US/GR BK/

THE FOUR-ELEMENT NRAO INTERFEROMETER

A PRELIMINARY DISCUSSION

[Internal Report]

Ed Fomalont

November 1, 1973

Introduction

The NRAO interferometer now consists of four elements, the newest addition being a 45-ft alt-az telescope. This antenna is portable and is electronically connected to the control building by a microwave link. At the present time the 45-ft is located on a mountaintop near Huntersville, about 35 km southwest of 85-1, for long baseline observations. Another foundation for the antenna is located about 500 meters east of 85-1 and future sites are anticipated.

This report is a preliminary update of Hjellming's An Introduction to the NRAO Interferometer (hereafter called the interferometer manual) incorporating changes in the on-line data handling and software in Charlottesville. The new observing system is now being used for all interferometer programs -- so these changes will effect all continuum observers.

It will be assumed that the reader has an understanding of the interferometer manual. In Section I specific changes and additions to the interferometer manual will be discussed. In Section II special problems and considerations with regard to the 45-ft telescope, especially at the Huntersville site, will be described.

I. INTERFEROMETER MANUAL UPDATES

A. Modes of Observing: (II-1, II-5 in Interferometer Manual)

The 45-ft telescope is equipped with four receivers; two at 2695 MHz (SBAND) sensitive to LCP and RCP, and two at 8085 MHz (XBAND) sensitive to LCP and RCP. Thus the usual four modes of operation M(Mixed), D(Dual), S(SBAND), X(SBAND) are all available with all 45-ft telescope correlators.

The correlator numbers now are:

MODE	CORRELATOR NUMBER	CORRELATOR DESIGNATION
M	0	X 1R2R
	1	S 1L2L
	2	X 1R3R
	3	S 1L3L
	4	X 2R3R
	5	S 2L3L
	6	X 1R4R
	7	S 1L4L
	8	X 2R4R
	9	S 2L4L
	10	X 3R4R
	11	S 3L4L
D	0	S 1R2R
	1	S 1L2L
	2	S 1R3R
	3	S 1L3L
	4	S 2R3R
	5	S 2L3L
	6	S 1R2L
	7	S 1L2R
	8	S 1R3L
	9	S 1L3R
	10	S 2R3L
	11	S 2L3R
	12	S 1R4R
	13	S 1L4L
	14	S 2R4R
	15	S 2L4L
	16	S 3R4R
	17	S 3L4L
	18	S 1R4L
	19	S 1L4R
	20	S 2R4L

MODE	CORRELATOR NUMBER	CORRELATOR DESIGNATION
S	0	S 1R2R
	1	S 1L2L
	2	S 1R3R
	3	S 1L3L
	4	S 2R3R
	5	S 2L3L
	6	S 1R2L
	7	S 1L2R
	8	S 1R3L
	9	S 1L3R
	10	S 2R3L
	11	S 2L3R
	12	S 1R4R
	13	S 1L4L
	14	S 2R4R
	15	S 2L4L
	16	S 3R4R
	17	S 3L4L
	18	S 1R4L
	19	S 1L4R
	20	S 2R4L
	21	S 2L4R
	22	S 3R4L
	23	S 3L4R

21	S 2L4R			
22	S 3R4L			
23	S 3L4R			
24	X 1R2R	X	0	X 1R2R
25	X 1L2L		1	X 1L2L
26	X 1R3R		2	X 1R3R
27	X 1L3L		3	X 1L3L
28	X 2R3R		4	X 2R3R
29	X 2L3L		5	X 2L3L
30	X 1R2L		6	X 1R2L
31	X 1L2R		7	X 1L2R
32	X 1R3L		8	X 1R3L
33	X 1L3R		9	X 1L3R
34	X 2R3L		10	X 2R3L
35	X 2L3R		11	X 2L3R
36	X 1R4R		12	X 1R4R
37	X 1L4L		13	X 1L4L
38	X 2R4R		14	X 1R4R
39	X 2L4L		15	X 2L4L
40	X 3R4R		16	X 3R4R
41	X 3L4L		17	X 3L4L
42	X 1R4L		18	X 1R4L
43	X 1L4R		19	X 1L4R
44	X 2R4L		20	X 2R4L
45	X 2L4R		21	X 2L4R
46	X 3R4L		22	X 3R4L
47	X 3L4R		23	X 3L4R

B. <u>Lobe Rotation</u> (II-5)

In the old system the fringe rate was 'natural' and proportional to the diurnal motion of the source through the fringe pattern. This produced some inconvenience at cross-over when the fringe rate went to zero, necessitated filter corrections to be applied, and would have produced an excessive fringe rate at XBAND with a 35 km baseline for proper sampling at 20 ms.

The computer now accurately adjusts the local oscillator frequency and phase to each antenna to produce sinusoidal fringes of constant period for each baseline and frequency. The fringe periods in seconds are:

Frequency	COR 1-2	COR 1-3	COR 2-3	COR 1-4	COR 2-4	COR 3-4
SBAND	15	15/2	15	15/3	15/2	15
XBAND	5	5/2	5	5/3	5/2	5

The DDP computer solves for A(u,v) and ϕ(u,v) every 30^s as before.

