AN ANALYSIS OF THE ERRORS IN INTERFEROMETRIC DATA

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The reduction of the LL data taken with the interferometer between July 1967 and November 1967 has been completed and the first transform maps have been made. Since there is as a by-product a large amount of data for the calibration sources (84000 15-second observations of 3C 48, 3C 147, and 3C 286), it seemed worthwhile to study the errors in the amplitudes and phases of these observations, both in order to judge the quality of the synthesis maps and as an aid in planning future observations.

i. Reduction of the Data.

a) The Phases.

The positions of the calibration sources and the corresponding baseline parameters were found in the manner described previously (Hogg 1968). After that report was written, an additional error was found to be present in the data; when this was corrected, the baseline parameters were slightly changed. The new values are given in Table 1.

Even after the phases of the calibrators are corrected for errors in assumed position and baseline parameters, they still differ from zero, because of variable delays in the instrument and in the atmosphere. There are three types of variation which may be distinguished by their time scale. The first is an abrupt step in the phase, which has subsequently been shown to arise from a failure of the 30 MHz reference signal in the phase-locked loop. The second is a phase variation with period of a few hours, which probably arises in the instrument, and which can be corrected by the calibration observations. The third is a short-term variation, of periods minutes to one hour which is probably due to the atmosphere. This correction necessarily must be a function of azimuth and elevation, and there is not sufficient information to determine this function in detail. It is best therefore to ignore the phase fluctuations of this time scale, and allow them to appear in the data as additional noise.

The phases of the calibrators are corrected for the position and baseline errors, averaged over one scan (about 15 minutes' observation) and plotted as a function of scan number, using the program TP2CAL. The variations in phase due to the instrument--i.e., the abrupt changes and the long term changes--are then read directly from this plot.

b) The Amplitudes.

The amplitudes require correction for three different effects. The first occurs when the source is at large zenith distance. The system noise temperature rises because of increased atmospheric radiation and, to a lesser extent, because of ground radiation into the near sidelobes. The system gain is correspondingly decreased by the Automatic Level Control circuit. In principle this could be corrected using the observed amplitude of the winking noise tube; however, B. Clark has found that the correction can be made more accurately by using the empirical relation

$$(\text{True Amp}) = (\text{Obs. Amp}) * 1/(1-0.035\ (\sec z-1))$$

which is based on atmospheric absorption of about 1-1/2 percent per air mass.

The second effect, found by C. Wade, is caused by the delays. It is not merely loss in the delay unit, because that is compensated by the ALC. It is presumably due to dispersion across the band, leading to a loss in correlation. Again, an empirical correction is used; the observed amplitudes of the calibrators are plotted as a function of delay, using the program TP2CAL, and the delay-amplitude curve is found. The curves differ markedly from correlator to correlator, and, to a lesser extent, from configuration to configuration for a given correlator. A typical set of delay curves is given in Figure 1. The range of the correction is 10-15 percent, except for one very bad configuration (2400-1800-600 m) where the correction for correlators 2 and 3 exceeded 20 percent.

The third effect is the change in system gain with time, produced for example by a change in noise figure of one of the parametric amplifiers. The observed amplitudes are corrected for the delay and atmospheric effects, and plotted, using TP2CAL. The system gains, in counts per flux unit, are read directly from the plot.

c) Preparation of Calibrated Data.

The phase corrections due to baseline errors, to error in assumed source position, and to time variation in the instrument are applied to the data on Tape 2, using the program ITAPE3. The amplitude corrections due to the atmospheric effect, to the delay effect, and to the system gain are also applied. All amplitudes are brought to the highest correlator gain, using the gain-step calibration made by W. Webster. Then ITAPE3 writes a new tape, in TAPE2 format, but with the amplitudes in flux units, and the phases 'absolute', relative to the assumed position.

II. Analysis of the Errors.

For all of the calibrators, the amplitude of the data on Tape 3 should be a constant, independent of hour angle or baseline length, and equal to the adopted flux of the source, while the phase should be zero at all points.

Figure 2 shows the distribution of phases observed for the calibrators, after all of the corrections have been applied. The data are the 15-second integrations. At the left edge are given the baseline length, in meters, the dates of the observations, and the mean phase with its rms. By far the worst deviations occur for the period July 8-23, 1967, when the configuration was 1500-1200-300 m. Although part of the problem might be caused by the weather, it is more likely to be with the instrument, since this was the first configuration occupied. Apart from this, it is seen that the rms uncertainty in the measurement of phase varies with baseline length, from a value of about 5° for the short baseline to about 12° for the longer baseline. The transition is not well-defined, but appears to occur between 700 and 900 m. There is also a tendency for the phase scatter to be smaller in the late fall than in the summer. For example, the rms at 500 m is smaller than that at 400 m, and the rms at 200 m is smaller than that at 100 m. The mean phase on all baselines is near zero, thereby confirming the calibration.

