dashed.

There will be no spectral line capability at the VLA in 1977.

b. Before you observe

Each outside program will be assigned to a VLA-friend who should be contacted several weeks in advance of the run. He or she (or any of the scientific staff) will disclose if the VLA is operating at the level expected in order to accomplish the goals of your program. A list of the most up-to-date sources for phase, gain and polarization calibration should also be obtained. It is also worthwhile considering several alternative observing schemes consistent with your proposal in anticipation of some current problems in the equipment or contingencies for inadvertent weather.

The generation of the observing program is best accomplished at the VLA site just before the observations. If the number of sources, excluding calibrators, is large, say greater than about 10, it is useful to punch the source coordinates (1950.0 epoch is most convenient) on cards as described in the OBSERV program (discussed in Appendix A). For useful on-line output and ease in mapping, an accurate position of the source, if available, should be used. Certainly the accuracy of the position should be a small part of the field of view. It is possible to follow a moving source with the VLA and one should have an accurate ephemeris for the object. Details of this type of source card will be furnished upon request.

It is advisable to arrive at the VLA site one or two days (avoid weekend) prior to the run and at least one week should be devoted after the run for editing, calibration and mapping the data. Some of the reductions can be also done in Charlottesville using a modified form of the NRAO interferometer package. At present there are no plans to carefully control the amount of processing time that is used by each observer. However, as pressure increases reduction time may be at a premium. Even now people with large processing problems may be requested to run them at night.

Before plunging into observing or even compiling your source lists you should check with the most recent observers and the VLA staff to find out how the VLA is currently behaving. You should also ask if the telescope pointing and baselines are accurately known. In general, the VLA staff will determine most of the instrumental parameters; however, additional observation time may be needed for your program - special observation source lists and aid are available.

During the course of the observations the gain and phase of the instrument changes considerably. Part of these changes can be monitored by periodically observing strong, point-sources which have accurately determined flux densities and positions. The frequency and care of calibrator observations needed varies from program to program. The VLA staff has compiled a preliminary set of calibrators which can be used by all observers. Positions are given in Table III-2. An up-to-date list of flux densities for some of these sources is available from the VLA staff. A list of polarization calibrators should be available by July 1977. For many programs these calibrators will suffice. All relevant lists concerning calibration of the VLA and other related information will be placed in the observer's office next to the operator area.

We currently suggest (April 1977) about one-fourth to one-half of the observing time be devoted to calibrator observations. As a general rule a calibrator should be observed at least every 30 minutes for a durations of at least five minutes, excluding slew time, at 21 and 6 cm. For work at 1.3 and 2 cm a calibrator every 15 to 20 minutes is recommended in order to follow the phase fluctuations in the system and in the atmosphere to an accuracy where it is possible to coherently combine observations over long intervals. It is important especially at the high frequencies to use a calibrator near the source to reduce the atmospheric phase fluctuations. In periods of inclement weather observations at 1.3

TABLE III-2

VLA PHASE CALIBRATORS

MARCH 31, 1977

IAU DESIGNATION	COMMON NAME	RIGHT ASCENSION Epoch 1950.0	DECLINATION	FLUX DENSITY at 1-2 cm	NOTE
0106+013	P0106+01	01 06 04.522	+01 19 00.20	3.0	
0134+329	3C48	01 34 49.832	+32 54 20.52	1.5	1,3,5
0224+671	D0224+67	02 24 41.166	+67 07 39.70	2.0	
0237-233	P0237-23	02 37 52.750	-23 22 04.80	2.5	4
0316+413	3C84	03 16 29.566	+41 19 51.92	45.	2,5
0333+321	NRAO140	03 33 22.407	+32 08 36.65	1.0	
0336-019	CTA26	03 36 58.956	-01 56 16.88	1.0	
0355+508	NRAO150	03 55 45.260	+50 49 20.30	13.5	5
0429+415	3C119	04 29 07.904	+41 32 08.50	1.5	1,3
0430+052	3C120	04 30 31.603	+05 14 59.62	6.0	5
0438-436	P0438-43	04 38 43.240	-43 38 56.20	3.5	4
0518+165	3C138	05 18 16.532	+16 35 26.85	1.2	1,3
0538+498	3C147	05 38 43.512	+49 49 42.83	2.0	1,3,5
0552+398	DA193	05 52 01.389	+39 48 21.78		
0605-085	P0605-08	06 05 36.025	-08 34 19.15	3.0	
0727-115	D0727-11	07 27 58.130	-11 34 53.50	4.5	4
0742+103	D0742+10	07 42 48.466	+10 18 32.67	1.5	
0814+425	OJ425	08 14 51.670	+42 32 07.70	1.5	5
0831+557	DA251	08 31 04.381	+55 44 41.37	3.0	
0834-201	P0834-20	08 34 24.600	-20 06 30.00	2.5	4
0851+202	OJ287	08 51 57.252	+20 17 58.44	2.0	
0923+392	DA267	09 23 55.321	+39 15 23.58	7.5	5
0953+254	OK290	09 53 59.742	+25 29 33.59	1.0	
1127-145	P1127-14	11 27 35.650	-14 32 54.30	3.5	4
1151-348	P1151-34	11 51 49.350	-34 48 47.50	2.0	4
1155+251	B1155+25	11 55 51.641	+25 06 59.86	1.0	3
1226+023	3C273	12 26 33.247	+02 19 43.34	30.	2,5
1245-197	P1245-19	12 45 45.209	-19 42 57.37	1.0	
1253-055	3C279	12 53 35.835	-05 31 07.95	9.0	2,5
1328+254	3C287	13 28 15.924	+25 24 37.58	1.5	3
1328+307	3C286	13 28 49.660	+30 45 58.70	3.0	1,3,5
1404+286	OQ208	14 04 45.616	+28 41 29.25	2.0	
1458+718	3C309.1	14 58 56.650	+71 52 11.15	1.5	1,3
1502+106	OR103	15 02 00.158	+10 41 17.77		
1508-055	P1508-05	15 08 14.940	-05 31 49.00	2.0	4
1510-089	P1510-08	15 10 08.910	-08 54 47.10	1.5	4
1555+001	D1555+00	15 55 17.686	+00 06 42.66	2.0	
1611+343	DA406	16 11 47.897	+34 20 19.83	1.5	
1638+398	NRAO512	16 38 48.171	+39 52 30.11	1.0	
1641+399	3C345	16 41 17.608	+39 54 10.84	8.5	2,5
1730-130	NRAO530	17 30 13.549	-13 02 47.06	4.0	
1741-038	OT068	17 41 20.619	-03 48 48.91		
1807+698	3C371	18 07 18.542	+69 48 56.88	2.0	2,5
1901+319	3C395	19 01 02.312	+31 55 13.75	1.0	
2005+403		20 05 59.560	+40 21 01.80	5.0	3,5
2021+614	OW637	20 21 13.263	+61 27 18.15	1.0	
2037+511	3C418	20 37 07.458	+51 08 35.72	3.0	

TABLE III-2 (cont.)

IAU DESIGNATION	COMMON NAME	RIGHT ASCENSION Epoch 1950.0	DECLINATION	FLUX DENSITY at 1-2 cm	NOTE
2128-123	P2128-12	21 28 52.710	-12 20 20.00	2.0	4
2134+004	P2134+00	21 34 05.209	+00 28 24.69	8.0	
2200+420	BLLAC	22 00 39.363	+42 02 08.59	3.0	
2203-188	P2203-18	22 03 25.710	-18 50 16.60	1.0	4
2230+114	CTA102	22 30 07.810	+11 28 22.78	2.0	
2251+158	3C454.3	22 51 29.521	+15 52 54.36	5.0	5
2345-167	P2345-16	23 45 27.687	-16 47 52.62	3.0	
2352+495	DA611	23 52 37.790	+49 33 26.76	1.0	3

Positions from Wade and Johnston measurements with the 35-km baseline at Green Bank, except where noted. Flux densities are very approximate because of variability.