C. <u>System Calibrations and Parameters</u> (II-7, II-9)

The system parameters are normally determined by the staff after each configuration change. These calibrations involved are: baseline parameters, pointing constants and delay centers. These parameters are entered into the DDP on cards, and rarely will the observer change these cards. The eight baseline cards are

```
         1111111111222222222233333333334444444444555555555566666666667777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

C   POSITION OF TELESCOPES 2,3,4 WITH RESPECT TO 85-1 (UNITS OF NANOSECONDS)

      BX                     BY                     BZ     SITE #       K

  -2527.746              -7955.482              3382.403    27  2       0.0          1
  -1775.744              -5598.140              2382.731    21  3       0.0          2
 -65465.622             -53469.051             81811.412     H  4      22.301        3

C   POINTING COEFFICIENTS FOR EACH TELESCOPE

1  87  118  -61    3   28  -58   21   44 -101  -42   48   -2  -18    4   44 -101   4
2 -75  102   17  156   15  -20   14   39 -100   70  -14  -20   41   35   39 -101   5
3 -88  144  -32   44    7  -24    8   39 -100   47   10  -60  -23   44   39 -100   6
4 434   59   47  -25 -171  165   13  -56 -128   72                                 7

C   DELAY CENTERS FOR TELESCOPES 2,3,4 WITH RESPECT TO 85-1 (OCTAL-UNITS OF
C         1000/1024 NANOSECONDS).  ALSO CLOCK OFFSET FOR 85-4 IN SECONDS OF TIME

002277     012316     00000350754                  -42.43                            8

         1111111111222222222233333333334444444444555555555566666666667777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

Results of the most recent pointing runs are located in the interferometer control building. The accuracy is ± 30" for the 85-ft telescopes and ± 45" for the 45-ft. The baseline values on the cards are best estimates and are accurate to about .02 ns ≃ .06 wavelength at SBAND. Further updating of the baseline values are made in Charlottesville after a baseline run of calibrators has been processed.

D. Limits of the 45-Ft (II-11)

The observing limits of the 45-ft telescope are

$$3° < \text{Elevation} < 120°$$

$$-163.^{\circ}2 < \text{Azimuth} < 373.^{\circ}9$$

The DDP program keeps track of any 'wrap-around' problems. The slewing speed is 40 degrees per minute, faster than the 85-ft telescopes. Occasionally the 45-ft will slew ~ 360° in azimuth causing a delay of ~ 9 minutes.

At the Huntersville site, the horizon contour is shown in Figure 1.

E. New Program Card and Calibrator List (II-10 to II-14; App. I & II.)

The program cards used at the interferometer have been revised. The revision was necessary in order to incorporate additional parameters needed for the four-element system. Because many improvements were made to the new "Four-element" system, it is being used for all interferometer programs, even those using only the three 85-ft telescopes.

The new program card is shown in the Figure. The card description is:

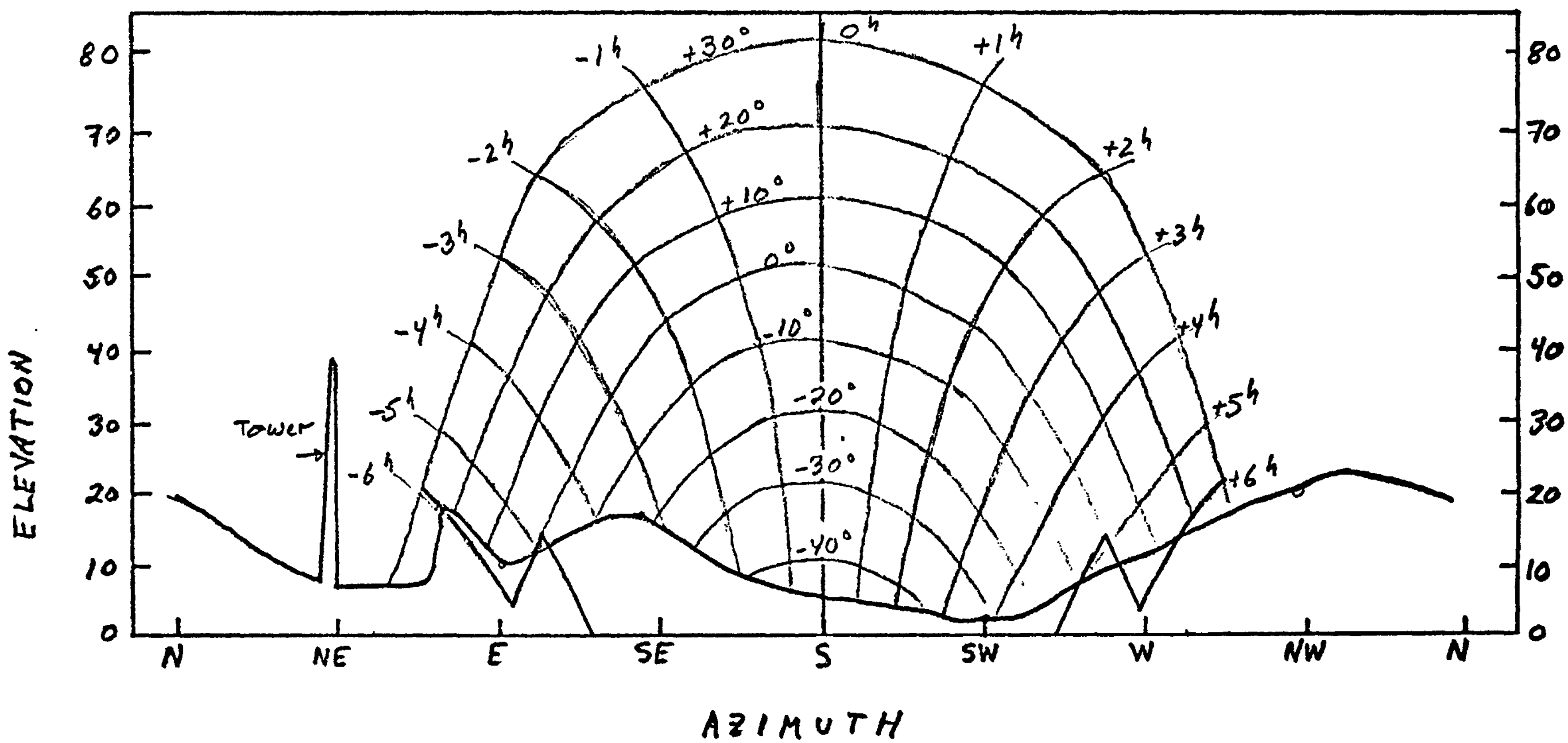
Column

1- 8 Source name of eight characters or less, left-hand adjusted, containing at least one non-numeric character and having no imbedded blanks. (14622 or 3C 48 are illegal source names).

10 The epoch of the source coordinates. blank=1950.0 epoch, all necessary corrections are applied. D=current position, only diurnal abberation is applied. M=mean position, only non-precession corrections are applied.

FIGURE 1

HORIZON AT HUNTERSVILLE SITE



12-23 }
25-36 } Right ascension and declination at the above epoch. All leading zeros must be included as well as the decimal point in columns 20 and 34.

38-46 Ignore the velocity field for continuum observations.

48-53 Correlator gains for all six total intensity correlators; use the table on page II-13 of the interferometer manual. For the 45-ft correlators the gain step from 0 to 1 should be applied to sources stronger than about 10 Jy (nee flux units).

55 The observations mode M,D,S or X as explained on page II-2. All of the modes are available with the 45-ft telescope. Do not leave this column blank.

57 A "C" in column 57 indicates that the source is a calibrator. No action, however, is presently taken.

60-64 The stop time of the observation-Local sidereal time. The duration time alternative has not yet been implemented.

66-72 }
73-80 } Flux density of the system gain calibrator. If the flux density is non-zero, the online CRT and teletype display of the source amplitude will be in units of counts per flux unit (CPFU). The system gain can then be easily checked.

A set of phase, gain and polarization calibrators are given in Table I, II, III. Slight revisions have been made to the lists in Appendix 1 and 2 of the interferometer manual. Prepunched calibrators cards are available at the interferometer. Only the observing mode and stop time need be added to these cards. Flux densities in columns 66-72 or 73-80 are only included for sources with wt greater or equal than 0.40. Revisions in flux densities are periodically made for variable sources and more accurate positions are expected from future 45-ft observations. A subset of calibrators for use with the 45-ft long baseline work is given in Table IV. Some of the standard

NRAO calibrators are resolved or have relatively large positional errors. This list should be considered as still tentative.

NEW PROGRAM CARD

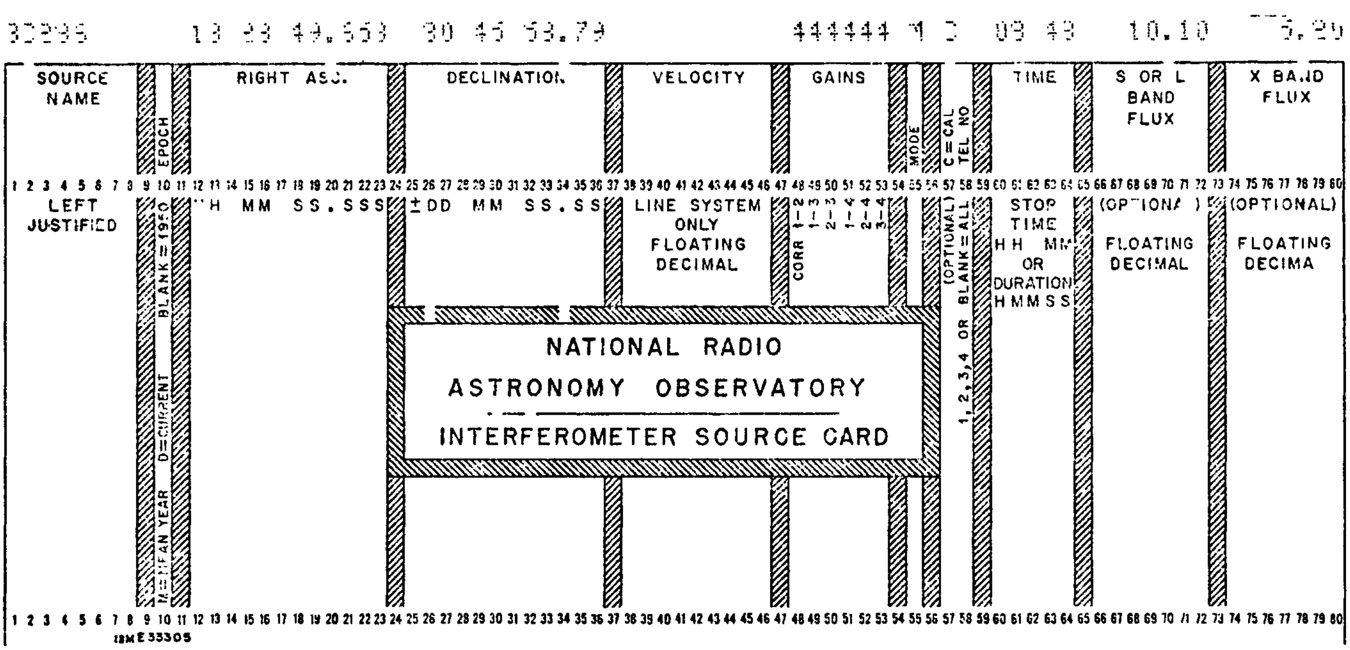


TABLE I

PHASE CALIBRATORS

P0056-00	P0106+01	P0114-21	3C48	NRAO91
D0224+67	P0237-23	CTA21	3C84	NRAO140
NRAO150	P0403-13	P0413-21	P0420-01	3C119
3C120	P0438-43	NRAO190	P0451-28	3C138
3C147	P0605-08	P0607-15	P0614-34	DA207
OI318	D0727-11	P0735+17	P0736+01	OI363
D0742+10	P0743-00	P0834-20	OJ287	P0859-14
P0906+01	DA267	3C232	3C236	P1015-31
P1055+01	P1116+12	P1127-14	P1148-00	P1151-34
3C268.3	P1237-10	P1245-19	3C279	3C287
3C286	P1345+12	OQ208	OQ323	3C298
3C309.1	3C371	3C395	OV080	3C418
P2127+04	P2128-12	P2134+00	P2145+06	P1508-05
P1510-08	D1548+05	D1555+00	P1607+26	DA406
3C345	NRAO530	P2149-28	BLLAC	P2203-18
3C446	CTA102	3C454.3	P2345-16	

FLUX DENSITY CALIBRATORS

SOURCE	SBAND	XBAND	WT
