VLBA Correlator Memo No. 76

(870206)

National Radio Astronomy Observatory
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To: VLBA Correlator Memo Series

From: John Benson

Subject: Simulations of the Digital Lobe Rotators.

This memo is the first in a series that reports results of computer simulations of the FX Correlator. The FX simulator is described in VLBA Correlator Memo No. 74.

The performance of the digital lobe rotators in the FX architecture was measured with the computer simulator. The simulator tests were used to help determine how many bits should be used in the lobe rotator phase word, and how many bit are necessary in the lobe rotator output words. You may recall that the digital lobe rotators operate on the quantized data in a station-based manner. The input data are, of course, two-level or four-level quantized samples.

1.0 Cross-correlation amplitude versus lobe rotator word sizes.

The plots in figure 1 show the dependence of the cross-correlation amplitude on the number of bits in the lobe rotator phase word, and the number of bits in the lobe rotator output words. The simulator setup was :

station #1 rate = 2000.0 samples/turn,
station #2 rate = 2150.0 samples/turn,
512k samples correlated, 4000 * 128 point FFT's,
2 bit (4 level) quantized input samples having equal weights,
model cross-correlation amplitude = 0.2

Figure 1a shows the relative error versus the number of bits in the lobe rotator phase word. For each point plotted, the bits in the output words equal the number of bits in the phase word. Figure 1b shows the relative error versus output word bits. Eight bits were used in the lobe rotator phase words. The relative errors are calculated with respect to model correlation coefficients corrected for two-bit quantization.

All combinations of lobe phase bits and output word bits were simulated. It is fairly clear that increasing the number of bits in the output words does not have much effect on the SNR as long as there are about 5 or more bits in the output words. Eight-bits in the lobe rotator phase word seems to be entirely adequate; an eight-bit word is also very convenient in the lobe rotator phase hardware.

2.0 Harmonic correlation versus lobe rotator word sizes.

Figures 2 through 5 show the results of test runs that searched for anomalous correlations as the lobe rotator frequencies were allowed to vary. We expect that the mix between the lobe rotator phasors and the one-bit or two-bit sampled data will produce harmonics in the output signals. Naturally, when the lobe rotator frequencies (in a particular baseline) are equal or multiples of each other, all or some of the harmonics will be aligned and they will correlate. Thus as the rotator frequency difference on a given baseline changes, we could encounter correlation variations that are entirely erroneous. This problem has been known and discussed for some time, and is often used as an argument against station-based digital lobe rotators having small word sizes.

In the following figures (2 through 4), I show the relative amplitude and phase errors for various ranges of lobe rotator frequency differences. The test results shown used 8-bit lobe phase words, and 5-bit lobe rotator output words.

Tests were also run with smaller word sizes, and the correlation of harmonics became very prominent. The excess correlation due to the lobe rotator harmonics is shown in figure 5.

Figure 2 shows the amplitude and phase errors while one lobe rotator is held fixed and the other stepped across four decades of frequency. The test setup was :

station #1 rate = 4000.0 samples/turn,
station #2 rate = 10 to 10**5 samples/turn,
512k samples correlated, 4000 * 128 point FFT's,
2 bit (4 level) quantizied input samples having equal weights,
8 bit lobe rotator phase words, 5 bit rotator output words,
model cross-correlation amplitude = 0.2

The relative errors in cross-correlation amplitude and phase show no departure from zero that is statistically significant. In particular, the relative errors are insignificant when both lobe rotator rates are equal (4000 samples/turn).

In figure 3, lobe rotator 2 is stepped from 1990 samples/turn to 2010 samples/turn, while rotator 1 remains fixed at 2000 samples/turn. 12.8 Msamples were correlated. Otherwise, the simulator parameters were the same as those for figure 2. And, like the previous test run, no statistically significant departures from the zero error level were observed.

The plots in figure 4 again show the cross-correlation error while the second lobe rotator is stepped in frequency. This test shows what happens to the cross-correlations as a baseline fringe rate goes through zero. Each point plotted consumed 2.25 cpu hours on the Cray. The simulator model was :

32 Msamples correlated (one second of VLBA data),
station #1 rate = 21333.33 samples/turn (1500.0 Hz),
2 bit (4 level) quantized input samples,
8 bit lobe rotator phase words, 6 bit rotator output words,
5,5,4 floating point words in FFT,
2048 point FFT's,
model cross-correlation amplitude = 0.2

In figure 5 the correlation error is plotted versus the number of bits in the lobe rotator phase word. The rotator rates are equal. The simulator model was :

station #1 rate = 4000.0 samples/turn,
station #2 rate = 4000.0 samples/turn,
2 bit (4 level) quantized input samples having equal weights,
rotator output word size = phase word size,
512k samples correlated for 2, 3, 4, 5, 6 bit tests,
12.8M samples correlated for 8 bit test,
128 point FFT's,
model cross-correlation amplitude = 0.2

The conclusions of the tests reported in this memo are that an 8-bit phase word and a 5-bit output word in the lobe rotator are entirely adequate. Harmonic correlation represents less than a 0.3 % increase in the model cross-correlation.