NOTES:

1. Source is resolved beyond about 100,000 wavelengths
2. Some large-scale structure. Use with caution at short baselines.
3. Position from Elsmore & Ryle, M.N. 174,411,1976 with 0.006 seconds added to their right ascension.
4. These southerly sources have positional errors of 0.5 to 1.5 arcseconds. Better positions will be forthcoming.
5. This source has a reasonably accurately determined (20%) flux density at 15 GHz and 23 GHz.

and 2 cm are not recommended. Finally, include a few observations of calibrators with well-known flux density in order to establish an accurate flux density scale for the observations. In general, IT PAYS TO OVER-CALIBRATE. The system reliability is still marginal and the response of the VLA to a calibrator source is the best way of determining if there are any problems.

For astrometric programs demanding extremely good phase stability (corresponding roughly to a positional accuracy of 0.2 arcseconds or better), for accurate flux density measurements of variability studies (at the one percent level or better), and for large dynamic-range mapping, more stringent calibration techniques may be necessary. At present the knowledge of the ultimate limit of the system capabilities are vague and the best observational and instrumental procedures are only now being developed.

The VLA can operate in several subarrays which each carry out independent and simultaneous observations. It is likely that some of the more recently built antennas will be assigned to a testing subarray for observations during your run. This subarray should not interfere at all with your observations. It is possible to use several subarrays (a total of 5 is the ultimate limit for the VLA but currently only two are implemented) for your observations although this is generally inefficient.

It is best not to observe sources below about 15 degrees elevations (perhaps 10 degrees at 21 or 6 cm in fine weather). The large atmospheric phase and gain effects cause errors. In addition at 1.3 and 2 cm the efficiency of the antennas decrease at low elevation. In Figure III-3 a plot showing the AZ/EL to HA/DEC conversion for the VLA is given as an aid to scheduling.

The elevation limits of the telescopes are eight degrees and 125 degrees (i.e., the telescopes can tip 35 degrees beyond the zenith point). The azimuth limits are 150 degrees to 690 degrees for the South-west arm or one and one-half revolutions. The

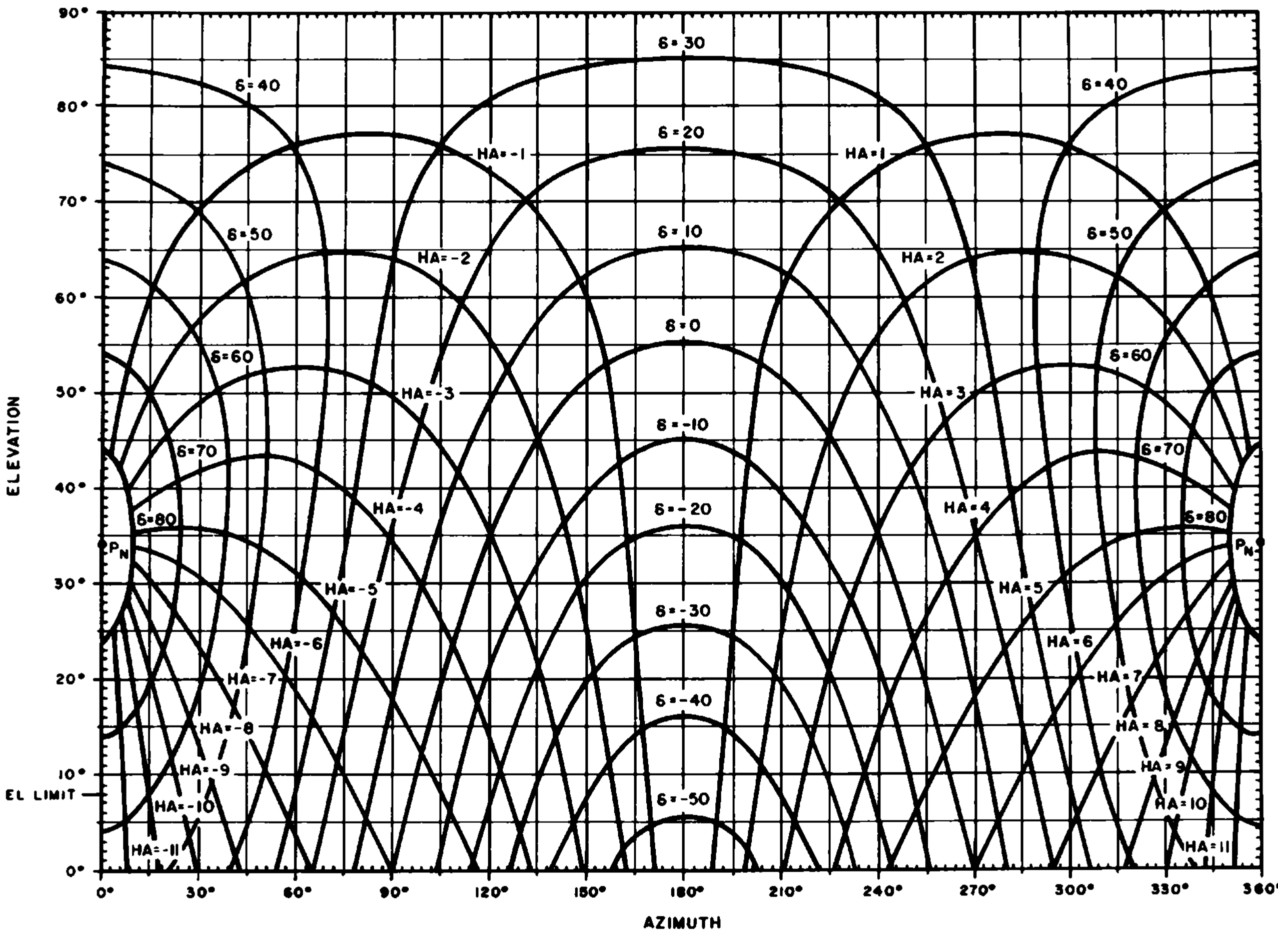

Figure III-3. Altazimuth to equatorial coordinate conversion chart for the VLA site.

antennas slew at 20 degrees per minute in elevation and 40 degrees per minute in azimuth. Some care should be taken in scheduling sources which require the antennas to move near the zenith point, as this may require an azimuth change of about 180 degrees. Also when moving across azimuths 150 degrees or 330 degrees between sources, the antennas may have to rotate nearly 360 degrees to avoid cable wrapping. It is not possible to observe a source within about 0.3 degree of the zenith. Sources between declinations $33^{o}40'$ to $34^{o}30'$ should not be scheduled through transit.

The antenna pointing can change by up to one arcminute over a day or less. Observers carrying out 1.3 and 2 cm runs should occasionally check the pointing. This procedure takes about 30 minutes per band to perform and the operators will help you in this check. (See STUpid in Section 1-c.)