P0056-00	1.800	1.100	0.10
P0106+01	3.200	5.200	0.30
P0114-21	2.200	0.700	0.10
3C84	16.500	52.400	0.10
3C48	9.000	3.300	1.00
NRAO91	3.600	2.500	0.40
D0224+67	1.200	1.900	0.40
P0237-23	5.000	2.400	0.10
CTA21	4.900	1.900	0.70
NRAO140	2.900	1.900	0.80
NRAO150	5.200	8.900	0.10
P0403-13	2.700	1.700	0.10
P0413-21	1.600	0.850	0.10
P0420-01	1.300	1.500	0.10
3C119	5.400	2.300	0.90
3C120	9.200	12.600	0.10
P0438-43	5.900	4.100	0.10
NRAO190	2.900	1.700	0.10
P0451-28	2.400	2.200	0.20
3C138	5.700	2.700	0.70
3C147	12.500	5.000	1.00
P0605-08	3.500	3.900	0.20
P0607-15	2.000	3.300	0.20
P0614-34	2.100	1.100	0.20
OI318	1.800	1.300	0.30
D0727-11	2.600	3.900	0.10
P0735+17	1.800	2.000	0.30
P0736+01	2.100	1.600	0.10
OI363	2.300	1.900	0.10
D0742+10	3.900	3.000	0.70
P0743-00	1.300	1.600	0.10
P0834-20	3.100	3.700	0.10
P0859-14	2.700	1.900	0.40
DA267	4.700	10.700	0.60
3C236	2.100	1.000	0.40
P1015-31	2.300	1.100	0.20
P1055+01	3.100	3.100	0.10
P1116+12	1.700	1.200	0.60
P1127-14	6.500	4.800	0.60
P1148-00	2.500	1.400	0.20

FLUX DENSITY CALIBRATORS

SOURCE	SBAND	XBAND	WT
P1151-34	4.300	2.000	0.10
P1237-10	1.400	1.000	0.10
P1245-19	3.700	1.700	0.50
3C279	12.800	11.100	0.20
3C287	4.600	2.200	1.00
3C286	10.100	5.200	1.00
P1345+12	3.800	2.200	0.50
3C298	2.800	1.000	0.20
3C309.1	5.300	2.500	1.00
P1508-05	2.700	1.900	0.70
P1510-08	2.100	2.600	0.10
D1548+05	2.000	2.100	0.10
D1555+00	1.400	1.500	0.10
DA406	2.300	2.000	0.60
3C345	9.200	11.300	0.10
NRAO530	4.300	5.100	0.70
3C371	1.800	2.000	0.40
3C395	3.000	1.800	0.50
3C418	4.000	3.600	0.60
P2128-12	1.700	1.900	0.40
P2145+06	3.500	3.900	0.10
P2149-28	1.900	0.800	0.40
3C446	5.200	3.800	0.40
BLLAC	6.000	8.100	0.10
3C454.3	11.000	10.000	0.10
P2345-16	4.200	4.300	0.10

TABLE II

POLARIZATION CALIBRATORS

Source	2695 MHz Flux Density	2695 MHz % Pol.	2695 MHz Pos. Ang.	8085 MHz Flux Density	8085 MHz % Pol.	8085 MHz Pos. Ang.	Comments
3C48	9.0	2.1	60	3.3	5.5	110	1
3C147	12.5	0.7	44	5.0	0.7	163	1
3C286	10.1	9.2	30.9	5.2	11.4	34.4	1
3C84	16.5	1.1	42	52.4	0.9	67	4
3C119	5.4	7.7	47	2.3	6.2	47	2
3C138	5.7	8.0	165	2.7	11.5	170	2
P1127-14	6.5	2.4	29	4.8	2.7	145	3
3C273	30	2.0	70	$\sim$40	1.4	130	4
3C309.1	5.3	2.0	84	2.5	2.2	40	2
3C345	9.2	3.1	48	11.3	2.5	16	3
NRAO530	4.3	4.5	43	5.1	4.0	85	3
P2134+00	7.4	1.0	40	11.0	2.7	140	4
3C454.3	11.0	5.0	58	10.0	3.5	173	3

1 Standard Calibrator $\pm$ 0.3% at 2695 MHz, $\pm$ 0.5% at 8085 MHz

2 Secondary Calibrators - Little variation

3 Moderately variable

4 Very Variable

STANDARD LIST OF PHASE AND GAIN CALIBRATORS UPDATED SEPT 24,1973 TABLE III

SOURCE	RHT ASC.	DECLINATION	GAINS	M	BAND	X BAND
P0056-00	00 56 31.760	-00 09 18.40		C		
P0106&01	01 06 04.482	01 19 00.95	444000	C		
P0114-21	01 14 25.910	-21 07 53.40		C		
3C48	01 34 49.827	32 54 20.63	444111	C	9.00	3.30
NRA091	02 02 07.410	14 59 50.50	111000	C	3.60	2.50
D0224&67	02 24 41.130	67 07 39.90		C	1.20	1.90
P0237-23	02 37 52.750	-23 22 04.80	111000	C		
CTA21	03 16 09.145	16 17 40.70	111000	C	4.90	1.90
3C84	03 16 29.562	41 19 51.99	888444	C		
NRA0140	03 33 22.390	32 08 36.75		C	2.90	1.90
NRA0150	03 55 45.245	50 49 20.55	444444	C		
P0403-13	04 03 14.020	-13 16 20.80		C		
P0413-21	04 13 53.650	-21 03 52.00		C		
P0420-01	04 20 43.530	-01 27 28.10		C		
3C119	04 29 07.895	41 32 08.65	111000	C	5.40	2.30
3C120	04 30 31.599	05 14 59.70	444444	C		
P0438-43	04 38 43.240	-43 38 56.20	444000	C		
NRA0190	04 40 05.280	-00 23 20.75		C		
P0451-28	04 51 15.140	-28 12 29.90		C		
3C138	05 18 16.526	16 35 27.06	111000	C	5.70	2.70
3C147	05 38 43.503	49 49 42.87	444111	C	12.50	5.00
P0605-08	06 05 35.970	-08 34 18.40	444000	C		
P0607-15	06 07 26.020	-15 42 04.20		C		
P0614-34	06 14 48.810	-34 55 08.60		C		
DA207	06 21 41.875	32 06 47.25		C		
OI318	07 11 05.600	35 39 52.60		C		
D0727-11	07 27 58.130	-11 34 53.50	444000	C		
P0735&17	07 35 14.125	17 49 09.45		C		
P0736&01	07 36 42.517	01 44 00.32		C		
OI363	07 38 00.165	31 19 02.35		C		
D0742&10	07 42 48.450	10 18 32.80	444000	C	3.90	3.30
P0743-00	07 43 21.040	-00 36 55.30		C		
P0834-20	08 34 24.650	-20 06 31.40	444000	C		
OJ287	08 51 57.250	20 17 58.45	444000	C		
P0859-14	08 59 54.960	-14 03 38.60		C		
P0906&01	09 06 35.190	01 33 48.10		C		
DA267	09 23 55.292	39 15 23.63	444444	C	4.70	10.70
3C232	09 55 25.390	32 38 23.40		C		
3C236	10 03 05.375	35 08 48.10		C	2.10	1.00
P1015-31	10 15 53.440	-31 29 12.50		C		
P1055&01	10 55 55.310	01 50 03.70	444000	C		
P1116&12	11 16 20.760	12 51 06.70		C	1.70	1.20
P1127-14	11 27 35.670	-14 32 54.70	444000	C	6.50	4.80
P1148-00	11 48 10.110	-00 07 12.92		C		
P1151-34	11 51 49.420	-34 48 46.40	111000	C		
3C268.3	12 03 54.090	64 30 18.70		C		
P1237-10	12 37 07.290	-10 07 00.60		C		
P1245-19	12 45 45.220	-19 42 57.60	111000	C	3.70	1.70
3C279	12 53 35.824	-05 31 07.69	444444	C		
3C287	13 28 15.940	25 24 37.25	111000	C	4.60	2.20
3C286	13 28 49.653	30 45 58.79	444444	C	10.10	5.20
P1345&12	13 45 06.180	12 32 20.07	111000	C	3.80	2.20
OQ208	14 04 45.617	28 41 29.38		C		
OQ323	14 13 56.285	34 58 29.70		C		
3C298	14 16 38.860	06 42 19.40		C		
3C309.1	14 58 56.644	71 52 11.17	111000	C	5.30	2.50

TABLE III (con't).

SOURCE	RIGHT ASC.	DECLINATION	GAINS	M	S BAND	X BAND
P1508-05	15 08 14.950	-05 31 49.10		C	2.70	1.90
P1510-08	15 10 08.880	-08 54 46.70		C		
D1548&05	15 48 06.900	05 36 12.40		C		
D1555&00	15 55 17.680	00 06 44.20		C		
P1607&26	16 07 09.290	26 49 18.50		C		
DA406	16 11 47.930	34 20 19.85		C	2.30	2.00
3C345	16 41 17.603	39 54 10.89	444444	C		
NRAO530	17 30 13.460	-13 02 45.80	444000	C	4.30	5.10
3C371	18 07 18.550	69 48 57.00		C	1.80	2.00
3C395	19 01 02.300	31 55 13.90	111000	C	3.00	1.80
OV080	19 47 40.130	07 59 36.90		C		
3C418	20 37 07.410	51 08 36.20	444000	C	4.00	3.60
P2127&04	21 28 02.615	04 49 04.05	111000	C		
P2128-12	21 28 52.760	-12 20 23.30		C	1.70	1.90
P2134+00	21 34 05.208	00 28 25.45	444444	C		
P2145&06	21 45 36.050	06 43 40.40	444000	C		
P2149-28	21 49 10.570	-28 42 36.50		C	1.90	0.80
BLLAC	22 00 39.362	42 02 08.69	444444	C		
P2203-18	22 03 25.710	-18 50 16.60	444000	C		
3C446	22 23 11.050	-05 12 17.50	444000	C	5.20	3.80
CTA102	22 30 07.793	11 28 22.89	444000	C		
3C454.3	22 51 29.510	15 52 54.54	444444	C		
P2345-16	23 45 27.610	-16 47 50.10	444000	C		

SOURCE SITIONS WITH GREATEST ACCURACY FOR USE WITH TH 5 KM BASELINE TABLE IV