A similar plot for the amplitudes is also shown in Figure 2. The distribution of the amplitude differences, in flux units, relative to the nominal flux of the source is given for 3C 48, 3C 147, and 3C 286. The distribution is slightly skewed at the longer baselines, which could be explained if there is a slight bias, in the sense that the flux scale for the longer baselines is systematically higher by about 2 percent. There is a tendency for the rms to be lower on the shorter baselines; the mean rms for baselines 100-400 m is 0.28 flux unit, while for baselines 1900-2700 m it is 0.34 flux unit. The effect is much less pronounced than with the phase, which implies that the phase fluctuations with periods less than 15 seconds have small amplitudes. As might be expected, the amplitudes with large error all fall to the left (low amplitude) side of the plot. The baselines with the largest rms are 1200 m, where the phase is also very bad, and 600 m, where the delay-amplitude effect was the worst.

The fluctuation in amplitude is much greater than the theoretical rms of 0.06 flux unit predicted for a correlation interferometer with system noise 115°, bandwidth 10 MHz and integration time of 15 seconds. Problems with the pointing, the delays, and the system gain all conspire to give an effect which might be proportional to amplitude. To explore this, the rms of polarized amplitudes for the sources 3C 48 and 3C 286 have been computed. These should be representative of weak point sources. For 3C 286, which has a polarized amplitude of 0.9 flux unit, the rms is 0.17 flux unit, or 0.14 flux unit if the worst baselines--600 m and 1200 m-- are omitted. The rms for 3C 48, which has a polarized amplitude of 0.2 flux unit, is 0.10 flux unit. Thus, the rms does decrease towards the expected value. As a rule of thumb, the rms in amplitude for a single 15-second observation on a source of flux S is

$$\mathrm{RMS} \sim 0.12 + 0.03 * S \quad \text{flux units.}$$

In contrast, the phase error increases for the weaker source. For a source of ten flux units, the rms in phase is 5° for short baselines and 12° for longer baselines. For a source of one flux unit, the corresponding quantities are 10° and 18° respectively.

A more detailed analysis of the phase fluctuations and the correlation of these fluctuations with weather conditions is being made and will be reported later.