For most work on relatively weak sources, the widest bandwidth of 50 MHz gives the best signal/noise. As indicated in Table III-1 the field of view with this bandwidth is much less than the antenna beam at 21 and 6 cm. This area rejection decreases the effects of confusion markedly. In some cases, it may be desirable, however, to synthesize all of the antenna beam -- which would mean using the narrower bandwidths of 12 MHz or 1.5 MHz with concommitant loss in signal/noise. For strong sources where sensitivity is not important but instrumental stability is, the narrower bandwidths should also be used.

Unless otherwise desired, standard frequencies will be used at each band and all calibrator fluxes will refer to these standard frequencies. At 21 cm it may be necessary to change frequencies as the interference warrants. Both IF channels are set to the same observing frequency in a band although this is not a restriction in the system. There is only one mode in which two frequencies in different bands can be observed simultaneously -- dicroic mode with 2 cm in one channel and 6 cm in the other channel.

It takes about 30 seconds to rotate the subreflector to change observing bands. When observing at several frequencies it is recommended that the sequence CHANGE BAND - CALIBRATOR - SOURCES(S) - CALIBRATOR - CHANGE BAND be used.

Observations for the VLA are controlled by many files resident in a magnetic disk attached to the Modcomps. A complete description of these files is given in VLA Computer Memorandum No. 131. An up-to-date description is also kept in the operator's manual -- a copy is available from the DEC-10 computer.

The files of most concern to the observer are the source files needed for the observing run. The files consist of a set of lines or card images, one per source observation, stored on disk. Each line contains the source name, source qualifier, stop sidereal time or duration time, source coordinates and epoch, frequency band, gain code, mode of operation, calibrator code, and bandwidth. (Additional option cards which follow the relevant observation cards exist for planetary motion, azimuth and elevation slewing instructions and specific oscillator settings.)

The generation of these observing files are the responsibility of the observer and a program called OBSERV is available to facilitate the preparation and editing of the files. For many observational programs some parameters needed in the file can be entered by default. Positions and gain codes for the calibrators listed in Table III-2 are also stored in the Modcomps. The responsibility for inserting the source file names in the appropriate subarray files, and all other system file alterations, falls with the telescope operator on duty or a member of the VLA scientific staff.

Source files created by an observer will be kept on the Modcomp computer disk for 4 weeks. After that period they will be removed. There is a "visitor's library" which is available for storing files needed for recurring or long-term observing files.

A brief description of the OBSERV program is included in Appendix A.

Additional documentation, including a greater variety of examples is available in the observer's office. The telescope operator will assist you in getting started in the use of OBSERV.

c. <u>While observing</u>

When another program has been running on the VLA prior to yours, no particular start-up procedure is needed except to load your observing file into the appropriate subarray file and continue. There will be occasions when you will be using part of the VLA which has not been used by the previous observer and a careful check should be made at the beginning to see if everything is in working order.

If the VLA is woken up for your observations, then a 'start-up' procedure is usually followed. The relevant observations are handled by the VLA staff and the operator but the observer should be aware of the procedure. The clock, ephemerides and various VLA parameters are checked and updated, if necessary. The telescopes, IF channels and observing bands are cycled through to see if all of the advertised systems are working. Delay centers and telescope collimation errors are checked. The general array stability and sensitivity is noted. Many malfunctions can be corrected within one hour or less. In some cases, if adequate observations have not been made to check the entire system behavior, they should be included in your run.

The Modcomp computer provides some very primitive facilities for monitoring how your observations are going. Eventually these functions will be performed by the DEC-10, and the first provisions for that -- sending correlator data to the 10 in real time -- will be installed in mid-1977. In the interim, however, the Modcomp programs must be used. There are three facilities in the Modcomp. They are the data checker program, the single baseline display, and the scan averager.

The data checker is a task named 'CHK' which runs in the monitor computer 'Monty'. It has access to the data returned from the various monitor points throughout the VLA by the digital communication system, and attempts to conclude from them whether that data is valid or not. The program is arranged to make a large variety of validity checks in a fairly easy way, so that the check limits or algorithms can be changed easily. There is even a provision for changing them dynamically so that a new check can be installed on an hour or two's notice to handle some transient condition; however, observers are warned to be very careful before requesting this, and should keep adequate notes to insure that they can recreate which error conditions were in use at any particular time. CHK informs you of the status of the instrument by printing a line on the line printer and, if appropriate, a line on the operator's CRT, as well as setting the appropriate flag bits in the correlator data. Because the length of these messages is restricted, you may find them rather obscure -- feel free to ask the oprator what they really mean.

The single baseline display is a program named D10, which every ten seconds displays the amplitude and phase of the fringes from a single baseline. It is normally left running with output on a CRT at the operator's station. The output can be directed to any system device; the operator will switch it to the printer if you wish. Because the printer is not a heavy-duty device, we request that you do not leave the output there for periods of hours, but for short samples of how things are going, the printer may be useful.

Because the printer is 132 columns wide and the screen only 80, you get additional data from the printer; when you use the screen display you get the two parallel polarizations correlators and one of the two crossed hand correlators, along with time and status flags. On the printer, you get the other crossed hand correlator and the u,v,w coordinates of the baseline.

The baseline being printed is selected by typing, on the operator communication unit of the computer in which D10 is running, /D10/R,antenna1,antenna2, where antenna1 and antenna2 are the physical ID's of the two antennas comprising the interferometer pair you wish to examine. Get the operator to show you how to do this, and don't do it unless you are sure you know what you are doing -- the computer operating system assumes its operator knows what he wants done, and there are many commands you can type on the operator communication unit which may necessitate a reload, or worse.

The scan averager calculates the vector average of all data taken during a particular scan, and dumps the answer on the printer. It currently does not take account of flagging, and therefore its answers should not be regarded as final outputs, but only as an indication of how the observation is going. It is expected that, as the number of antennas and baselines increase, this program will become less useful, and other provisions will have to be made to achieve the same effect. The scan averager, because of core memory limitations, must currently run in the space allocated for the background in Monty. The observer must choose between this averager program and any other convenient background program such as OBSERV. We shall see whether this situation can be alleviated.

In addition to these three basic programs, there are several other programs and services of interest to the observer. The operator can, on request, manipulate your source lists from his console -- he can extend the observing time for a given source, he can skip to the next card image in your list, or he can skip back to a previous image (in case you get confused, typing /SLIST displays the card before the current one in your list, the current one, and the next 3 cards). The operator can also cause the observing mode to be changed to pointing mode to check pointing if you suspect a problem.

There is also the startup program, STUpid. This program checks delay centers, phase zero points, and pointing offsets. It requires about 20 minutes per band to perform these checks. Ask the operator how to use this program if needed. We will normally run this program on all bands that observers will be using when we turn on the system for the observing run. Depending on your observations and the state of the instrument at the time, it may be worthwhile for you to run it during your own observing time.

As soon as normal observations are begun, have the operator execute the scan averaging program. Check the sensitivites of the system periodically by using the amplitude of the scan average for a calibrator of known flux density. The measured visibility amplitude divided by the flux density of the source should not differ by more than 50% from the entries in Table III-3. (By late 1977 this sensitivity check will be done automatically in the Modcomp system.) Any anomolous results on calibrators should be discussed with the operator. If he can not satisfactorily explain it, you should immediately consult a member of the VLA scientific staff. Almost always a low sensitivity is associated with a specific antenna channel and isolates the part of the VLA having problems. In short, many problems can be seen quickly by utilizing the scan averages.

In a similar manner the average phase of the calibrator observations should be noted. If it is claimed that the antenna positions are accurately known, then the phases should not vary by more than about 30 degrees at 6 cm. Also the phase difference between the A and C channels for any correlator should be constant to about ten degrees.