OCTOBER 26,1973

SOURCE	RIGHT ASC.	DECLINATION	GAINS				
3C48	01 34 49.827	32 54 20.63	444111	C	9.00	3.30	RESOLVED AT XBAND
P0237-23	02 37 52.741	-23 22 04.29	111000	C			DERIVED POSITION
✓ 3C84	03 16 29.562	41 19 51.99	888444	C			
NRAO150	03 55 45.258	50 49 20.38	444444	C			DERIVED POSITION
✓ 3C119	04 29 07.895	41 32 08.65	111000	C	5.40	2.20	
3C120	04 30 31.599	05 14 59.70	444444	C			DERIVED POSITION
✓ 3C138	05 18 16.526	16 35 27.06	111000	C	5.60	2.80	
3C147	05 38 43.503	49 49 42.87	444111	C	12.70	5.00	RESOLVED AT XBAND
✓ OA251	08 31 04.378	55 44 41.40	444444	C			
OQ208	14 04 45.617	28 41 29.38		C			ACCURATE POSITION BUT UNCHECKED
3C309.1	14 58 56.644	71 52 11.17	111000	C	5.30	2.50	ACCURATE POSITION BUT UNCHECKED
✓ 3C345	16 41 17.603	39 54 10.89	444444	C			
3C395	19 01 02.302	31 55 14.19	111000	C			DERIVED POSITION
✓ BLLAC	22 00 39.362	42 02 08.69	444444	C			
✓ CTA102	22 30 07.793	11 28 22.89	444000	C			
✓ 3C454.3	22 51 29.510	15 52 54.54	444444	C			

✓ USE THIS CALIBRATOR WHENEVER POSSIBLE

F. Interferometer Logs (II-17)

The new log sheet format is shown in Table V. The log headings are similar to the old logs. We have added an entry called 'first scan on tape' which gives the number of the first scan dumped on the current tape. In rare cases when several programs are mixed and a tape does not contain consecutive data, the appropriate scan ranges can be included.

The station locations of 85-2, 85-3 and the 45' telescope are useful to have. The 45' station has been designated by H for Huntersville.

It was felt that the listing of EST versus LST on the log heading was sufficient to convert EST to LST throughout the log sheet. Otherwise LST is used exclusively on the log.

The general weather conditions - cloud cover and precipitation - should be noted. This is one piece of information not recorded on tape. Large phase fluctuations occur in cloudy weather and loss of gain at X-band can occur during heavy rain and snow. For a proper analysis and interpretation of the data, the weather conditions are needed. Significant changes of cloud cover and precipitation should also be placed in the comment column of the logs as necessary.

The scan number and source name are given in columns 1 and 2. At the start of each scan only two numbers will generally be recorded, the LST and the hour angle (taken from the CRT for any telescope).

The positions for all telescopes should be quickly compared with the source position and a check placed in the RA/DEC column. There is no need to record the positions.

Four spare columns A, B, C, D are provided. Ordinarily, these columns will be blank but special observations may necessitate their use. For example, when the 45' telescope is first used we might wish to record the

INTERFEROMETER OBSERVING LOGS

TAPE NO. 876 FIRST SCAN ON TAPE: 7315 PROGRAM BS2 OPERATOR DW JW PAGE NO. 61

DATE 7/26/73 OBSERVER BB FREQUENCY 2695/8085 STATIONS 18-27-11 EST 0546 AT LST 0143 WEATHER OC. HAZY

SCAN NO.	SOURCE	LST START HH MM	HA START HH MM	RA / DEC	A 45'α	B 45'δ	C	D	CPFU	RCVR STATUS	COMMENTS: WEATHER CHANGES, GENERAL COMMENTS, RCVR & CPFU CHANGES, ALL TIMES IN LST, XNOTE ALL COMMENTS
7315	W3-P	0150	-0032	✓	022420	615547				✓	
16	3C84	0202	-0116	✓	031833	412129			✓		
17	W3-W	0211	-0011	✓	022401	615706					
18	W3-P	0221	-0002	✓	022418	615547					
19	3C84	0231	-0046	✓	031839	412705			✓	✓	
20	W3-W	0241	0018	✓	022427	615627					
21	W3-P	0251	0027	✓	022429	615547					
22	3C84	0301	-0016	✓	03 18 30	41 25 40			✓	✓	
23	W3-W	0311	+0048	✓	02 24 20	61 55 47					45' RA R/O very jumpy
24	W3-P	0321	+0058	✓	02 24 56	61 56 47					
25	3C84	0331	+0013	✓	03 18 48	41 19 50			✓		
26	W3-W	0341	+0118	✓	02 23 43	61 58 16					
27	W3-P	0351	+0127	✓	02 25 02	61 55 08					3 EXC. PT. ERRORS 85-3
28	3C84	0404	+0047	X	03 19 00	41 21 09			✓		85-3 RUNAWAY - OFF LINE
29	W3-W	0411	+0149	X	02 24 25	61 57 55					85-3 OFF LINE
7330	W3-P	0420	+0157	X	02 24 50	61 55 08					"
31	3C84	0431	+0113	X	03 19 00	41 23 47			✓		"
32	W3-W	0442	+0219	X	02 24 53	61 55 47					"
33	W3-P	0450	+0226	X	02 24 50	61 57 46					"
34	3C84	0501	+0143	X	03 19 06	41 23 07			✓	✓	"
35	W3-W	0511	+0247	X	02 24 30	62 02 23					"
36	W3-P	0521	+0257	X	02 27 50	61 57 46					"
37	3C84	0531	+0213	X	03 18 59	41 25 06			✓		"
38	W3-W	0541	+0318	X	02 24 10	62 51 10					"

TABLE V

right ascension and declination for each scan; for H line work synthesized settings are logged; some VLB observations may wish EST recorded; special monitoring of receiver functions for solar observations; etc. The spare column use can be specified on the observer sheet. However, arbitrary or useless data should not be logged.

A check of the counts per flux unit (CPFU) is the most useful check on the system response that the operator or observer can make. The CPFU for each correlator is obtained from the teletype output for a flux density calibrator. All values should agree to about 20% with the numbers obtained earlier, in which case check column 'CPFU'. If not, place a cross in the column and note in comments column and try to determine the cause of the error. Observations at very low elevation, incorrect flux densities, severe weather can cause an abnormal CPFU reading. Most system problems cause all correlators associated with the faulty receiver, delay, etc. to be affected. Inaccurate flux density values will cause all counts to be too low or high and more detailed discussion is given in Section G.

The next column is a check for the receiver status. Every few hours the system monitors should be thoroughly checked in the back room. If all meters read normally, place a check in this column. If not, place a cross and comment. Some abnormal readings may demand immediate attention.

Finally, the size of the comment column has been generously increased. We have already discussed some comments that should be included. General comments - interference, baseline drifts, computer stops, delay switching effects, limits...etc. are still to be included. All comments should have an LST time and if applicable an LST time range. All comments (except the most trivial ones - computer stops, source card errors) should be 'XNOTED' onto the disk. Although the comments are on the log sheets, it is very useful and convenient to have these written messages physically on the tape. The data editing process is greatly facilitated if these messages are written along with the affected data.