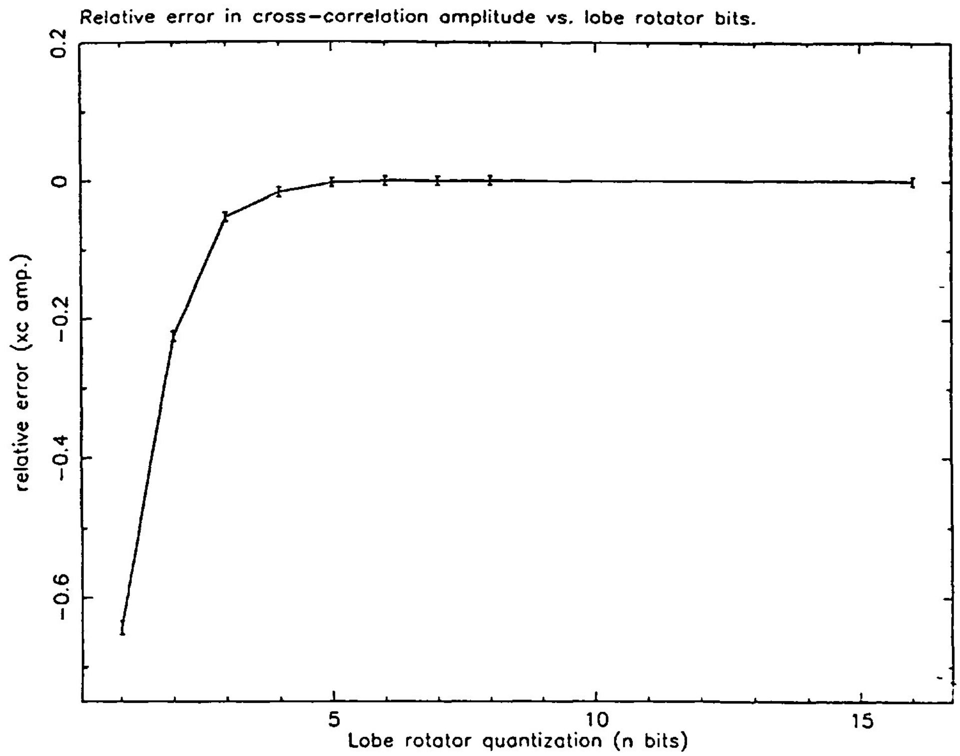


FIGURE 1a.