In a ten-minute scan average at 20 and 6 cm, a five mJy signal can be easily seen. With little effort one can monitor the results of the observations at this sensitivity level and make any adjustments in the observing program if called for. The observation list can be

TABLE III-3

NOMINAL AMPLITUDE PER JANSKY

(Subject to change without prior notice)

FREQUENCY	20 cm	6 cm	2 cm	1.3 cm
AMPLITUDE/jansky	0.25	0.30	0.06	0.04

easily modified using OBSERV without interrupting the data taking. At 20 cm there is a reasonable chance of detecting a 5 mJy source in the field of view; however, there will be a significant phase drift with time (say 5-50 degrees per minute) if the source of radiation is far from the phase center. Confusion at this level will occur about ten percent of the time at 6 cm and hardly ever at 2 and 1.3 cm.

Tapes are not generally dismounted and taken to the DEC-10 for off-line reduction until they are full. In special circumstances it is possible to interrupt observing to process the data from the tape. This interruption takes about twenty minutes, if all goes well. In mid-1977 we expect to send data directly from the Modcomps to the DEC-10.

Finally, quick and efficient communication of all problems encountered is extremely important. It is in this way that bugs, inconsistencies, inconveniences, etc. can be found and corrected, or misunderstandings can be rectified.

Before going to the next section where the off-line processing is described, the phase convention as used at the VLA in the DEC-10 should be noted. In Section II. 1. b. the topocentric coordinate system used to define the antenna locations were given. The location values are resident in the Modcomp file 'antennas' in units of nanoseconds (0.2997925 meters/nanosecond). The baseline separation associated with an antenna having an ID number M and an antenna having an ID number N is defined as a vector from the antenna with the LOWER ID number to the HIGHER. Thus one should always refer to baseline (1,2) not baseline (2,1). (For the Modcomp program, this convention may be reversed, the order is given in the header.)

For many array applications it is useful to define as astrometric coordinate system defined by the incoming radiation from a source at hour angle h and declination δ. The plane of radiation is defined by the u-axis which points east as viewed by someone on the source and the v-axis which points north for this same observer. The w-axis is defined to be in the direction of propagation. This component is usually called the delay and it is greater than zero if the incoming radiation strikes the higher number antenna first. The astrometric components of the baseline (u,v,w) are related to the topocentric coordinates (B_x, B_y, B_z) by:

$$u = B_x \sin(h) + B_y \cos(h)$$

$$v = -B_x \sin(\delta) \cos(h) + B_y \sin(\delta) \sin(h) + B_z \cos(\delta)$$

$$w = B_x \cos(h) \cos(\delta) - B_y \sin(h) \cos(\delta) + B_z \sin(\delta)$$

The phase P of an observation is:

$$P = W_0 - W$$

where W_0 is the calculated delay of the incoming radiation assuming a source position (α_0, δ_0), a baseline separation $(B_{x_0}, B_{y_0}, B_{z_0})$ and using various ephemeral and atmospheric corrections. The term W is the true delay of the incoming radiation.

The phase can be expressed, to first order, as:

$$P = P_0 + (B_{x_0} - B_x) \cos(h_0) \cos(\delta_0) - (B_{y_0} - B_y) \sin(h_0) \cos(\delta_0)$$
$$+ (B_{z_0} - B_z) \sin(\delta_0)$$
$$+ U \cos(\delta_0) (\alpha - \alpha_0) + V (\delta - \delta_0)$$

where P_0 is instrumental phase constant. Thus the observed phase will be positive if the source is nearer than expected to the first mentioned (lower numbered) antenna. Problems concerning the phase convention used at the VLA should be mitigated by the above discussion.

2. Off-line Processing

a. Off-line systems

The asynchronous computer is a DEC-10 machine (Digital Equipment Corporation). It is used for all off-line processing of data recorded by the Modcomp computers. There are 256K words (36-bit) of core memory; an additional 64K words will be available by late 1977, for a total of 320K words eventually. The other primary storage devices are 6 disk drives each having 20 million 36-bit words of storage. There are a total of five tape drives which can handle all densities of both 7 and 9 track one-half inch magnetic tapes. Other peripherals include a high-speed (600 lines/minute) upper/lower case line printer, a card reader (300 cards/minute), and a card punch.

The DEC file management system allows users to easily store, access, and manipulate many types of disk files including text, source programs, relocatable modules, executable modules, data, etc. Each observer will be assigned a programmer number upon the first visit to the site; this establishes two disk areas, one with project number 14 where visibility data bases are stored, and one with project number 13 where working files and other miscellaneous files created by the observer will automatically be stored.

The DEC-10 is a time-sharing machine; our system can currently handle up to 24 jobs. Communication with the machine is done via terminals; there are a total of 11 CRT-type terminals (one of which is reserved for observers) and 1 Tektronix storage-tube terminal. All have upper/lower case characters and graphics capability, and operate at 4800 baud. From the terminal you can run programs interactively, edit text files, prepare control files, submit jobs to be run in batch mode, and obtain job, system, and file information. You can also easily allocate temporary disk files in your private disk area.

Most of the existing software is written in SAIL, a modified version of Algol. No subroutines or other aids have been written to make access to the VLA data easy from any other language. Although Fortran and Basic are available on the DEC-10, they are therefore not easy to use for VLA data processing problems.

Another off-line computer is a PDP-11/40, also called the Graphics System. The main processor has 28K words (16-bit) of core memory, and two disk drives with 1.2 million words of storage each. There are three display screens. The main control and communication is via a refresh CRT with 1024x1024 resolution, 8 brightness levels, upper/lower case characters, and a light pen. The Comtal image system consists of a black and white monitor with 256 brightness levels, and a color monitor with 64 colors possible simultaneously. Both monitors have 256x256 resolution and a non-destructive cursor. A data tablet enables the user to do such things as manipulate the cursor and change the image transfer function. Data can be transferred to the PDP-11/40 from the DEC-10 and subsequently loaded onto the Comtal system. Currently the data transfer rate is the same as that for terminals (4800 baud). The hard copy device for the graphics system (and also for the Tektronix terminal on the DEC-10) is a Versatec electrostatic printer.

There is currently on order, for delivery in late 1977, a large minicomputer system which includes an array processor ("FFT box") which will relieve the DEC-10 of the chore of map making.

b. Caveats and principles

The off-line software available in the VLA site is still under development. The programs discussed here are expected to remain relatively stable during 1977. The principal dynamic feature that the user can expect in the off-line software is that more programs and program features are likely to be available than are described here. The most recent documentation for programs will be available in the observer's office at the VLA site.

Data obtained during VLA observing runs are recorded on magnetic tapes. These tapes serve as the data archiving system during 1977. Separate tapes are maintained for visibility data and for monitor data. Programs in the DEC-10 called FILLER (for visibility data) and MONFIL (for monitor data) take the data from the archive tapes and place it in files on disk in the DEC-10. DEC-10 data handling programs then access this data.

c. <u>Listing data from tape</u>

Listings and summaries of the data contained on the visibility archive tapes can be obtained using special purpose programs called SYNLST and TAPIND. SYNLST provides listings of averaged or un-averaged visibility data. TAPIND provides a summary or index of selected files of data on tape.

d. <u>Visibility data base</u>

All of the programs in the DEC-10 that deal with VLA generated data access the data from files stored on disk. These files are stored in the user's "14" area on disk and the files have a specific data format. This system constitutes a data base. The user will need to know what data is stored in the data base. There are two principle forms of data: visibility data and monitor data.

