BASELINE CALIBRATION FOR THE SYNTHESIS PROGRAM
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The purpose of this report is to outline the steps used in the calibration of the three-element interferometer, and to give values of the baseline parameters appropriate to the synthesis program of Conway, Wade and Hogg, which occupied the instrument during the period June - December 1967.

A. Assembling the Data

The IBM 360 programs have been described by Conway (1967), and will only be summarized here. The data are received on a seven-track tape which is written by the DDP 116 computer in Green Bank. The seven-track tape is rewritten, in Fortran-compatible form, on a nine-track tape (called Tape 1), and a listing of the data is made, using the program IREAD. The data are inspected, and the scans containing bad observations are noted. After the observations on a given configuration are completed, a new nine-track tape (called Tape 2) is written, using the program IEDIT. This program not only rejects bad data, spurious headers, and bad records, but also makes a number of changes to the phase of the data, as follows:

1) For the first three configurations of the Conway program (July 8 - Aug. 21, 1967) the right ascensions of all sources must be corrected. The Besselian "A" term, accounting for precession, was omitted in the DDP 116.
2) For all configurations the clock correction is applied.
3) For all configurations a detailed correction for refraction in the plane-parallel case is made. This correction has been described in more detail elsewhere (Hogg 1967).

4) The phases are referred to the frequency 2695.000 MHz.

5) For the first six configurations, the local oscillator loop was open, but the phase error was read into the A/D records. This phase error is computed and applied to the data.

B. Determination of the Parameters BX, BY

i) Notation.

In the present notation the interferometer baseline is specified in terms of the three rectangular components: BX, which is positive towards $H = 0^h$, $\delta = 0°$; BY, which is positive towards $H = +6^h$, $\delta = 0°$; and BZ, which is positive towards $\delta = +90°$. The reference meridian of the instrument is taken to be +79°50'. The interferometer phase, in turns, is given by

$$\phi = \vec{B} \cdot \vec{S} \qquad \text{------------------------------(1)}$$

where $\vec{S}$ is the vector in the direction of the source, having components $SX = \cos\delta \cos H$; $SY = \cos\delta \sin H$, and $SZ = \sin\delta$.. In terms of the old notation, using B1, B2 and h, $BX = B2 \cos h$, $BY = B2 \sin h$, and $BZ = B1$.

The phase recorded on Tape 2 would be zero for any source observed at any hour angle if an accurate position for the source has been assumed, if the baseline parameters are well-known, and if there is no spurious contribution to delay either in the atmosphere or in the instrument. If, however, there are position errors $\Delta\alpha$, $\Delta\delta$; baseline errors ΔBX, ΔBY, ΔBZ; and an instrumental/atmospheric term ΔBO, the phase recorded on Tape 2 will be, in turns

$$\phi(H) = -\Delta\delta \cdot BZ \cdot \cos\delta - \Delta BZ \cdot \sin\delta - \Delta BO$$
$$+ \cos H\,(-\Delta BX \cdot \cos\delta + \Delta\alpha \cdot BY \cdot \cos\delta + \Delta\delta \cdot BX \cdot \sin\delta)$$
$$+ \sin H\,(-\Delta BY \cdot \cos\delta - \Delta\alpha \cdot BX \cdot \cos\delta + \Delta\delta \cdot BY \cdot \sin\delta) \quad \text{--------------------(2)}$$

where ΔBX --- ΔBO are in turns, and $\Delta\alpha$, $\Delta\delta$ are in radians.

For purposes of calibration, assume that $\Delta\alpha = \Delta\delta = 0$. Then the phase as a function of hour angle is simply

$$\phi(H) = -\Delta BZ \cdot \sin\delta - \Delta BO - \Delta BX \cdot \cos\delta \cdot \cos H - \Delta BY \cdot \cos\delta \cdot \sin H \quad \text{--------------------(3)}$$

and the phase drift, in circles per radian, is

$$\frac{d\phi}{dH} = \Delta BX \cdot \cos\delta \cdot \sin H - \Delta BY \cdot \cos\delta \cdot \cos H \quad \text{-----------------(4)}$$

ii) The Baseline Program PHIFIT

The program PHIFIT uses all of the data taken at zenith distances less than 75° on a given source on a given day. It attempts to find the combination ΔBX, ΔBY which makes ϕ independent of hour angle.

Since the initial values of the baseline parameters which are used in the on-line reduction could be in error by many wavelengths, first estimates of ΔBX and ΔBY are obtained by solving equation (4); the phase drift is independent of the ambiguities of 2π which may be present in the phase. The data for the source under consideration are grouped into blocks. For each block a phase drift is obtained, assuming a linear drift within a block. These phase drifts are used in a least-squares solution of equation (4) to yield the desired first estimates ΔBX_1 and ΔBY_1.

