AN IMPROVED METHOD FOR POINTING THE 85-FT. ANTENNAS

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INTRODUCTION

Each time the 85-ft. antennas are moved to obtain a new interferometer configuration, time must be provided for determining the pointing parameters. The pointing parameters are the sixteen coefficients (9 for hour angle and 7 for declination) used by the computer to define the pointing curves. While each of the parameters has a unique physical significance, the set is not orthogonal and several parameters play against each other. Altenhoff, in his memo of 10 May 1971, suggested 1) at least seven are independent of the move and should be held constant to a "best" value. 2) Incorporate the known effects of axis alignment and station slope into the pointing parameters. 3) Point at S-band rather than X-band. For the last five configurations we have determined the pointing parameters of the moveable 85-ft antennas using the suggestions of Altenhoff. We have been able to obtain good solutions in only 12 to 15 hours where it had taken as much as 24 hours previously.

The resulting analysis of the previous five interferometer configurations involving nine antenna moves confirm that the use of Altenhoff's suggestions will obtain the same pointing accuracy with increased understanding and speed. The purpose of this memo is to describe in sufficient detail: 1) the estimation of the pointing parameters incorporating the known effects, 2) an observing method and source list for the pointing, 3) the analysis of the pointing using the DDP computer. Although the "friend" of the interferometer is now responsible for the pointing after a move, we hope that any observer with this memo could

obtain the pointing and that with sufficient practice, the pointing could be successfully handled by the operators.

I. ESTIMATING THE POINTING PARAMETERS

The equations (See Appendix A) used to determine the pointing curves represent a reasonable choice of physical parameters. The reader is referred to the memo of Herrero, 25 April 1972, for a clear derivation of these equations. Additional, less important parameters have been found to be unnecessary and non-linear terms in the pointing can be incorporated into the present parameters, albeit with some loss of physical meaning of the individual parameters. Some of the parameters are related and under ideal circumstances: C7 = C'5 = refraction $\approx$ 1!0; C4 = C'3 = elevation error of alignment; C5 = C'4 = azimuth error of alignment.

Based on the analysis of Altenhoff and confirmed by our own observations, the estimated values for the pointing parameters C3, C6, C7, C8, C'2, C'5, C'6 are now more independent and should be held fixed for each antenna. The values assigned to the other parameters are averages determined from the pointing data over the years. The values are listed in Table I and are given in "DDP" units (40 units equal 1 arc minute). The parameters Co, C4, C5, C'3, C'4 also incorporate effects that can be measured. The misalignment of the axis of the antenna at set down is measured by S. Smith after each move and are available from him. The errors are generally less than 10 arc seconds with an accuracy of 10 arc second. Since these five parameters are not held fixed, the misalignment effects need not be incorporated into the initial estimate. The slope of each station, given in Table II, should be incorporated into the parameter C0 since it is large.

We have found that the estimates based on Tables I and II are within 20 arc seconds of the values determined after the pointing analysis. This is in marked contrast to a much larger variation in the parameters if all 16 parameters are used in the solution. A comparison of the two methods will be discussed later. The large uncertainty in C0 is due to a rotation of the antenna while being set. At present, this rotation cannot be measured accurately with the available surveying techniques.

The choice of fixed parameters is obvious from the physical meanings for these parameters except for the term C'2. This term is highly correlation with C'0 (they only differ by a cosine declination) so that their values are inseparable except with very accurate and detailed pointing data. The sum of the two parameters are found to be nearly constant. Thus, one of them should be held constant. The terms C8 and C1, which also differ by only the cosine of the declination, are highly correlated. Here we have C8 constant for a physical reason as well.

Although telescope 85-1 is fixed, the pointing parameters C0, C1, C2, C'0, C'1, which refer to the encoder offset and eccentricity, may change due to maintenance, wear and power cutoffs. When determining the pointing parameters for 85-1 or a telescope which has not been moved, all but the above five parameters can be held fixed. Even with only limited data, better values can be reliably obtained.