If PN stands for the programmer number assigned to each user in the DEC-10, the user's visibility data base is stored in the following files:

runnam.INX[14,PN]	which contains an index of information about the visibility data, but no actual visibilities,
runnam.VIS[14,PN]	which contains visibility data, and
runnam.GAI[14,PN]	which contains a table of antenna-based complex gain information,

where runnam is a six letter name assigned when the data base is filled. The filling of a data base is accomplished with a program called FILLER. FILLER takes data from the magnetic tapes upon which the on-line Modcomps write data during observing. Sometime during 1977 the filling of the data base will be done in essentially real time using programs in the DEC-10 that read data written on a fixed head disk by the on-line Modcomps.

The index of information in the runnam.INX[14,PN] file describes the data associated with a scan (all data associated with a single source observation card). For each scan there are the following: source name, source qualifier, type of observing mode, the number of IFs used (2 or 4), the scaling or gain factor for visibilities, a sort code saying whether the ordering of the visibility data is time order or u,v order (only time order initially implemented), the averaging time chosen when filling the data base, two pointers that describe the locations (in the runnam.VIS[14,PN] file) of the first and last visibility records associated with the scan, two pointers that describe the locations (in the runnam.GAI[14,PN] file) of the first and last gain information records associated with the scan, the right ascension and declination used on the observing control "card", the right ascension and declination precessed to the beginning time of the scan, the Julian Atomic date, the beginning and ending IAT for the scan, the beginning LST of the scan, the polarization of each of the IFs used, the observing band (1.3, 2, 6, or 20) for each IF, the observing frequency for each IF, the bandwidth for each IF, and the signed sum of the L.O. frequencies for each IF.

Each record in the runnam.VIS[14,PN] file, associated with a scan contains the following: the time (IAT), a date code, an antenna pair code that identifies the two antennas producing the visibility data in the record, projected baseline (u and v), the delay between antennas (w), the 0, 1, 2, or 3 flagging level for each of eight correlators, and the real and imaginary parts of the visibility function for eight correlators. The eight correlators are the AA, CC, AC, CA, BB, DD, BD, DB correlators produced from cross-correlation of the A, B, C, and D IF channels. Associated with each scan there will be a sequential stream of records of this type containing the data for all antenna pairs.

The runnam.GAI[14,PN] file in the data base contains the following: date, time, and eight arrays containing complex gain and polarization information. Each array has dimensions (1:number of antennas,1:number of IFs). The first two arrays describe the real and imaginary parts of the nominal complex gain applied to the data in real time by the on-line Modcomps. The next two arrays contain the real and imaginary parts of a complex correction gain (G) for each antenna and IF. The next two arrays contain the real and imaginary parts of the nominal polarization correction applied in real time by the on-line Modcomps. The last two arrays contain the real and imaginary parts of the corrections to the polarization gain (D). This system is based upon combining the information about all corrections and empirical calibration into a pair of complex numbers for each antenna and IF. The corrections for each correlator are then obtained by multiplication of the correction gains for two antennas, and the application of the corrections consists of complex multiplications like the following:

$$AA'_{ij} = G_{Ai}\ G^*_{Aj}\ AA_{ij}$$

$$CC'_{ij} = G_{Ci}\ G^*_{Cj}\ CC_{ij}$$

$$AC'_{ij} = G_{Ai}\ G^*_{Cj}\ AC_{ij} - (1/2)\ I_{ij}\ (D_{Ai}+D^*_{Cj})\ \exp(+2i\chi)$$

and

$$CA'_{ij} = G_{Ci}\ G^*_{Aj}\ CA_{ij} - (1/2)\ I_{ij}\ (D_{Ci}+D^*_{Aj})\ \exp(-2i\chi)$$

where $I_{ij} = AA'_{ij} + CC'_{ij}$.
i and j are two antenna ID numbers ($i<j$), and χ is the parallactic angle.

The implementation of this type of antenna-based calibration system and the full use of the gain measuring capabilities of the gain calibration system is one of the major goals of VLA staff during 1977.

e. Standard program format

The DEC-10 programs of interest to the users during 1977 will be mostly either programs in a standard format or CANDID. Since the CANDID-based system will not be available until late 1977, the user will be initially most interested in a collection of separate program using this standard format. Examples of programs that use this standard format are FILLER, LISTER, VISPLT, MONPLT, BASFIT, GAINTB, GTTSYS, VISCAL, UVPLOT, INTMAP, MONLST, MONDEF, and MONFIL.

The standard format is based upon a primarily terminal input system where at any stage "menu"'s can be provided. At any time after the user has requested the running of a program, he can type either HELP or INPUTS. The result of the HELP command is the display of all of the commands (with syntax and brief explanation) that can be used. These commands perform two general functions; they either initiate computational tasks or they allow parameter input to computational tasks. The status or values of current parameters is always obtained as a result of typing INPUTS. Almost all parameters will be initialized with default values, although a few, such as the RUNNAME command, must be used to specify the name assigned to the data base files the user wishes to access.

In many cases the GO command initiates the computational task of interest.

The following are some of the major parameter type commands that will be encountered in programs using this standard format:

Command	Parameter Syntax	Sample Input Parameters
startdate	<date>	77feb20 , 77127yd , 770220ymd
stopdate	<date>	77FEB21 , 77300yd
starttime	<time>	13:30:45
stoptime	<time>	24:
sourcename	'<string>'	'3C48', 'all' (for all sources)
sources	'<strl>','<str2>',..	'3C48','3C418','NRAO530'
sourcequalifier	<integer> or 'all'	0, 'all'
band	'<string>'	'1.3', '2', '6', or '20'
mode	'<string>'	'all', 'IA'
antennas	<integer>,<integer>,...	1,2,3,4,6
ifs	'<string>'	'AC', 'BD', or 'ACBD'
corrs	'<string>'	'SELF', 'CROSS', or 'BOTH'

The notation for parameter syntax is the same as developed as part of the CANDID system. Therefore the following units suffices are meaningful:

Suffix	Description	Suffix	Description
e,E,@	exponent 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	milli-seconds	GHz	gigahertz
usec	micro-seconds	Jy	Jansky
nsec	nano-seconds	mJy	milli-Janskys
psec	pico-seconds	uJy	micro-Janskys
K	degrees Kelvin	yd	year and day of year
C	degrees Centigrade	ymd	year-month-day

Numbers without units are assumed to have the standard cgs units.

The syntax for all commands in this standard format is:

<command name> <parameters (if any)>

The nature of the commands and the consequence of their use will depend upon the program.