These logs are to help the operator as well as the observer in obtaining accurate data and in detecting receiver troubles early. Any comments concerning omissions in the logs are welcome.

G. On-Line Monitoring (II-18 to 21)

There are three monitoring devices; the analogue recorder, the CRT display of the 30^s integrated results, and the teletype (or line printer).*

The analogue records are useful for catching some errors. There should be obvious fringes on all calibrators. A "saw-tooth" fringe amplitude implies a delay center error. Interference spikes are obvious. Baseline shifts or jumps indicate problems.

The CRT display, as before, shows the actual 30^s data points for selected correlators. The proper 'XSHOW' command is described at the interferometer.

The teletype output has been significantly modified. An example is given in Table VI. The output is shown for a flux density calibrator and a standard source.

The sensitivity of each correlator can now be checked using the teletype output for any flux density calibrator. The amplitude units are in counts per flux unit and should remain constant $\pm$ 20% for any correlator. Next to the teletype will be a 'CPFU' sheet listing the current values for all correlators. This sheet will be updated after each configuration change, or more often, if necessary. An example is given in Table VII.

As described in connection with the new log sheet, the operators will check the CPFU on the log whenever a flux density calibrator is used. However, it is up to the observer to include the appropriate sources and accurate flux densities in their observing list. Use the prepunched cards at the interferometer.

---

* A line printer will soon be used at the interferometer.

3C309.1 CAL SCAN = 15356 MODE=D STOP=20:40 GAINS=444444
POS(CARD) 14 58 56.644 +71 52 11.16 S-FLUX= 5.29 } FLUX DENSITY
POS(DATE) 14 58 58.149 +71 46 37.64 X-FLUX= 2.50 } CALIBRATOR

203232 3C309.1
XDLY4
XDLYR
SET THUMBWHEELS=0, AND RETYPE.
XPT45EC
XPT45CC
2448653 204012 SECT 00079 RETURN 00001

			ARITH AMP	VECTOR AMP	PHASE	OFF SET	RMS	#
0	1R2R.S	1	1670	1670	-81	40	120	8
1	1L2L.S	1	1390	1390	89	00	100	8
2	1R3R.S	1	1340	1340	-77	10	100	8
3	1L3L.S	1	1390	1390	-128	00	90	8
4	2R3R.S	1	1200	1200	-177	-20	100	8
5	2L3L.S	1	1110	1110	-39	-20	100	8
12	1R4R.S	1	270	270	163	-60	80	6
13	1L4L.S	1	310	310	-127	-30	80	6
14	2R4R.S	1	220	210	67	-10	90	6
15	2L4L.S	1	00	00	-90	40	80	6
16	3R4R.S	1	00	00	0	-60	120	6
17	3L4L.S	1	00	00	45	-50	80	6
24	1R2R.X	1	960	960	15	70	220	7
25	1L2L.X	1	830	830	92	-50	180	7
26	1R3R.X	1	830	830	103	00	190	7
27	1L3L.X	1	960	960	100	20	190	7

↓ INCOMPLETE

3C345 CAL SCAN = 15357 MODE=D STOP=20:50 GAINS=444444
POS(CARD) 16 41 17.603 +39 54 10.89
POS(DATE) 16 42 05.301 +39 51 43.60

204228 3C345
2448653 205012 SECT 00111 RETURN 00001

0	1R2R.S	1	15860	15820	-75	320	840	8
1	1L2L.S	1	12770	12740	95	-40	680	8
2	1R3R.S	1	13000	12980	-67	140	730	8
3	1L3L.S	1	12920	12910	-118	100	640	8
4	2R3R.S	1	12240	12240	-171	-120	640	8
5	2L3L.S	1	10840	10830	-32	-100	640	8
12	1R4R.S	1	3230	3220	-160	-780	520	8
13	1L4L.S	1	4320	4310	-88	-270	570	8
14	2R4R.S	1	2780	2770	93	-60	530	8
15	2L4L.S	1	40	10	-45	250	460	8
16	3R4R.S	1	60	00	45	-300	690	8
17	3L4L.S	1	50	30	-45	-280	450	8
24	1R2R.X	1	10980	10850	50	190	680	7
25	1L2L.X	1	9530	9410	127	-120	550	7
26	1R3R.X	1	9600	9560	147	30	630	7
27	1L3L.X	1	10810	10770	144	110	710	7
28	2R3R.X	1	8080	8060	-82	-120	500	7
29	2L3L.X	1	9560	9520	-161	-120	630	7
36	1R4R.X	1	2070	2060	109	-750	500	7
37	1L4L.X	1	2670	2660	111	-180	520	7
38	2R4R.X	1	2070	2060	-121	-30	520	7
39	2L4L.X	1	50	20	-27	290	430	7
40	3R4R.X	1	50	20	-90	-260	680	7
41	3L4L.X	1	30	00	45	-210	460	7

SYSTEM SENSITIVITY
'CPFU'

DATE: OCT 19 '73 CONFIG: 27-19-8 H

DUAL-MODE

CORR #	CORR NAME	CPFU
0	1R2R S	1700
1	1L2L S	1375
2	1R3R S	1300
3	1L3L S	1340
4	2R3R S	1200
5	2L3L S	1140
12	1R4R S	290
13	1L4L S	430
14	2R4R S	250
15	2L4L S	–
16	3R4R S	–
17	3L4L S	–
24	1R2R X	900
25	1L2L X	790
26	1R3R X	760
27	1L3L X	890
28	2R3R X	610
29	2L3L X	730
36	1R4R X	170
37	1L4L X	230
38	2R4R X	170
39	2L4L X	–
40	3R4R X	–
41	3L4L X	–

MIXED MODE

CORR #	CORR NAME	CPFU
0	1R2R X	900
1	1L2L S	1375
2	1R3R X	760
3	1L3L S	1340
4	2R3R X	610
5	2L3L S	1140
6	1R4R X	170
7	1L4L S	290
8	2R4R X	250
9	2L4L S	–
10	3R4R X	–
11	3L4L S	–

COMMENTS: ±20 % 85-FT CORRELATORS
±50 % 45-FT CORRELATORS
ONLY 1R4R, 1L4L, 2R4R 45-FT CORRELATORS USED

H. System Noise (II-23)

Each 45-ft - 85-ft correlator should theoretically have a signal to noise about 1/2 of an 85-ft correlator. In practice we are getting about 1/3 the sensitivity; a CPFU of 500 for S-Band and 400 for X-Band. In poor weather conditions or when the local oscillator is noisy over the link, the X-Band sensitivity can be seriously degraded. In twenty-five minutes the rms signal to noise with a 45-ft correlator is $\sim$ 0.03 f.u. per pair.

I. Data Reduction (III)

At present, four-element data can be completely reduced using a "patch" system of the three-element software by splitting the DDP 7-track telescope tape into two 9-track tapes. The 85-ft tape contains only those data associated with the 85-ft correlators and is virtually identical to the old three-element tape. Thus all of the programs described in Chapter III of the interferometer manual are useable.

The second 9-track tape contains the 45-ft correlator data. The data format is similar to the 85-ft tape with all data pertaining to correlators 1-4, 2-4 and 3-4 stored in exactly the same manner as 85-ft data of correlators 1-2, 1-3 and 2-3. Thus to process 45-ft data of correlator 1-4, for example, all of the programs described in Chapter III can be used on the 45-ft tape by specifying correlator 1-2. One special precaution is that the program INTCOR45 should be run in pace of INTCORR (application of atmospheric phase effects) for both the 85' tape and the 45' tape.

A sample deck set-up to calibrate raw 45-ft data might be:

```
//CAL45_JOB_(123,P,6,8,4),FOMALONT,MSGLEVEL=1,CLASS=C
//_EXEC_INTCOPY,INTAPE=2173,INNAME=RAW45,INDISP=OLD,
//_OUTUNIT=DISK,OUTDISP='(NEW,PASS)',OUTNAME='§§COPY'
//SYSIN_DD_*
INCLUDE 1R2R  (1R-4R DATA)
INCLUDE 1L2L  (1L-4L DATA)
//_EXEC_INTCOR45,INNAME='&&COPY',
//_OUTUNIT=DISK,OUTDISP='(NEW,PASS)',OUTNAME='&&CORR'
//_EXEC_INTCAL,INNAME='&&CORR'
//_OUTUNIT=DISK,OUTDISP='(NEW,PASS)',OUTNAME='&&CEN'
//SYSIN_DD_*
INCLUDE
//DATA.PHICALS_DD_*
3C48    3C84    3C138   3C147   DAL51   3C345   3C309.1   BLLAC
CTA102  3C454.3
//DATA.AMPCALS_DD_*
3C48    9.0   3.3   1.0
3C84   16.5  52.4   1.0
3C345   9.2  11.3   1.0
//_EXEC_INTSCRIB,INNAME='&&CEN'
/*
```

Use only those calibrators listed in Table IV for the phase reduction. In several months more automatic reduction programs, as currently used with the three element system, may be implemented.

A complete four-element data reduction system is being developed. The present inconvenience of two tapes is not that bad. With the 45-ft at Huntersville, the baseline difference between the 85-ft correlators and 45-ft correlators limits any useful direct combination of the data for most inversion methods.

J. <u>Polarization</u> (III-11, 18)

Since the 45-ft telescope has an alt-az mount, as a source is tracked its feed angle rotated with respect to the feeds of the polar mounted 85-ft telescopes. With circularly polarized feeds this produces a phase change equal to the change in the parallactic angle and opposite in sense for the two polarizations. This phase effect is subtracted by the DDP.

Otherwise, the reduction of total intensity data, linearly polarized data, and circularly polarized data is unchanged.

II. THE 45-FT AT HUNTERSVILLE

A. Location, Fringe Spacing, u-v Coverage

The Huntersville site is located 35 km south-west of 85-1. It is at an elevation of 200 meters above 85-1.

Accurate baselines are still being procured, but the preliminary baseline is

$$
\begin{aligned}
Bx &= -176429.851\ \lambda_{11cm} &&= -65465.622 \text{ ns} \\
By &= -144099.092\ \text{"} &&= -53469.051 \text{ ns} \\
Bz &= 220481.755\ \text{"} &&= 81811.412 \text{ ns} \\
k &= 60.100\ \text{"} &&= 22.300 \text{ ns}
\end{aligned}
\qquad \pm\ 0.05 \text{ ns}
$$

between 45-ft and 85-1. The maximum spacing is 35.6 km = 117634 ns = 217024 λ (SBAND) = 951072 λ (XBAND). This corresponds to a minimum fringe spacing of 0.217 and 0.651 at XBAND and SBAND, respectively.

Tracks in the (u-v) plane are given for δ = 90, 60, 45, 30, 15, 0, -15, -30 and -45° in Figure 2a and 2b. The plots are normalized to 35.6 km and the inner circle has a radius of 2.7 km.

