NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROJECT

VLA TEST MEMORANDUM NO. 120

INTERFEROMETRIC ANTENNA EFFICIENCY MEASUREMENTS

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The intent of this memo is to set down the procedure for interferometric aperture efficiency measurements. The results are not, at the moment, entirely useful because of apparent decorrelation of the signals. This intent will be accomplished by describing in detail the reduction of an observation of July 21, 1977.

This measurement was directed to the efficiency of antenna 8, and therefore more care was taken with this telescope, for instance a careful K-Band focusing and pointing before the measurements started, and measurements were made before and after the cal value determination. Measurements were also made on antenna 6. Antenna 2 was used as a reference.

Measurements were made in pointing mode: the on-source point only was considered. Sets of 4 100 second cycles were used. The on-source amplitudes were arithmetically averaged, and the pointing offsets for antennas 6 and 8 were arithmetically averaged.

The source was 3C345, bandwidth 12 MHz, band center frequency 22.485 GHz, gain 0. RMS thermal noise, in our conventional units is $\sim 70 \times 10^{-4}$.

As an example of a set of 4 determinations we have, amplitudes $*10^4$

Time	26AA	28AA	68AA	26CC	28CC	68C
00:48:20	552	525	1526	1145	1460	1953
00:50:00	494	507	1470	1182	1471	1647
00:53:20	403	490	1356	1064	1609	1622
00:55:00	295	557	1682	1011	1502	1486
Average	436	520	1508	1100	1510	1677
Log Average	6.078	6.254	7.319	7.003	7.320	7.425

There is a general formula that gives the (least squares) voltage V_i in the i^{th} channel from the correlation C_{ij} with all other channels. V_i is so defined that, if a second IF channel, identical to the i^{th}, is correlated with it, the correlation should be V_i^2.

$$\text{Log } V_i = \frac{1}{N-2} \sum_j \log C_{ij} - \frac{1}{(N-1)(N-2)} \sum_i \sum_j \log C_{ij}$$

where $C_{ii} \equiv 1$.

For 3 antennas, e. g.,

$$\text{Log } V_1 = \tfrac{1}{2}(\log C_{12} + \log C_{13} - \log C_{23})$$

For the example above, then

	6A	6C	8A	8C
Log V	3.571	3.554	3.747	3.871
V^2	1264	1222	1797	2303
Pointing error Az	-0!09	-0!31	0!02	-0!36
Pointing error El	0.66	0.77	-0.38	0.03
Pointing error total	0.67	0.83	0.38	0.36
Pointing error correction	1.29	1.53	1.08	1.07
Corrected V^2	1630	1870	1940	2470

Pointing errors were determined by the normal pointing reduction programs and the correction calculated assuming a 2' Gaussian beam. The pointing corrections for antenna 6 are, unfortunately, uncertain as well as large, because the source was sitting on a sloping part of the beam.

The hard part is now to convert these numbers into source/system ratio. We must make the correction for the two level sampler. Our conventional amplitudes are 2^8 * {correlated counts/(average self counts)}. In the 3 level system, the output is non-zero 54% of the time. Therefore, after N samples, the noise on the correlator counts for a Nyquist sampling rate is $\sqrt{0.54N}$. But the average self correlator count is 0.54N. Therefore the noise on the quotient is $(0.54N)^{-\frac{1}{2}}$.

The source/system ratio is given for a continuous, or Nyquist sampled, system, simply by the average correlation coefficient when the input voltage is unity. The sampled system has a noise in the mean of $\sqrt{2/N}$.

The 3 level system has 0.81 the signal-to-noise ratio of the continuous system. Combining these relations gives

$$\text{source/system} = \frac{\sqrt{1.08}}{0.81} * \text{(3 level correlation coeff.)}$$

The final factor converting from amplitudes to source/system is

$$10^{-4} \frac{\sqrt{1.08}}{.81} 2^{-8} = 5.01 \times 10^{-7}.$$

Given a source/system, we can find source/cal by multiplying by the system/cal ratio from the logged monitor data.

	6A	6C	8A	8C
V^2	1630	1870	1940	2470
Source/System	.000817	.000937	.000972	.001237
System/Cal	54.2	47.8	68.9	58.3
Source/Cal	.0443	.0448	.0670	.0721

The measurements of the above type were done once before the antenna 8 cal measurement and four times after it, during a period of about an hour and a half, with the following result

	Source/Cal			
TAI	6A	6C	8A	8C
00:50	.0443	.0448	.0671	.0722
01:25	.0455	.0382	.0734	.0708
01:32	.0442	.0442	.0686	.0748
01:40	.0488	.0454	.0596	.0766
02:20	.0467	.0469	.0598	.0751
Mean	.0459	.0439	.0657	.0739
Cal	7.97	9.51	5.95	6.45
T_A	.366	.417	.391	.477
Efficiency	24%	27%	26%	31%

The last line of the preceding table was based on a K-Band flux for 3C345 of 8.6 Jy, based on early June ratio to 3C286 determined by Ed Fomalont and 3C286 flux transferred from the 36 foot, via various intermediate stages by Fomalont, Geldzahler, Owen, and others. The uncertainty in this flux is of order 10%.

A similar determination was done at C-Band in an attempt to prove the procedure, with the following results:

C-Band

	6A	6C	8A	8C
Source/System	.00659	.00956	.00808	.0155
System/Cal	43.3	41.6	37.8	36.4
Cal	1.64	1.74	0.96	1.33
T_A	.466	.693	.293	.751
Efficiency	36%	55%	23%	59%

The critical dependence here is on the cal values - those for antenna 6 were measured May 3, 1977, and those for antenna 8 were measured in the lab before lifting the system. The flux of 3C345 was taken to be 7.13 Jy at this frequency.

Measurements of the same sort have been repeated by me and by Peter Napier at various times since July. 6 cm efficiencies came out slightly low - for instance a careful 6 cm determination by Peter Napier in August gave

	5A	5C	8A	8C
Efficiency	58%	48%	61%	54%

At the same time he confirmed the K-Band measurements quoted above. In October, I obtained the following measurements at K-Band:

	7A	7C	8A	8C	9A	9C
Efficiency	28%	4½%	31%	32%	30%	31%

We thus see the decorrelation of a factor ~0.7 in most measurements, except for that for IF 7C, which must have been broken.

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ERRATUM TO

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Larry D'Addario has pointed out to me that the small signal correlation efficiency $\rho/\rho_{3\text{-level}} = 0.810$ quoted in Cooper (Aust. J. Phys., *23*, 521, 1970) is normalized in exactly the way we do our normalization, by division by N_{max}, the correlation coefficient for perfectly correlated signals. The factor $\sqrt{1.08}$ in my relation between observed correlation and the source/system ratio is therefore wrong. The correct value is, for DEC standard scaled correlation coefficients,

$$\text{source/system} = 4.82 * 10^{-6}\ \rho.$$

This reduces my quoted efficiencies by 4% of their value (the K-Band efficiencies by ~1%, the C-Band by ~2%). The conclusions remain unchanged.