The possible paths of use of the programs which we will discuss next are schematically illustrated in Figure III-4. In Figure III-4 circles represent data storage on disk, squares represent magnetic tapes, ovals represent things to be accomplished, and arrows are associated with program names to indicate what data is accessed to accomplish what purpose with what program. A dashed arrow indicates features that will be implemented later in 1977.

f. Short program descriptions

i. FILLER

FILLER takes the data from the visibility data tapes and places it in the data base files previously discussed. After requesting the running of FILLER the standard HELP and INPUTS commands are available to inform the user about what he can do and what the status of current parameters might be. Commands are available to select a number of options that determine the nature of the data in the users data base. Some of the more important are the following:

<table>
<tr><th>Command (and Syntax)</th><th>Purpose</th></tr>
<tr><td>runname '<name,ext[14,PN]>'</td><td>Supply name and user area for data base</td></tr>
<tr><td>collect 'C'|'N'|'CN'</td><td>Collect calibrators (C), non-calibrators (N), or both</td></tr>
<tr><td>ifname '<4 characters>'</td><td>Assign IF channel names (ABCD,RLRL,HVHV)</td></tr>
<tr><td>avgtime <time></td><td>Averaging time (>= 10 seconds)</td></tr>
<tr><td>errorlevel 0|1|2|3</td><td>Maximum allowed error level</td></tr>
<tr><td>subarray <number></td><td>Select sub-array</td></tr>
</table>

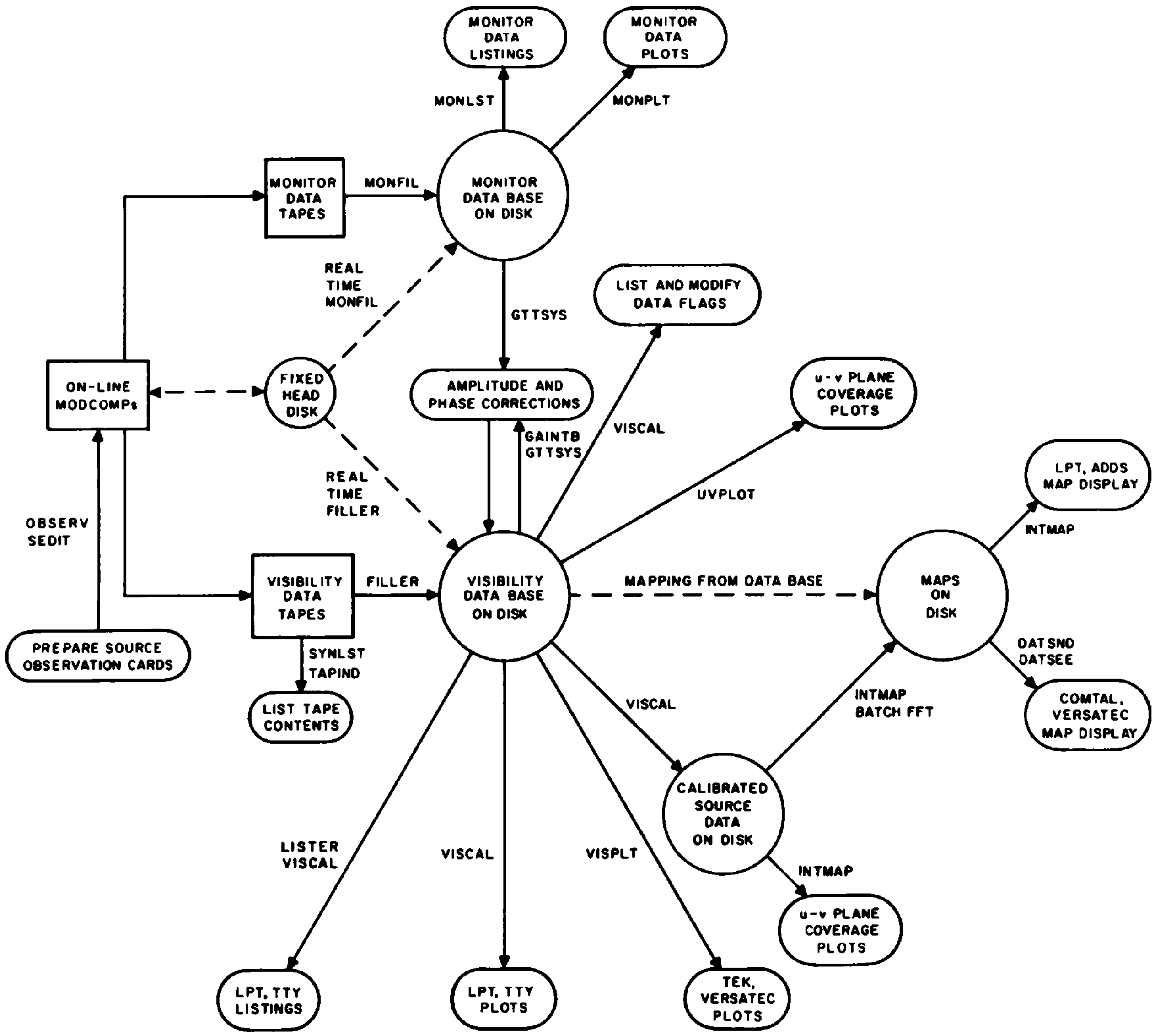

Figure III-4. OFF-LINE DATA PROCESSING.

The GO command initiates execution of FILLER, and as the data are put in the appropriate data base files in the user's [14,PN] area on disk, a short summary of date, time, source, source qualifier, mode of observation, calibrator status, frequency, bandwidth, and the number of visibility records is displayed for each scan.

ii. LISTER

LISTER is a special purpose program to display visibility data on the user's terminal (TTY) or on the line printer (LPT). In addition to standard parameter input commands, which in this case serve to allow data selection, there are a number of commands specific to LISTER. The major commands are: OUTPUT 'TTY'|'LPT'|'BOTH' by which the user selects the form of output; LISTING 'SUMMARY'|'DETAIL' which allows choice of either a summary of the major parameters of selected scans or that plus a detailing columnar listing of amplitude and phase information for selected dates, times, antenna pairs, IFs, etc.; ERRORLEVEL 0|1|2|3 which selects the maximum level of error flagging to be allowed; AVGTIME <time> which specifies averaging time; and AVGTYPE 'VECTOR'|'AMP' which selects complex or amplitude averaging. With LISTER up to 7 columns of amplitude or phase information can be listed on a terminal screen or up to 12 columns on the line printer.

iii. VISPLT

VISPLT is a special purpose program to make up to 10 superimposed plots of amplitude or phase as a function of IAT, LST, hour angle, altitude, or parallactic angle. VISPLT displays the plots upon the screen of the Tektronics 4012 terminal. Hard copy of the resulting plots can be obtained by pushing a button with the result that an image of the screen is reproduced on the Versatec electro-static printer plotter. VISPLT has commands allowing the user to select line and point types, automatic scaling of the data to fill the screen, and various commands controlling the appearance, re-appearance, or removal of the current picture image.

iv. GAINTB, GTTSYS and BASFIT

The program GAINTB allows the user to place corrections in the gain table in runnam.GAI[14,PN] files. With GAINTB commands the user can multiply amplitudes by a constant, shift phases, carry out correction for effects linearly dependent on sec(zenith angle), and, given user-supplied baseline errors, correct antenna phases for such errors. Once such corrections are inserted in the gain table, subsequent runs of LISTER and VISPLT result in display of data with the gain table corrections applied.

The program GTTSYS uses information in the monitor data base to determine the system temperature, and then turns this into amplitude corrections inserted in the runnam.GAI[14,PN] file.