The mean estimated DDP pointing parameters for 85-1 are listed in Table III. With good coverage over the sky, additional parameters C4, C5, C'3, C'4 may also be varied to be consistent with the procedure for the moveable telescopes. However, these parameters should not vary significantly.

TABLE I

ESTIMATED VALUES OF THE DDP POINTING PARAMETERS

	Telescope 2		Telescope 3	
Parameter	Value	Variation	Value	Variation
C0	5-SS*	25	-35-SS*	30
C1	97	10	137	10
C2	0	10	-3	10
C3	156	Fixed	44	Fixed
C4	27-ΔEL†	15	24-ΔEL†	15
C5	0-ΔAzcosL†	15	5-ΔAzcosL†	15
C6	15	Fixed	8	Fixed
C7	40	Fixed	40	Fixed
C8	-100	Fixed	-100	Fixed
C'0	95	15	25	10
C'1	-20	15	-25	15
C'2	-19	Fixed	-60	Fixed
C'3	29+ΔEL†	15	-12+ΔEL†	15
C'4	66-ΔAzcosL†	10	43-ΔAzcosL†	10
C'5	40	Fixed	40	Fixed
C'6	-100	Fixed	-100	Fixed

* SS = Station Slope - see Table II

† (ΔEL,ΔAz) = Telescope Alignment Error. See S. Smith for values after each move.

TABLE II

STATION SLOPE

Station	Slope* (DDP Units)
27	75
24	39
21	59
19	83
18	-1
15	44
12	33

* Taken from Altenhoff's memo, corrected for cosine latitude term and converted to DDP units.

TABLE III

ESTIMATED VALUE OF THE DDP POINTING PARAMETERS FOR 85-1

Parameter	Altenhoff Estimate	Last Solution June 8, 1972	Expected Variation
C0	71	99	< 30
C1	98	105	< 30
C2	-15	-38	< 30
C3	4	-	Fixed
C4	53	60	< 10
C5	-30	-30	< 10
C6	22	-	Fixed
C7	44	-	Fixed
C8	-100	-	Fixed
C'0	-45	-74	< 30
C'1	39	48	< 30
C'2	-1	-	Fixed
C'3	-6	7	< 10
C'4	7	13	< 10
C'5	44	-	Fixed
C'6	-100	-	Fixed

II. OBSERVING TECHNIQUE

We have found that when seven parameters are held constant, it is possible to adequately predict the remaining parameters. Generally, less than 12 to 15 hours of observing time is needed for satisfactory results even allowing for bad weather and other bad luck. Because of much less interplay between the remaining parameters, the solution is safe for extrapolation at low elevations and high declination. With interferometer pointing, good sky coverage could be obtained in 4 to 6 hours with more reliable results.

We suggest the S-Band be used for the pointing for the following reasons:

1) Because of the non-thermal spectrum of the typical radio source, pointing should be done at S-Band where there are more strong sources.

2) Although the beam width of the telescopes is smaller at X-band, many of the sources in use are not much smaller than the X-band beam width and cause significant beam broadening. This is not compensated for by the DDP analysis program, resulting in incorrect pointing offsets.

3) Atmospheric effects are much more severe at X-band.

4) Offsets greater than half of the beam width (3 arc minutes at X-band) cannot be handled because of the nature of the DDP solution.

Short pointing times are dependent on the use of weak sources (about 8 flux units. A complete list of sources is given in Table IV. These are most of the sources above 10.0 f.u., smaller than 5 arc minute. The positions at epoch 1950.0 and the S-band flux density are given. The sources W31, SGRA and G348.7-1.0 should be observed at X-band since these sources are confused at S-band. [Four separate observing program decks covering 0^h - 12^h, 6^h - 18^h, 12^h - 24^h, 18^h - 6^h are available at the interferometer. Each give good sky coverage for a satisfactory solution. See Appendix D.]

A few suggestions:

1) Always try to observe 3C309.1 at several hour angles. It is weak and only some of the observations will be useable, but it is worth the time. The source 3C58 is a good second choice for a high declination calibrator.

2) Observed CENTA or P0518-45 (PICA) near transit.