The next step is to apply a correction $\Delta BX_1 \cdot \cos\delta \cdot \cos H + \Delta BY_1 \cdot \cos\delta \cdot \sin H$ to the observed phases. The "corrected" phases will be more or less constant, independent of hour angle; they will certainly lie within $\pm$ 1/2 circle. Finally, a least-squares solution of the phase equation (3), using the "corrected" phases, gives the values of ΔBX, ΔBY, and $(\Delta BZ \cdot \sin\delta + \Delta BO)$.

iii) A Proposed System of Values of BX, BY.

The best solutions for all calibration sources on each configuration were tabulated. It was clear that the baseline parameters required if the optical and radio images coincide differed from source to source, by an amount which was large in comparison with the internal dispersion of the values for a given source. These differences will be interpreted as errors in the defined (i.e., optical) positions of the calibration sources, and a new system of coordinates for the calibrators will be defined.

The zero point of the new system is arbitrary; for convenience the interferometer baseline parameters BX and BY have been chosen to be the average of the values found for the sources 3C 48, 3C 147, and 3C 286, with equal weight to each source. In the case where a baseline was common to several configurations--for example, correlator 2 of configurations 7, 8, and 9--the relevant data from all configurations were averaged to get a single value of BX and of BY. Finally, in order to get the best possible estimates of the BX and BY, the observed values were adjusted, within the limits of the internal standard deviations, so that on a given configuration, the BX, BY would satisfy the relations

$$BX\ (\text{corr. }1) - BX\ (\text{corr. }2) \equiv BX\ (\text{corr. }3) \quad \text{-----------------(5)}$$

$$BY\ (\text{corr. }1) - BY\ (\text{corr. }2) \equiv BY\ (\text{corr. }3) \quad \text{-----------------(6).}$$

The alterations were typically 0.01 λ, except in the case of BX for correlator 1, configuration 1; here the change was 0.025 λ. The calibration data for this configuration was of lower quality.

The proposed values of BX, BY are tabulated in Table 2.

iv) Errors in the Positions of the Calibration Sources.

With these values of BX, BY, it is possible now to return to the PHIFIT solutions for each source, and deduce the position errors relative to the system. In practice, the quantities which have been determined are the ΔBX, ΔBY relative to the system; equation (2) shows that these errors are related to the errors $\Delta\alpha$, $\Delta\delta$ in position by

$$\Delta\alpha = \frac{\Delta BY \cdot BX - \Delta BX \cdot BY}{BX^2 + BY^2} \qquad \text{------------------(7)}$$

$$\Delta\delta \tan\delta = - \frac{(\Delta BX \cdot BX + \Delta BY \cdot BY)}{BX^2 + BY^2} \qquad \text{------------------(8)}$$

In order to insure the highest accuracy in the baseline parameters, only those correlators common to two or more configurations were used; i.e., correlator 2, configurations 1, 2; correlator 1, configurations 2, 3, 4; correlator 2, configurations 5, 6; correlator 1, configurations 6, 7; and correlator 2, configurations 7, 8, 9.

The positions thus derived, and the differences between the radio and optical positions for the eight calibration sources are given in Table 1. The last column gives the reference for the optical position which was assumed. Also shown are the internal standard deviations of the radio positions. It must be emphasized that these errors do not reflect any bias which might be present in the proposed system.

C. Determination of the Parameter BZ

Once $\Delta\alpha$, $\Delta\delta$, ΔBX, and ΔBY are known, the phase on any calibrator at any hour angle can be corrected, using equation (2). The phase residual has the form

$$\phi = -\Delta BZ \cdot \sin\delta - \Delta BO \qquad \text{------------------------}(9)$$

The phases were read from Tape 2, and corrected for the known errors $\Delta\alpha$ --- ΔBY, using the program BZCAL. This program also averages the phase over each scan, and prints out this average, along with the sine of the declination. The values ΔBZ and ΔBO are then obtained by a least-squares solution of equation (9). Again, the final BZ were forced to satisfy the relation

$$\text{BZ (corr. 1)} - \text{BZ (corr. 2)} \equiv \text{BZ (corr. 3)} \qquad \text{---------------}(10).$$

The adopted values of BZ are given in Table 2. The standard deviations are about 0.03 λ, except for all correlators in the first two configurations, where they are about 0.06 λ.

Also shown in Table 2 is the total baseline length B, in wavelengths, for the frequency 2695.000 MHz.

D. Summary

Tables 1 and 2 contain a self-consistent set of source positions and baseline parameters to be used specifically for the synthesis data obtained during the period June-November 1967. The baseline parameters of Table 2 will also be useful as input to the DDP 116, since they appear to be stable to at least 0.1 λ.