The program BASFIT uses a least squares technique to solve for baseline errors in selected visibility data treating a single baseline at a time. Used in conjunction with GAINTB and LISTER the user can remove phase errors due to antenna position errors.

v. MONFIL, MONLST, MONPLT, and MONDEF

MONFIL, MONLST, MONPLT, and MONDEF are programs to fill, list, plot, and select contents of monitor data base files using data taken originally from monitor data archive tapes. The program MONDEF allows the user to choose the contents of monitor data base files according to chosen antenna number, data set numbers, and multiplex addresses. With MONFIL selected monitor data can be placed in a previously defined monitor data base. MONLST is then available to list the selected contents of monitor data base files. For selected data, MONLST gives a columnar display of date, time, and the values of the monitor data points for selected antennas for a single combination of data set number and multiplex address. MONPLT allows plotting of different monitor data points as a function of time on the line printer, an ADDS terminal, or the Tektronics 4012 graphics terminal (with hard copy from the Versatec electro-static plotter).

vi. VISCAL

VISCAL is an interim multi-purpose program to allow correction and calibration of visibility data during the period before the complete antenna-based correction and calibration system is available for reliable use. VISCAL has a two level command structure, with the second level corresponding to major tasks with special purposes and their own HELP and INPUTS commands. In VISCAL the SETJY command contains sub-commands to allow inputs of source fluxes, with storage and retrieval of this information from runnam.SJY[14,PN] files. LIST has sub-commands allowing not only LISTER type listings of data, but also listing of counts per Jansky (CPJY). Listings can have corrections and/or calibrations applied, and the corrected and calibrated data can be written into PREMAP files (nam.VTB[14,PN] and nam.HDR[14,PN]) that are used by the INTMAP program and an FFT mapping system. Options allow up to 12 columns of amplitude, phase, or CPJY data to be displayed on a terminal screen and up to 24 columns on the line printer. PLOT is oriented toward plotting amplitudes, phases, or CPJY as a function of IAT days, IAT hours, elevation, sec(zenith angle), hour angle or LST on either terminal or line printer. Options allow the plots to show corrected and/or calibrated data. Automatic scaling is available.

With VISCAL's FLAG command one can use sub-commands to list, and modify for editing purposes, the flags for selected sources, times, antenna pairs, and correlators. With the CORR command one can call on sub-commands to supply parameters to correct for position error, time error, station position error, and amplitude corrections linear in sec(zenith angle). With the CAL command one can use sub-commands to generate a baseline oriented calibration table, to list this calibration table, and to get the calibration table on and off disk storage in runnam.CAL[14,PN] files.

Depending upon the setting of the DOCORR and DOCAL parameters the data dealt with in VISCAL can be in raw form or at any stage of correction and calibration.

vii. UVPLOT

UVPLOT allows the user to examine plots of the u-v plane coverage for selected visibility data in the data base. The plots can be produced for line printer or terminal screen display.

viii. INTMAP

INTMAP is a interactive program for mapping and map display. It uses the name.VTB[14,PN] and name.HDR[14,PN] files generated with the PREMAP option of LIST in VISCAL. The user can then plot the u-v coverage, carry out mapping of the data using the CFTMAP command which does mapping via the classical (or direct) transform algorithm. The resulting maps stored in mapnam.IXY (or mapnam.IBM for a beam) associated with mapnam.HXY (or mapnam.HBM for a beam) header files can then be displayed on ADDS terminals using the ADDSMAP commands, or displayed in character map form on the line printer using the LPTMAP command.

The calibrated data files generated for mapping by VISCAL can also be used as input to a set of programs doing mapping using the FFT algorithm. These programs were generated as part of a mapping simulation package and can be used to make large sized maps in reasonable computing time. By the middle of 1977 this system will be replaced by programs that map data taken from the data base in addition to data in the simple format supplied with the PREMAP command of LIST in VISCAL.

g. CANDID

By the latter part of 1977 it is probable that CANDID (Command and Algorithm Notation for Data Inundation Device) will be available for general use as a control language for data processing in the DEC-10. At this time the user will be able to make use of not only the LISTER, VISPLT, VISCAL, INTMAP, etc. programs as CANDID commands, but will also have capabilities to define his own additional or replacement programs. This stage of development awaits completion of the solution of certain system software problems.

h. PDP 11 programs

The DEC-10 is linked to the PDP 11/40 that runs the map display system by a terminal-type line. The display is oriented around a COMTAL gray scale and color CRT display system and a DEC GT40 refresh line graphics system. A program named DATSND allows maps generated in the DEC-10 to be sent into disk storage in the PDP 11/40. A map display program named DATSEE can then be run. DATSEE is a menu oriented program with a dozen or so options. There are gray scale, inverted gray scale, color scaling, and color contouring map displays. The transfer function can be altered to enhance any of the intensity levels in the map. Program control is primarily through a data tablet. Cross-sections of maps displayed on the COMTAL screens can be displayed on another refresh screen. Hardcopy of COMTAL images is obtained from the use of the Versatec electro-static printer-plotter. The most effective display on the Versatec is a 33-level gray scale display that also shows the effects of intensity contouring.

APPENDIX

APPENDIX A

Preparing An Observing Program

1. Overview with examples

The shift operator will help you in locating devices and getting started. Ask David Rosenbush (phone 299) for a DEC-10 project-programmer number. You will constantly use this in the data reduction. It designates your private magnetic disk areas.

Preparing a Source Catalog

The first step is to prepare a punched card catalog of sources. The calibrators in Table III-2 are already stored in the Modcomps and should not be included in your user catalog. The format is as follows:

NAME,RIGHT ASCENSION,DECLINATION,21 cm GAIN CODE,6 cm GC,2 cm GC,1 cm GC

Gain code 0 is good up to 2 Jansky at 21 and 6 cm, and 8 Jansky at 2 and 1.3 cm. The flux limit doubles for each unit of gain code increase. When in doubt be conservative with the gain codes, to avoid saturation.

General convention: fields are separated by any number of blanks or one comma (but not both). The last card must have a $$ in the first two columns. The standard calibrators (see Section III.1.b) and other well known sources are known to the program, and can be invoked by name. Examples of user source catalog:

```
3C48     01 34 49.832   +32 54 20.52  5 5 2 2
3C120    04 30 31.603   +05 14 59.62  3 3 0 0
DA267    09 23 55.321   +39 15 23.58  3 3 0 0
3C286    13 28 49.660   +30 45 58.70  4 4 0 0
3C84,03 16 29.56,41 19 51.93,5,5,2,2
3C124,12 03 67.234,-23 18 54,0,0,0,0
$$
```

Not all fields need appear explicity e.g.

```
3C84,3 16 29.56,41 19 51.93,,,2,2
```

<u>Observing List Preparation Example</u>

Ask the telescope operator on duty to give you a Modcomp terminal to use, and job control.

Type:

```
$JOB
$OBSERV,filename
```

The file name is of your choice, up to 8 characters. The operator will need to know this name before the observation starts.

```
./ID,YOUR LAST NAME, YOUR PROGRAMMER NUMBER
```

Now, deposit your card catalog in the hopper of the card reader and turn on power (back panel switch).

Press green button and wait a few seconds, type

```
./USE,CR
```

Cards will be read in.

```
./CAL,3C84,NRAO140,CTA26,BLLAC   etc.
```

Specifies which sources will be used as calibrators.

```
./SET BAND=CC  (LL for 21 cm,CC for 6 cm,UU for 2 cm,KK for 1.3 cm)
```

```
./INFORMAT,NAME,STOPTIME
```

Defines the input format to the source name, followed by the stop time.

```
./ADD
```

Begin to add sources to the list.

```
3C84,2 15
```

3C286,2 30

3C345,3 00

CYGX-1,3 15

Which means 3C84 will be observed until 2h 15m local sidereal time, etc. Source positions will be taken from the card catalog, calibrators from the master catalog in the computer.

./LIST Lists the observing list as it stands.

F1 stops listing, F2 continues listing (orange buttons) the format is: NAME,QUALIFIER,STOP TIME,RA,DEC, BAND,MODE,GAIN,BANDWIDTH

./ADD Go back to adding sources. Make sure you are at the end of the list.