3) Try to cover the extreme hour angles as well as a reasonably uniform coverage of the sky. It is better to rely on interpolation rather than extrapolation for the pointing.

TABLE IV

85-FT POINTING SOURCE LIST

Source	RA	Dec	Flux Density 2695 MHz*
3C48	01 34 49.82	32 54 20.5	9
3C58	02 01 52.8	64 35 14.	30
3C84	03 16 29.61	41 19 51.8	10
3C123	04 33 55.23	29 34 14.	28
PICA	05 18 18.18	-45 49.39.	40
P0521-36	05 21 13.3	-36 30 15.	12
3C144	05 31 30.5	21 59 02	700
3C147	05 38 43.51	47 49 42.8	12
3C147.1	05 39 11.8	-01 55 40.	75
3C161	06 24 43.0	-05 51 14.	12
3C196	08 09 59.41	48 22 07.2	8
3C218	09 15 41.3	-11 53 05.	25
3C273	12 26 33.26	02 19 42	40
3C274	12 28 17.0	12 39 56.	115
3C279	12 53 35.82	-05 31 06.9	9
CENTA	13 22 35.00	-42 45 30	900
3C286	13 28 49.67	30 45 58.3	10
3C295	14 09 33.5	52 26 13.	14
3C309.1	14 58 56.62	71 52 11.3	6
G348.7-1.0	17 16 39.6	-38 54 42.0	100†
3C353	17 17 55.8	-00 55 54.	36
SGRA	17 42 29.0	-28 58 48.	300†
W31	18 06 25.6	-20 19 36.0	50†
CYGA	19 57 44.5	40 35 46.	900
P2134+00	21 34 05.23	00 28 25.7	10
3C454.3	22 51 29.52	15 52 53.7	13
CASA	23 21 06.8	58 32 47.	1500

† Point at X-band. Confused region at S-band.

* When IF level is set to 25, the amplitude of the DDP analysis $\tilde{\sim}$ 1.5 x S

4) Don't shy away from weak sources. Over a typical thirty minute observation, five independent determinations are obtained for a coordinate offset. An obvious incorrect observation can be rejected in the editing. An observation of a weak source with a 2 arc minute scatter in an unsampled region of the sky is more useful than an observation of a strong source in an already heavily sample region.

A justification of the present method for the pointing of the 85-ft antennas is given in Appendix B and C. In Appendix B we have listed the difference between the estimated parameters taken from Table I and Table II, incorporating the effects of the antenna move, and the values determined after 12 to 15 hours of observations. The variations are small and suggest that the method of pointing is reasonable. There is little correlation of the variable parameters, so that extrapolation of the pointing fit should be valid.

A comparison of the pointing solutions using the fixed parameters (FP) versus the variable parameter (VP) solution for 85-3 is shown in Appendix C. There is much more variation for the VP solution and a comparison among them is difficult. The rms of the fit (the room-mean-square deviation of the VP solution of an observation from the fit) is insignificantly smaller in most cases than the FP solution. The instability of the VP solution is illustrated by the change of parameters with only slight editing on the June 16 data. Three observations of 3C309.1 with residuals 0!4 in right ascension and 2!5 in declination were deleted.

III. POINTING ANALYSIS

The pointing data is normally reduced on the DDP and sent to Charlottesville only if desired because the 360 pointing analysis program cannot hold parameters fixed. The operator instructions at the computer are adequate for running the program. A remaining "bug" in the DDP pointing analysis program is the dropping of the tens digit in the listing of the pointing change on the teletype or the pointing rms on the CRT while analyzing the data.

A reasonable method for analyzing the data follows:

Pass 1. Hold the appropriate parameters constant and display the data on the CRT. In this pass we are interested in discarding the very poor data, mostly of observations of weak sources. A good method is to check for consistency in the pointing error of the four or five individual observations for each scan. If all of the observations scatter chaotically, delete the entire scan. If the scatter is large but a mean error is believable, it is fair to delete the extreme observations keeping the average error about the same. This method, in essence, reduces the weight of the scan.