Reference

D. E. Hogg, "Baseline Calibration for the Synthesis Program June-November 1967" June 1968.

Table 1

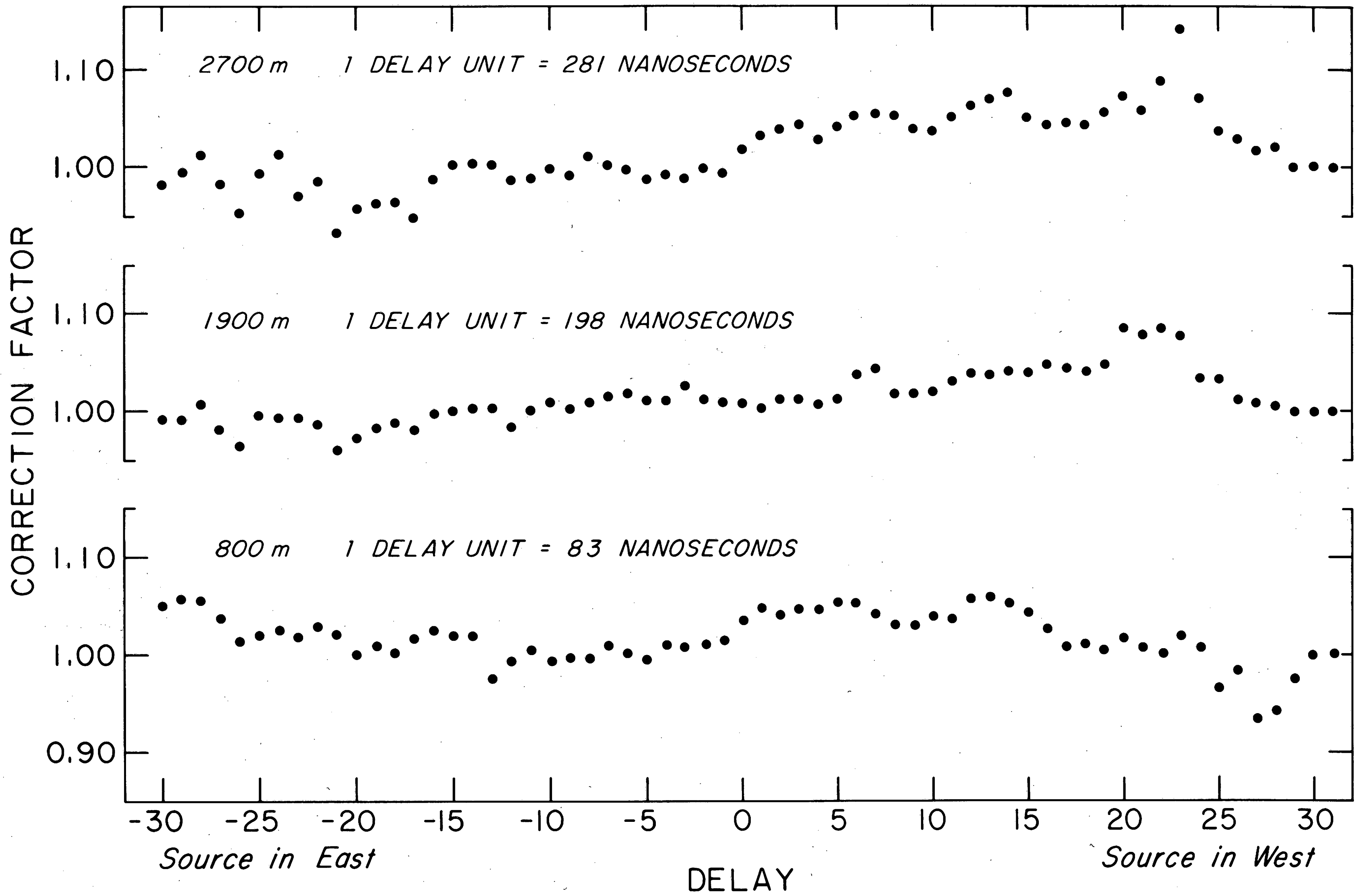
REVISED BASELINE PARAMETERS FOR THE SYNTHESIS PROGRAM

Configuration	Correlator	Station	BX	BY	BZ
1	1	15	-3774.01	-11910.22	5072.72
	2	12	-3009.77	- 9528.50	4065.87
	3	15/12	- 764.24	- 2381.72	1006.85
2	1	19	-4785.65	-15086.88	6421.24
	2	12	-3009.76	- 9528.50	4065.84
	3	19/12	-1775.89	- 5558.38	2355.40
3	1	19	-4785.65	-15086.88	6421.24
	2	18	-4533.38	-14292.70	6083.45
	3	19/18	- 252.27	- 794.18	337.79
4	1	19	-4785.65	-15086.88	6421.24
	2	15	-3774.09	-11910.23	5072.52
	3	19/15	-1011.56	- 3176.65	1348.72
5	1	24	-6048.51	-19056.60	8107.30
	2	18	-4533.41	-14292.67	6083.43
	3	24/18	-1515.10	- 4763.93	2023.87
6	1	27	-6812.28	-21440.00	9115.47
	2	18	-4533.41	-14292.67	6083.43
	3	27/18	-2278.87	- 7147.33	3032.04
7	1	27	-6812.28	-21440.00	9115.47
	2	19	-4785.72	-15086.90	6421.24
	3	27/19	-2026.56	- 6353.10	2694.23
8	1	24	-6048.50	-19056.58	8107.38
	2	19	-4785.72	-15086.91	6421.24
	3	24/19	-1262.78	- 3969.68	1686.14
9	1	21	-5280.89	-16675.20	7103.86
	2	19	-4785.72	-15086.91	6421.24
	3	21/19	- 495.17	- 1588.29	682.62