B. Coherence Area

By tracking a radio source with an array we obtain Fourier components of the radio structure in the field of view of the interferometer. The field of view is limited by the primary beam of the individual elements, by the coherence area, and by other minor effects. With a total bandwidth of ∿ 60 MHz the field of view of the 35 km baseline is limited by the coherence area and is only about one arc minute. This will significantly influence the observing procedure of large sources.

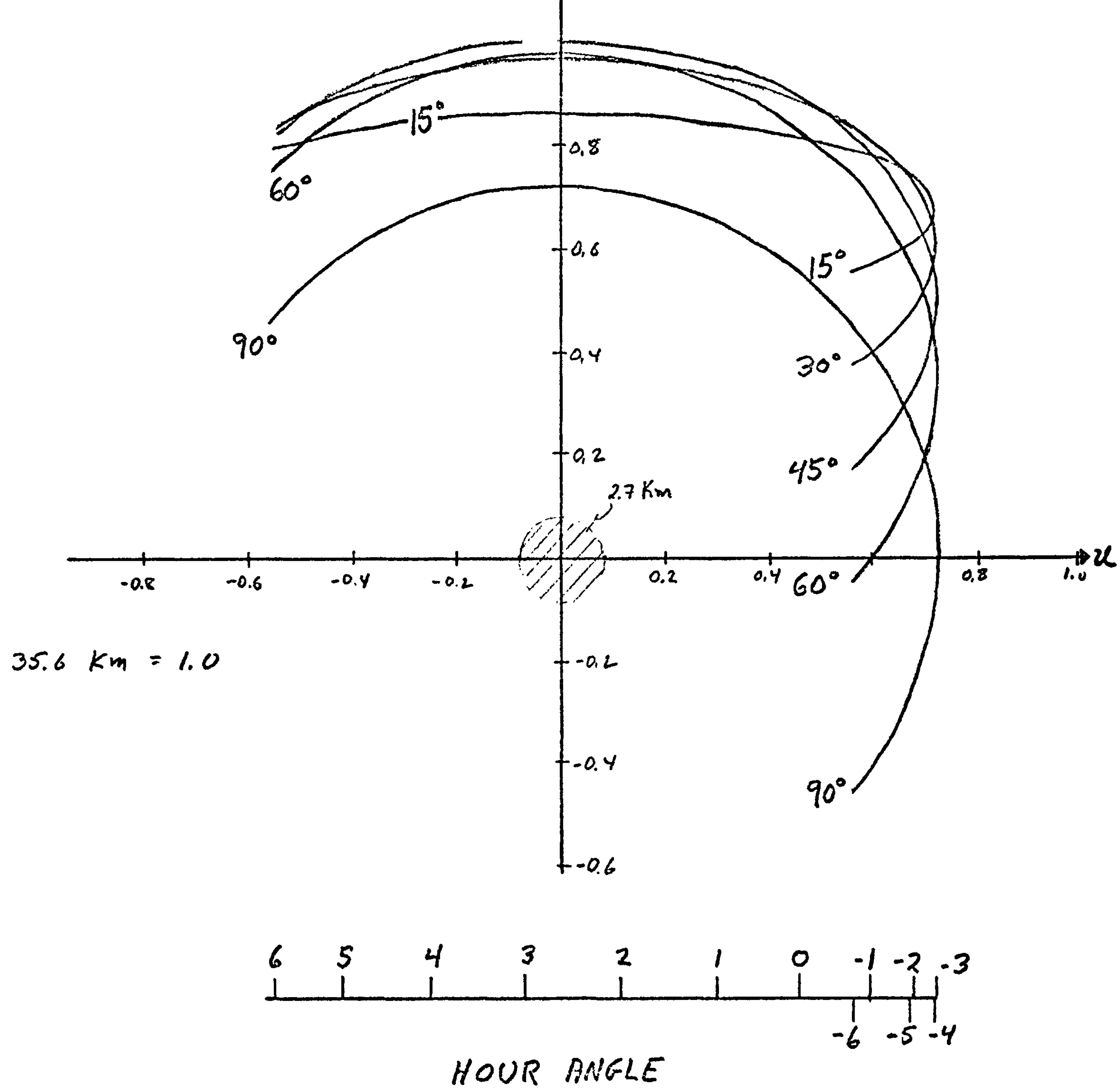
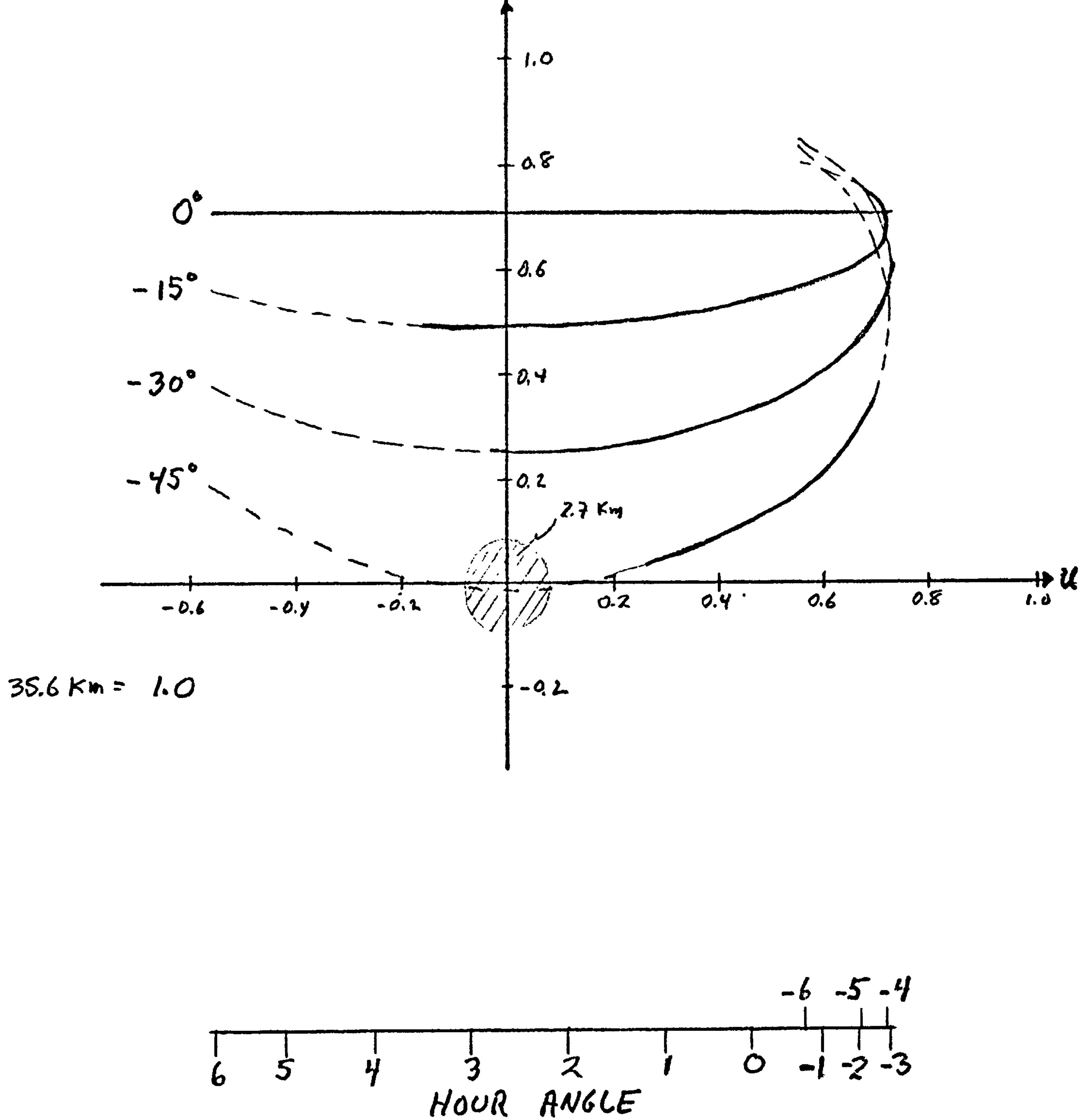

15°
60°
0.8
0.6
0.4
0.2
2.7 Km
90°
15°
30°
45°
60°
90°
-0.8
-0.6
-0.4
-0.2
0.2
0.4
0.8
1.0
u
-0.2
-0.4
-0.6
35.6 Km = 1.0
6 5 4 3 2 1 0 -1 -2 -3
-6 -5 -4
HOUR ANGLE

FIGURE 2a.


1.0
0.8
0°
0.6
-15°
0.4
-30°
0.2
-45°
2.7 Km
u
-0.6
-0.4
-0.2
0.2
0.4
0.6
0.8
1.0
35.6 Km = 1.0
-0.2
-6 -5 -4
6 5 4 3 2 1 0 -1 -2 -3
HOUR ANGLE

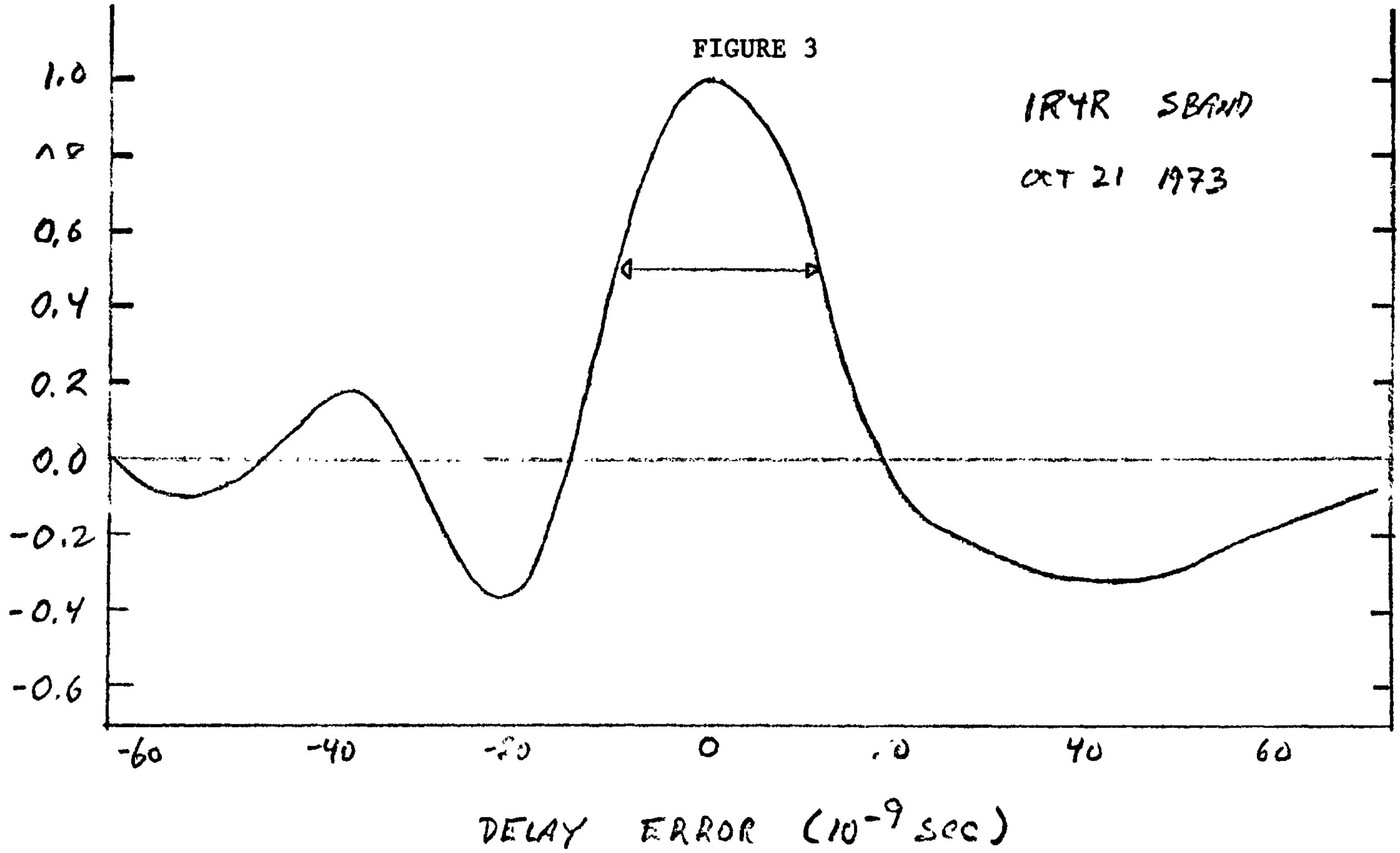
At each correlator the radiation from a pair of telescopes is multiplied, producing the fringe pattern. The amplitude is maximum if the difference in travel time of the radiation via the two possible paths is set to zero. This requires balancing the cables after each configuration (delay setting) and having the computer insert delay (track delay) in one telescope line to compensate for the delay change as the source moves. Errors in delay cause a loss of sensitivity - as shown in Figure 3.

The delay is tracked for the position indicated on the program card. Radiation displaced $\overline{\Delta S}$ from this position will, at the correlator, have a delay error $\Delta\tau$

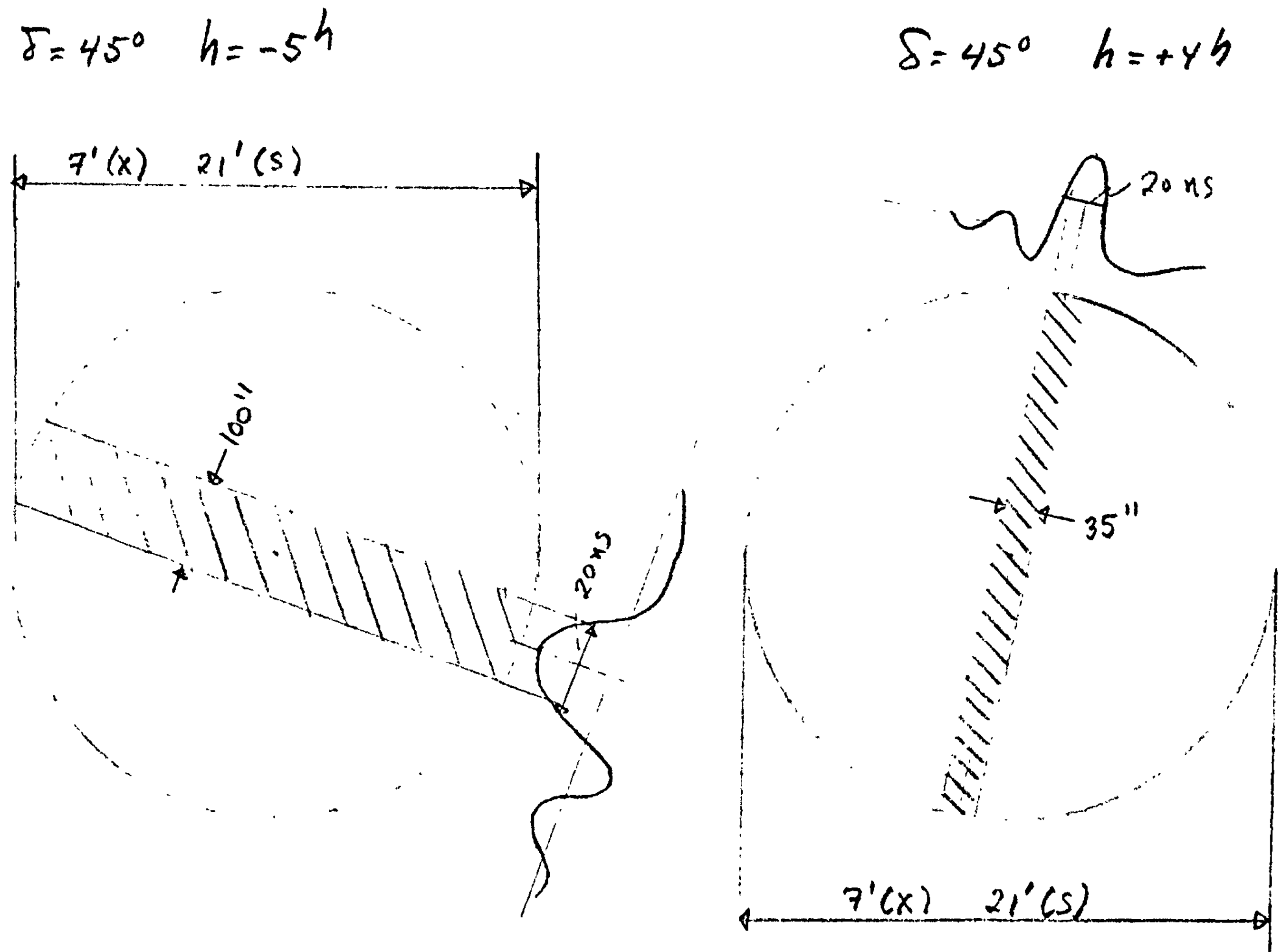
$$\Delta\tau = \overline{B}_p \cdot \overline{\Delta S}$$

where $\overline{B}_p$ is the projected spacing (see the u-v plot) and $\overline{\Delta S}$ is the source displacement from the phase center. Clearly, radiation displaced along the projected baseline will produce a decreased deflection by its apparent delay error. For maximum projected baseline of 117000 ns, the 20 ns half-power delay coherence width corresponds to 20/117000 radians = 35". Thus the field of view is essentially a strip scan of width 35" (suitably scaled inversely with the projected spacing - independent of wavelength) by 7' at XBAND or 21' at SBAND. Because the delay pattern has high sidelobes, the field of view contains many strips, of diminishing strength and of alternating sign. Woe to extended sources. The effective field of view for a source at $\delta = 45°$ at he $= -5^h$ and ha $= +4^h$ is also shown in Figure 3.