0851+202	3 30
0923+39	3 45
3C147	4 00

./LIST At this point you discover you have made a mistake in line number n

./GOTO,n

./MODIFY,NAME= ,STOPTIME= ,RA= ,DEC= ,BAND= ,MODE= GAIN= ,WIDTH=

Only identifiers you want to modify need be specified.

If you need to change several consecutive cards with the same modification:

./CHANGE,IDENTIFIER,number of cards to change

VALUE

Example: in the current card, and the one following, the bandwidth is 50 MHz, and you want it changed to 12 MHz (code 2).

./CHANGE,WIDTH,2

2222

./DELETE,linenumber

Will delete the given line and renumber cards following; it is wise to do your deleting starting from the end. To delete more than one card, type

./DELETE,starting linenumber,ending linenumber

When your source list is complete:

./CHECK Asks for a minimum elevation (8 degrees physical telescope limits or higher) and start time, and checks for errors in the list. Ask operator before using this command, as it uses the printer, or type ./CHECK,SB1 for messages on your terminal.

./LIST TYC Prints the list on the line printer. Ask telescope operator before using this command to be sure the printer is available. Listings can also be made on the DEC line printer.

./CATALOG Give the shift operator instructions on when this particular file should be used and a copy of the listing.

The preceding example illustrates just one of the many possible procedures. The following listing of commands and identifiers will enable you to set up a format best suited to your needs.

2. Command definitions

Any command name may be abbreviated to the first 3 characters.

./ADD Enables the user to start or continue adding sources to the current position in the list.

./ADD,LO,AN,LI,PM

Adds a local oscillator, azimuth wrap, line observation, and/or planetary motion card, as specified. See identifier definitions and card formats (VLA Computer Memorandum No. 131 or operator's manual).

./BACK,N Backs current line pointer by N.

./CAL,NAME1,NAME2,etc.

Specifies the list of calibrator sources.

./CAL,LIST Lists the calibrator list on the terminal.

./CAL,DELETE,NAME1,NAME2,etc.

Deletes names from the calibrator list.

./CATALOG Writes the list on magnetic disk (partition DVP, other partitions are possible).

./CHANGE,IDENTIFIER,N

VALUE Changes specified fields in N cards starting with the current card, to the specified VALUE. See identifier definitions and./LINENUMBER.

./CHECK,outputdevice

Checks the source list, with default output to the line printer, for stoptime sequence errors and elevation limit errors. Asks for a minimum elevation (hardware limit is 8 degrees), and a starting sidereal time.

./DELETE,N,M Deletes cards N thru M. Cards following M are renumbered. It is advisable to start deleting from the end, to avoid confusion, or to ./LIST after each deletion. M need not be specified, in this case only card N is deleted.

./DUPLICATE,N,M

Duplicates cards N thru M, inserting them immediately after the current card. See ./LINENUMBER.

./EXIT Provides for an orderly termination of OBSERV.

./FORWARD,N Advances current card pointer by N.

./GOTO,N Sets the current card pointer to N.

./INFORMAT,IDENTIFIER1,IDENTIFIER2,etc.

Defines the desired ./ADD format. Without any identifiers, it allows you to inspect input parameters, without changing a previously specified format.

./LIST,device Lists the source list; default device is the terminal that you are using. TYC designates the line printer in the control room. Ask telescope operator before using this printer.

./LINENUMBER Displays the current card number.

./MODIFY,IDENTIFIER1=value,IDENTIFIER2=value,etc.

Modifies specified fields in the current card. See identifier definitions and ./LINENUMBER.

./OUTFORMAT,IDENTIFIER1,IDENTIFIER2,etc.

Specifies the ./LIST format

./PRINT,N Prints n cards starting with the current card. See ./LINENUMBER.

./RECOVER,FILENAME

Retrieves the specified file for further editing. Without a name, it recovers the file last produced by OBSERV from this terminal, if the scratch area has not been disturbed by other users.

./SET,IDENTIFIER1=value,IDENTIFIER2=value,etc.

Sets default parameters for specified items. See identifier definitions.

./STARTTIME,hh mm ss

Converts a source list specified in durations to stop times, beginning the first observation at the specified STARTTIME. It is recommended that you do this for all but very short lists. Otherwise, operators may get confused as to what you want done if your observations are interrupted for any reason.

./USE,CR — Commands the reading of the observer's source catalog from the card reader. Other hardware devices, or a disk partition can also be specified, but punched cards are most convenient.

3. Identifier definitions

BAND — LL,CC,UU,KK, where:

L=	21 cm band
C	6 "
U	2 "
K	1.3 "

First letter for channel A, second for channel C. CU,UC are used to specify the dual frequency mode, which requires manual installation of the dichroic mirror (advance scheduling needed).

CALIBRATOR

C — Designates a calibrator. (Other codes, as in Section II 3-e, are being implemented).

DEC — dd mm ss.sss

DURATION hh mm ss

Specifies a duration ($ in column 14) rather than a stoptime. It is often convenient to make a source list with durations, to be converted to stoptimes before you start observing.

EPOCH

blank	1950.0
C	2000.0
D	apparent position of date
Y yyyy	equinox of yyyy.0

GAIN

The following are recommended codes:

gain code	0	1	2	3	4	5	
21 or 6 cm flux Jy,	<2	<4	<8	<16	<32	<64	etc.
2 or 1.3cm "	<6	<12	<24	<48	etc.		

LO1AB

LO1CD

First local oscillator frequency for channels AB or CD. In GHz, permissible values are multiples of 0.1 GHz in the range:

19.1-20.2	GHz	at the 2 cm band
17.2-19.3		" 1.3 "
-3.2		" 20 "

LOSYA,LOSYB,LOSYC,LOSYD

Frequency synthesizer setting, in MHz. Permissible values are 50*n±10.

MODE

blank - normal interferometer mode

PA or PC - single dish pointing mode with channel A or C

IA or IC - interferometer pointing mode

D - delay setting mode

NAME	Source name, 8 characters, no imbedded blanks or commas.

ODU	Observation duration hh mm ss

CDU	Calibration " "

(These identifiers are used only with the ./SET command to set default durations.)

PMDRA	Planetary motion right ascension rate, seconds of time per day.

PMDDEC	Planetary motion declination rate, arcseconds per day.

PMEPOCH	Epoch for the planetary coordinates hh mm ss

The date for the epoch is the date of observing. Do not permit a scan to go past midnight UT.

QUALIFIER	Source name extension, number less than 32768.

RA	Right ascension, hh mm ss.sss

STOPTIME	Local sidereal stop time hh mm ss (ss may be omitted).

WIDTH	bandwidth	0	49 MHz
		2	12 "
		D	1.5 "

All four channels must be specified; example:0000,0D0D

4. Sedit examples

Sedit is the Modcomp computer text editor. In a few instances it may be to your advantage to correct the source list directly thru SEDIT.

$JOB

$EXE SED

ASS USL DVP

POSITION filename

RANDOM

LIST

GOTO LINENUMBER

CHANGE :OLDSTRING: :NEWSTRING: 1 ncards

Oldstring is replaced by newstring, once per line, starting with the current card, in ncards.

OVER :^ xxxx: ncards

The space after OVER is required, as is the four character word OVER, and the caret after the semicolon.

Non-blank characters replace characters in the old line, at the column where they are located. Other characters are not changed. To specify a blank, use the & character.

FOR n

BACK n Moves the card pointer forward and back n lines.

SCAT filename Catalogs the file and saves the oldfile under the old name ,truncated to 7 characters, preceded by a period.