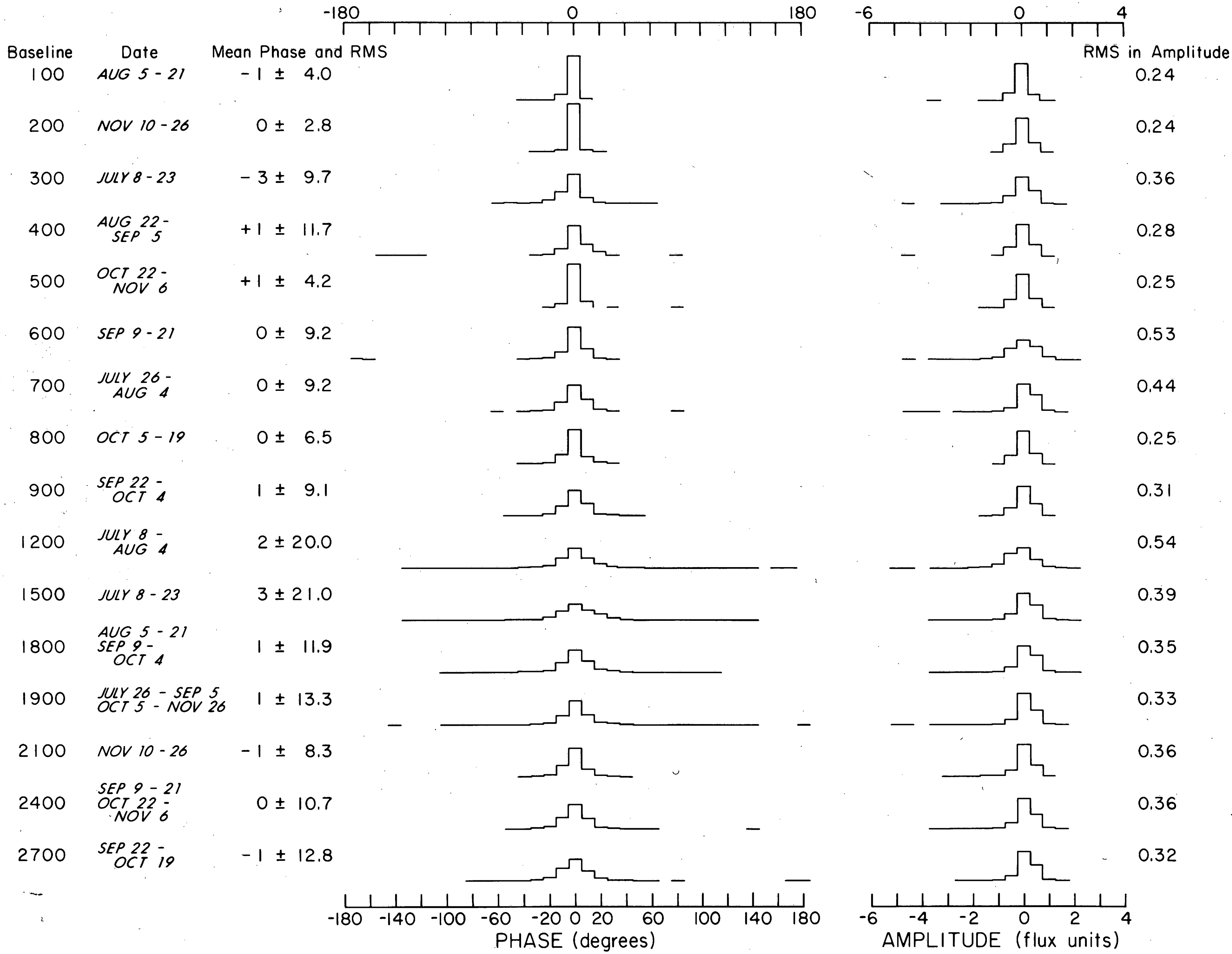
FIGURE CAPTIONS

Figure 1. Delay-amplitude curves. The abscissa gives the delay, in units as defined in the figure, while the ordinate gives the factor by which the amplitudes must be divided in order to remove the delay effect.

Figure 2. Distribution of observations of phase and amplitudes for the calibrators. The series of histograms at the left is for phase, and at the right, for amplitude.



2700 m 1 DELAY UNIT = 281 NANOSECONDS
1900 m 1 DELAY UNIT = 198 NANOSECONDS
800 m 1 DELAY UNIT = 83 NANOSECONDS
CORRECTION FACTOR
1.10
1.00
0.90
-30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30
Source in East
Source in West
DELAY



Baseline
Date
Mean Phase and RMS
RMS in Amplitude
100 AUG 5 - 21 − 1 ± 4.0 0.24
200 NOV 10 - 26 0 ± 2.8 0.24
300 JULY 8 - 23 − 3 ± 9.7 0.36
400 AUG 22 - SEP 5 + 1 ± 11.7 0.28
500 OCT 22 - NOV 6 + 1 ± 4.2 0.25
600 SEP 9 - 21 0 ± 9.2 0.53
700 JULY 26 - AUG 4 0 ± 9.2 0.44
800 OCT 5 - 19 0 ± 6.5 0.25
900 SEP 22 - OCT 4 1 ± 9.1 0.31
1200 JULY 8 - AUG 4 2 ± 20.0 0.54
1500 JULY 8 - 23 3 ± 21.0 0.39
1800 AUG 5 - 21 SEP 9 - OCT 4 1 ± 11.9 0.35
1900 JULY 26 - SEP 5 OCT 5 - NOV 26 1 ± 13.3 0.33
2100 NOV 10 - 26 − 1 ± 8.3 0.36
2400 SEP 9 - 21 OCT 22 - NOV 6 0 ± 10.7 0.36
2700 SEP 22 - OCT 19 − 1 ± 12.8 0.32
-180 -140 -100 -60 -20 0 20 60 100 140 180
PHASE (degrees)
-6 -4 -2 0 2 4
AMPLITUDE (flux units)