Pass 2. Hold the appropriate parameters constant and display the data again on the CRT. Most of the gross observation should have been discarded in pass 1. Observations with a residual in excess of about 1.5 arc minutes should be scrutinized. For weak sources it is useful to delete some observation of a scan, even if they all agree, to reduce the weighting as compared with the stronger, more dependable sources.

Pass 3. After all of the editing has been done, one more pass is necessary to obtain the rms of the fit. An rms between 0.3 and 0.7 arc minutes is acceptable.

Pass 4. (If you wish) Hold none of the parameters constant. Notice the variation of the parameters and the rms of this fit. If time allows, a feeling for the goodness of fit can be obtained by holding various combinations of parameters constant or deleting additional data.

The improved DDP parameters for the relevant telescopes are then punched and read in the computer. Note that there is a round-off error of 1 DDP units.

APPENDIX

A. Equation Used for the Fit

$\Delta h \cos \delta = C0 \times \cos \delta$		Encoder Offset
$+ C1 \times \sin h \times \cos \delta$		Encoder eccentricity
$+ C2 \times \cos h \times \cos \delta$		" "
$+ C3 \times \sin \delta$		Perpendicularity
$+ C4 \times \sin \delta \times \sin h$	Elevation	Alignment of axes
$+ C5 \times \sin \delta \times \cos h$	Azimuth	" " "
$+ C6$		Collimation error
$+ C7 \times \cos L \times \sin h \times \sec z$		Refraction
$+ C8 \times \cos L \times \sin h$		Sag (Flexure)
$= C'0$		Zero error
$+ C'1 \times \sin \delta$		Encoder eccentricity
$+ C'2 \times \cos \delta$		" "
$+ C'3 \cos h$	Elevation	Alignment of Axes
$+ C'4 \sin h$	Azimuth	" " "
$+ C'5 \times (\sin L \times \cos\delta - \cos L \times \sin\delta \times \cos h)$ $\times \sec z$		Refraction
$+ C'6 \times (\sin L \times \cos\delta - \cos L \times \sin\delta \times \cos h)$		Sag (Flexure)

Δh = hour angle pointing error (indicated - true)
$\Delta\delta$ = declination pointing error (indicated - true)
(h,δ) = (hour angle, declination) of observation
L = latitude at Green Bank
z = zenity angle of observation
C = hour angle parameters
C' = declination parameters

B. Comparison of Estimated and Fitted Parameters

Parameter	Difference of Estimated and Fitted Parameters							
	Telescope #2				Telescope #3			
	72/3/5	72/10/5	72/23/5	72/6/6	72/3/5	72/10/5	72/23/5	72/15/6
	19	15	19	27	15	12	18	19
C0	-24	-13	-2	-20	+1	-27	-57	+16
C1	-24	-4	-7	-8	-32	+12	+9	-8
C2	-11	+3	-5	+12	-11	-8	+18	-11
C3	-	-	-	-	-	-	-	-
C4	+29	-1	-4	-4	-48	+15	-10	+19
C5	-6	-1	+17	+2	+8	-14	+29	+35
C6	-	-	-	-	-	-	-	-
C7	-	-	-	-	-	-	-	-
C8	-	-	-	-	-	-	-	-
C'0	+2	-4	-7	+31	+7	-1	0	-30
C'1	-20	-5	+7	-28	-13	-15	-12	+12
C'2	-	-	-	-	-	-	-	-
C'3	-19	+14	+17	+6	-22	0	-32	-1
C'4	+8	+1	+22	+15	+1	-12	+3	+1
C'5	-	-	-	-	-	-	-	-
C'6	-	-	-	-	-	-	-	-