In estimating parameters for other combinations of stations, it might be noted that the telescope 85-3 sits $\sim .05\ \lambda$ closer to the pads than does 85-2, to judge from the baseline parameters found when the telescopes occupied stations 15 and 19. A move of an antenna has surprisingly little effect. Thus the return of 85-3 to station 18 produced a difference in the total baseline length of only 0.03 λ, with a difference in BY of 0.03 λ; the return of 85-2 to station 24 produced differences of only 0.01 λ and 0.05 λ in the total length, and in BZ, respectively. However, since the pads on stations 18 and 19 have not been grouted, as of this writing, it is to be expected that baseline parameters involving these stations will show more scatter from move to move.

References

Conway, R. G. Aug. 1967 "The IDATA System of Programs."

Hogg, D. E. Dec. 1967 "Correction of the Interferometer Phase for the Attitude Difference Effect."

TABLE 1

3 ELEMENT INTERFEROMETER: RADIO POSITIONS DERIVED FOR THE CALIBRATORS

Source	α(1950)	δ(1950)	Radio - Optical α	Radio - Optical δ	Ref
3C 48	$01^h34^m49^s.85 \pm .01$	$+32°54'20''.7 \pm 0''.2$	$+0^s.037$	$+0''.5$	1
147	$05\ 38\ 43.51 \pm .01$	$+49\ 49\ 42.8 \pm 0.2$	-0.021	-0.3	1
287	$13\ 28\ 15.95 \pm .015$	$+25\ 24\ 37.9 \pm 0.3$	-0.171	+0.8	2
286	$13\ 28\ 49.67 \pm .01$	$+30\ 45\ 58.7 \pm 0.2$	-0.072	-0.6	2
345	$16\ 41\ 17.59 \pm .01$	$+39\ 54\ 11.3 \pm 0.2$	-0.109	+0.2	2
3C 380	$18\ 28\ 13.49 \pm .01$	$+48\ 42\ 40.8 \pm 0.2$	+0.108	+1.4	2
CTA 102	$22\ 30\ 07.90 \pm .015$	$+11\ 28\ 24.5 \pm 0.4$	+0.185	+1.7	2
3C 454.3	$22\ 51\ 29.59 \pm .01$	$+15\ 52\ 55.2 \pm 0.4$	-0.022	+1.6	3

1. Griffin, R. F. 1963, A. J., **68**, 621.
2. Véron, P. 1965, Ap.J., **141**, 332.
3. Véron, P. 1966, Ap.J., **144**, 861.

TABLE 2

BASELINE PARAMETERS FOR THE SYNTHESIS PROGRAM OF JUNE-NOVEMBER 1967

Configuration	Correlator	Station	BX	BY	BZ	B
1	1	15	-3773.990	-11910.254	5072.53	13484.351
	2	12	-3009.750	- 9528.522	4065.92	10788.097
	3	15/12	- 764.240	- 2381.732	1006.61	2696.289
2	1	19	-4785.650	-15086.917	6421.40	17080.746
	2	12	-3009.750	- 9528.522	4065.92	10788.097
	3	19/12	-1775.900	- 5558.395	2355.48	6292.683
3	1	19	-4785.650	-15086.917	6421.40	17080.746
	2	18	-4533.380	-14292.734	6083.59	16181.590
	3	19/18	- 252.270	- 794.183	337.81	899.156
4	1	19	-4785.650	-15086.917	6421.40	17080.746
	2	15	-3774.080	-11910.254	5072.64	13484.417
	3	19/15	-1011.570	- 3176.663	1348.76	3596.334
5	1	24	-6048.484	-19056.643	8107.53	21574.796
	2	18	-4533.395	-14292.700	6083.59	16181.564
	3	24/18	-1515.089	- 4763.943	2023.94	5393.235
6	1	27	-6812.263	-21440.062	9115.69	24273.010
	2	18	-4533.395	-14292.700	6083.59	16181.564
	3	27/18	-2278.868	- 7147.362	3032.10	8091.456
7	1	27	-6812.263	-21440.062	9115.69	24273.010
	2	19	-4785.703	-15086.939	6421.40	17080.780
	3	27/19	-2026.560	- 6353.123	2694.29	7192.240
8	1	24	-6048.480	-19056.633	8107.58	21574.806
	2	19	-4785.703	-15086.939	6421.40	17080.780
	3	24/19	-1262.777	- 3969.694	1686.18	4494.027
9	1	21	-5280.878	-16675.230	7104.03	18879.042
	2	19	-4785.703	-15086.939	6421.40	17080.780
	3	21/19	- 495.175	- 1588.291	682.63	1798.291