FIGURE 3



FIELD OF VIEW



C. Phase

Obtaining accurate phase information at a baseline of 35 km requires careful calibration. For example, a ten degree phase error at XBAND is equivalent to a position error of .005"! A complete understanding of the phase and its proper calibration will take several months but the following effects should be considered.

1. Source positions of calibrators must have an accuracy of $\pm$ ''05 or better. At the present time only a handful of sources are available and these have been listed in Table IV. Many more suitable calibrators should be available in several months.
2. Atmospheric effects are important. The difference of the integrated refractivity of the atmosphere along the line of sight of each telescope, due to an elevation difference between the elements and the curvature of the earth, affects the phase. The temperature, dew point and barometric at the interferometer control building and at the 45-ft telescope are recorded on tape enabling the total refractivity of the dry air and wet air components above each antenna to be calculated (this is done in INTCOR45). A simple model atmosphere is assumed. At elevations below 20° large errors may be present in the above calculation.
3. Clock errors are now significant. At the present time clock errors are applied to the data in CV. However, the nominal accuracy of $\pm$ 5 ns is not sufficient. A clock error of E milliseconds will produce a phase change at XBAND of

$$\Delta\phi = 18^\circ \, E \cos\delta \cos(h + 3^{h}.39)$$

The SBAND error is a factor of 3 smaller. At the present time Cam Wade is looking into a more accurate time keeping system for Green Bank.

D. Amplitudes and Polarizations

Most sources unresolved at the 35 km baseline are variables. We hope to keep track of the flux densities of these calibrators and update internal lists which are used to calculate the system gains. However, each observer should include some good 3-element flux density calibrators which, though resolved at 35 km, enable one to obtain correct flux densities for the variable sources used as calibrators.

The same strategy should also apply to polarization data. The list in Table III includes sources with variation in polarization over short time scales. At least one hour observing time (for each source per observing session) should be spent on 3C 48, 3C147 and 3C286, as well as any other sources to be used to calibrate the long baseline.

Various effects due to systematic delay errors, dish efficiency, and polarization characteristics are now being studied.