C. Comparison of Fixed Parameter and Variable Parameter Solutions for 85-3

Parameters	Fixed Parameters					Variable Parameters				
Date	May 3	May 10	May 23	June 16	June 16	May 3	May 10	May 23	June 16	June 16
Station	15	12	18	19	19 Minor Editing	15	12	18	19	19 Minor Editing
C0	-80	-95	23	-134	-134	-103	-100	26	-109	-114
C1	169	125	128	145	146	124	13	38	179	177
C2	8	5	-21	8	8	13	-8	-31	-10	-11
C3	44	-	-	-	-	50	31	19	- 1	- 5
C4	-36	-9	26	5	5	-12	-41	-22	49	48
C5	- 4	27	-22	-40	-39	-15	38	9	15	19
C6	8	-	-	-	-	24	21	13	3	2
C7	40	-	-	-	-	42	45	35	59	59
C8	-100	-	-	-	-	.78	21	19	-216	-212
RMS	0.54	0.15	0.42	0.65	0.65	0.53	0.61	0.38	0.57	0.57
C'0	18	24	25	60	55	28	-76	- 6	-147	-62
C'1	-12	-10	-13	-46	-37	-19	68	34	111	50
C'2	-60	-	-	-	-	-57	-32	-93	27	-10
C'3	22	6	12	-22	-13	17	44	36	33	16
C'4	41	65	43	33	32	42	66	45	39	35
C'5	40	-	-	-	-	45	48	43	56	51
C'6	-100	-	-	-	-	-134	-50	-42	-3	-53
RMS	0.54	0.48	0.41	0.69	0.52	0.51	0.45	0.38	0.58	0.48

D. POINTING PROGRAMS

POINTING SOURCE LIST 00 TO 12 HOURS

3C58	02 01 52.8	64 35 14.	00 30	
3C144	05 31 30.5	21 59 02.	01 00	
3C147.1	05 39 11.8	-01 55 40.	01 30	
3C123	04 33 55.23	29 34 14.	02 00	
3C84	03 16 29.61	41 19 51.8	02 30	
3C147.1	05 39 11.8	-01 55 40.	03 00	
3C144	05 31 30.5	21 59 02.	03 30	
3C58	02 01 52.8	64 35 14.	04 00	
3C84	03 16 29.61	41 19 51.8	04 30	
P0521-36	05 21 13.3	-36 30 15.	05 00	
PICA	05 18 18.18	-45 49 39.	05 30	
3C84	03 16 29.61	41 19 51.8	06 00	
3C48	01 34 49.82	32 54 20.5	06 30	
3C58	02 01 52.8	64 35 14.	07 00	
3C161	06 24 43.0	-05 51 14.0	07 30	
3C273	12 26 33.25	02 19 42.	08 00	
3C144	05 31 30.5	21 59 02.	08 30	
3C147.1	05 39 11.8	-01 55 40.	09 00	
3C218	09 15 41.3	-11 53 05.	09 30	
3C274	12 28 17.0	12 39 56.	10 00	
3C295	14 09 33.5	52 26 13.0	10 30	
3C309.1	14 58 56.62	71 52 11.3	11 00	
3C274	12 28 17.0	12 39 56.	11 30	
3C295	14 09 33.5	52 26 13.0	12 00	

POINTING SOURCE LIST 06 TO 18 HOURS

P0521-36	05 21 13.3	-36 30 15.	06 30	
3C48	01 34 49.82	32 54 20.5	07 00	
3C58	02 01 52.8	64 35 14.	07 30	
3C144	05 31 30.5	21 59 02.	08 00	
3C273	12 26 33.26	02 19 42.	08 30	
3C286	13 28 49.67	30 45 58.3	09 00	
3C295	14 09 33.5	52 26 13.0	09 30	
3C309.1	14 58 56.62	71 52 11.3	10 00	
3C274	12 28 17.0	12 39 56.	10 30	
3C286	13 28 49.67	30 45 58.3	11 00	
3C295	14 09 33.5	52 26 13.0	11 30	
3C309.1	14 58 56.62	71 52 11.3	12 00	
3C274	12 28 17.0	12 39 56.	12 30	
3C353	17 17 55.8	-00 55 54.	13 00	
CENTA	13 22 35.0	-42 45 30.0	13 30	
3C295	14 09 33.5	52 26 13.0	14 00	
3C309.1	14 58 56.62	71 52 11.3	14 30	
3C353	17 17 55.8	-00 55 54.	15 00	
W31	18 06 25.6	-20 19 36.0	15 30	XBAND SS1 UP
3C274	12 28 17.0	12 39 56.	16 00	SBAND SS1 DOWN
3C273	12 26 33.26	02 19 42.	16 30	
3C295	14 09 33.5	52 26 13.0	17 00	
3C309.1	14 58 56.62	71 52 11.3	17 30	
SAGA	17 42 29.00	-28 58 48.0	18 00	XBAND SS1 UP

