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

VLA ELECTRONICS MEMORANDUM NO. 171

CLOSURE - SOME EXAMPLES

B. G. Clark

April 1978

To clarify the effects of some electronics effects on closure problems I have written down a few examples, intended to be representative but not, by any means exhaustive. For simplicity in the discussion, noise is emitted from consideration; it has no substantive effects in the present context. Also, never mind that the examples below cannot be produced by physically realizable devices.

1.0 PHASE ANOMALIES AT THE END OF BAND

Four antennas, all with flat frequency responses in amplitude from 0 to f_o. Two, 1 and 2, also have flat phase responses at 0^o. The other two have flat phase responses from 0 to 0.8 f_o, then a linear phase run to 90^o at f_o for 3, to -90^o at f_o for 4. Delays are set using #1 as reference. This results in a delay for #3 of $.119/f_o$ and for #4 of $-.119/f_o$.

Baseline	Ampl.	Phase	Amp. Closure	Phase Closure
1 - 2	1.000	$0^o.0$	-5.3%	0
1 - 3	0.959	-12.8	+3.3%	0
1 - 4	0.959	+12.8	+3.3%	0
2 - 3	0.959	-12.8	3.3%	0
2 - 4	0.959	+12.8	3.3%	0
3 - 4	0.757	0.0	-6.3%	0

2.0 DIFFERENT FREQUENCY CUTOFFS

Antennas 1 and 2 are flat in amplitude and phase between 0 and f_o, and then have a sharp cutoff. 3 and 4 continue only to 0.9 f_o, also flat in amplitude and phase. All phases are zero.

Baseline	Amplitude	Amplitude Closure Error
1 - 2	1.000	3.5%
1 - 3	0.900	-6.5
1 - 4	0.900	-6.5
2 - 3	0.900	-6.5
2 - 4	0.900	-6.5
3 - 4	1.000	3.5

3.0 DIFFERENT FREQUENCY CUTOFFS WITH PHASE ANOMALIES

All antennas have flat amplitude and phase from 0 to 0.9 f_o. Antenna 1 cuts off, antennas 2, 3, and 4 have flat amplitudes from 0.9 f_o to f_o. In this interval, antenna 2 has phase 0, antenna 3 has phase 90, antenna 4 has phase -90. Antenna 1 was the reference for delay setting.

Baseline	Ampl.	Phase	Amp. Closure	Phase Closure
1 - 2	0.900	0^o	-4.1%	$0^o.0$
1 - 3	0.900	0	2.1	-2.1
1 - 4	0.900	0	2.1	2.1
2 - 3	0.906	$6^o.3$	2.1	-2.1
2 - 4	0.906	$-6^o.3$	2.1	2.1
3 - 4	0.800	0	-6.1	0.0

4.0 AMPLITUDE RIPPLE

All antennas have flat phase response, and a sharp amplitude cutoff at f_o. For antenna n, $f < f_o$, the amplitude response is $1 + 0.2 \cos (f/f_r + n\pi/2)$, where the ripple period, $f_r << f_o$. The

phase of the ripple pattern is shifted depending on antenna. All phases are zero.

Baseline	Amplitude	Amplitude Closure Error
1 - 2	.995	0.3%
1 - 3	.985	-0.7
1 - 4	.995	0.3
2 - 3	.995	0.3
2 - 4	.985	-0.7
3 - 4	.995	0.3

5.0 DELAY ERRORS

All passbands flat to f_o in amplitude and phase, delays set correctly in antennas 1 and 2, in error by $0.15/f_o$ in 3 and $-0.15/f_o$ in 4.

Baseline	Ampl.	Phase	Amp. Closure	Phase Closure
1 - 2	1.000	0.0	-2.6%	0
1 - 3	0.963	27.0	1.3	0
1 - 4	0.963	-27.0	1.3	0
2 - 3	0.963	27.0	1.3	0
2 - 4	0.963	-27.0	1.3	0
3 - 4	0.858	0.0	-2.5	0

6.0 SLOPED BAND-PASSES

In antennas 1 and 2 the voltage band-pass slopes linearly from 0.7 to 1 (3 dB, a rather severe case) with frequency. In antennas 3 and 4, the voltage band-pass slopes linearly from 1 to 0.7. Phases are zero.

Baseline	Amplitude	Amplitude Closure Error
1 - 2	1.000	1.4%
1 - 3	.979	-0.7
1 - 4	.979	-0.7
2 - 3	.979	-0.7
2 - 4	.979	-0.7
3 - 4	1.000	1.4

7.0 SLOPED BAND-PASSES AND DELAY ERRORS

Band-passes same as example 6, but antenna 2 has a delay error of $0.1/f_o$ and antenna 3 a delay error of $-0.1/f_o$.

Baseline	Ampl.	Phase	Amp. Closure	Phase Closure
1 - 2	.984	$20^{\circ}.1$	2.1%	$1^{\circ}.1$
1 - 3	.963	-18.0	-0.1	-1.0
1 - 4	.979	0.0	-1.7	0.0
2 - 3	.917	-36.0	-1.7	0.0
2 - 4	.963	-18.0	-0.1	-1.0
3 - 4	.984	15.9	2.1	-1.1

Conclusion: it is relatively easy to produce the 5% amplitude closure errors we see, extremely hard to get the 5° phase closure errors we see.