POINTING SOURCE LIST 12 TO 24 HOURS

3C274	12 28 17.0	12 39 56.	12 30	
3C273	12 26 33.26	02 19 42.	13 00	
CENTA	13 22 35.0	-42 45 30.0	13 30	
3C309.1	14 58 56.62	71 52 11.3	14 00	
3C353	17 17 55.8	-00 55 54.	14 30	
3C274	12 28 17.0	12 39 56.	15 00	
3C273	12 26 33.26	02 19 42.	15 30	
3C286	13 28 49.67	30 45 58.3	16 00	
W31	18 06 25.6	-20 19 36.0	16 30	XBAND SS1 UP
SAGA	17 42 29.00	-28 58 48.0	17 00	XBAND SS1 UP
3C309.1	14 58 56.62	71 52 11.3	17 30	SBAND SS1 DOWN
3C295	14 09 33.5	52 26 13.0	18 00	
3C286	13 28 49.67	30 45 58.3	18 30	
SAGA	17 42 29.00	-28 58 48.0	19 00	XBAND SS1 UP
3C309.1	14 58 56.62	71 52 11.3	19 30	SBAND SS1 DOWN
W31	18 06 25.6	-20 19 36.0	20 00	XBAND SS1 UP
3C454.3	22 51 29.52	15 52 53.7	20 30	SBAND SS1 DOWN
3C461	23 21 06.8	58 32 47.	21 00	
W31	18 06 25.6	-20 19 36.0	21 30	XBAND SS1 UP
3C58	02 01 52.8	64 35 14.	22 00	SBAND SS1 DOWN
3C84	03 16 29.61	41 19 51.8	22 30	
3C48	01 34 49.82	32 54 20.5	23 00	
3C461	23 21 06.8	58 32 47.	23 30	
3C58	02 01 52.8	64 35 14.	00 00	

POINTING SOURCE LIST 18 TO 06 HOURS

W31	18 06 25.6	-20 19 36.0	18 30	XBAND SS1 UP
3C286	13 28 49.67	30 45 58.3	19 00	SBAND SS1 DOWN
3C295	14 09 33.5	52 26 13.0	19 30	
3C309.1	14 58 56.62	71 52 11.3	20 00	
3C353	17 17 55.8	-00 55 54.	20 30	
W31	18 06 25.6	-20 19 36.0	21 00	XBAND SS1 UP
3C58	02 01 52.8	64 35 14.	21 30	SBAND SS1 DOWN
3C48	01 34 49.82	32 54 20.5	22 00	
3C84	03 16 29.61	41 19 51.8	22 30	
3C454.3	22 51 29.52	15 52 53.7	23 00	
3C461	23 21 06.8	58 32 47.	23 30	
3C58	02 01 52.8	64 35 14.	00 00	
3C84	03 16 29.61	41 19 51.8	00 30	
3C144	05 31 30.5	21 59 02.	01 00	
3C147.1	05 39 11.8	-01 55 40.	01 30	
3C58	02 01 52.8	64 35 14.	02 00	
3C461	23 21 06.8	58 32 47.	02 30	
3C147.1	05 39 11.8	-01 55 40.	03 00	
3C144	05 31 30.5	21 59 02.	03 30	
3C48	01 34 49.82	32 54 20.5	04 00	
3C454.3	22 51 29.52	15 52 53.7	04 30	
P0521-36	05 21 13.3	-36 30 15.	05 00	
PICA	05 18 18.18	-45 49 39.	05 30	
3C58	02 01 52.8	64 35 14.	06 00	