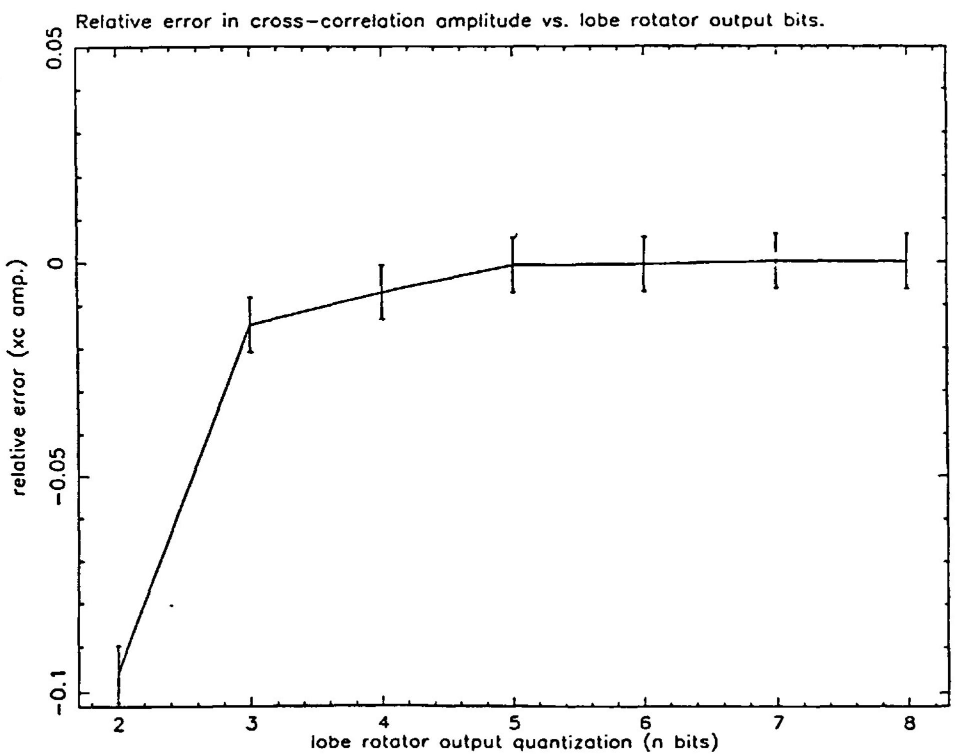
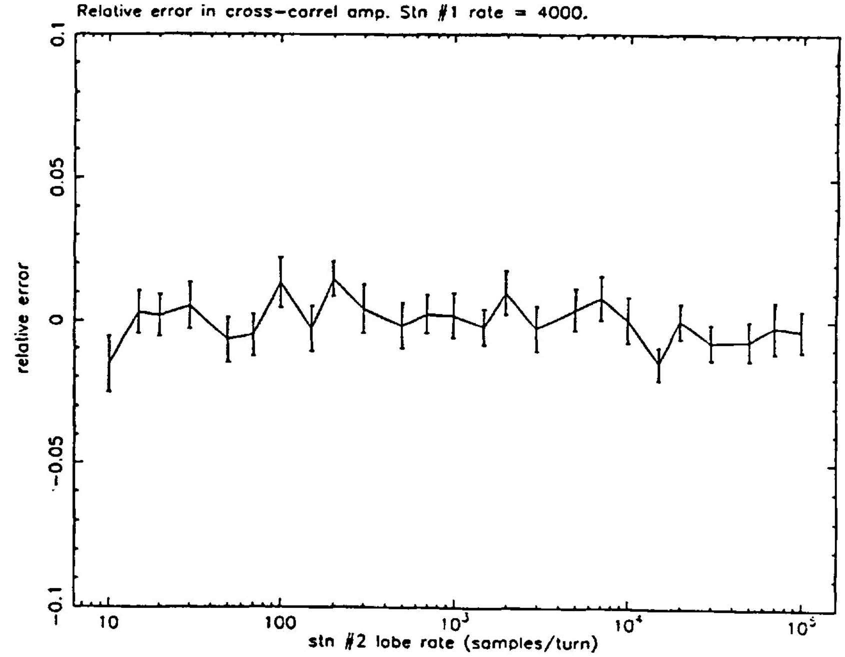


FIGURE 1b.

Relative error in cross-correl amp. Stn #1 rate = 4000.



Error in cross-correl phase. Stn #1 rate = 4000.

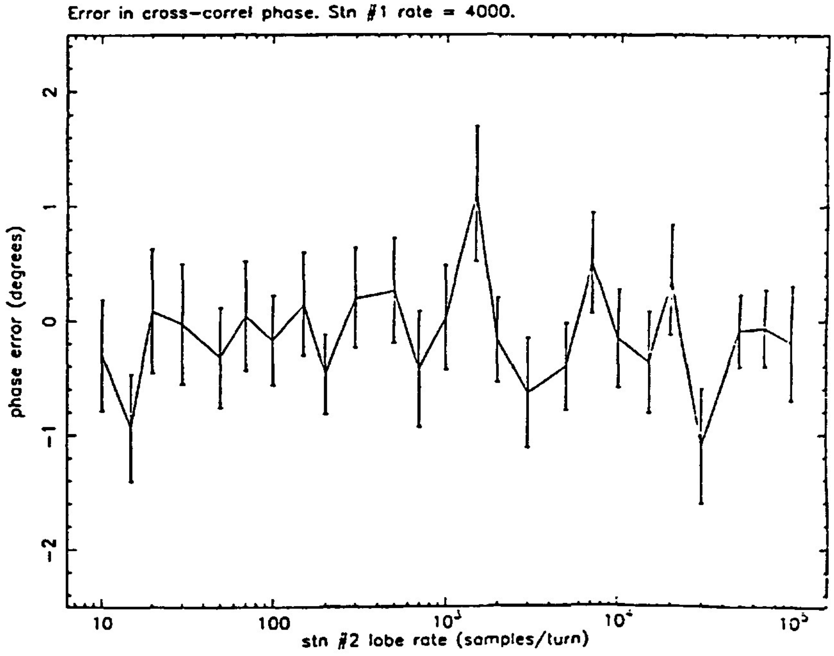
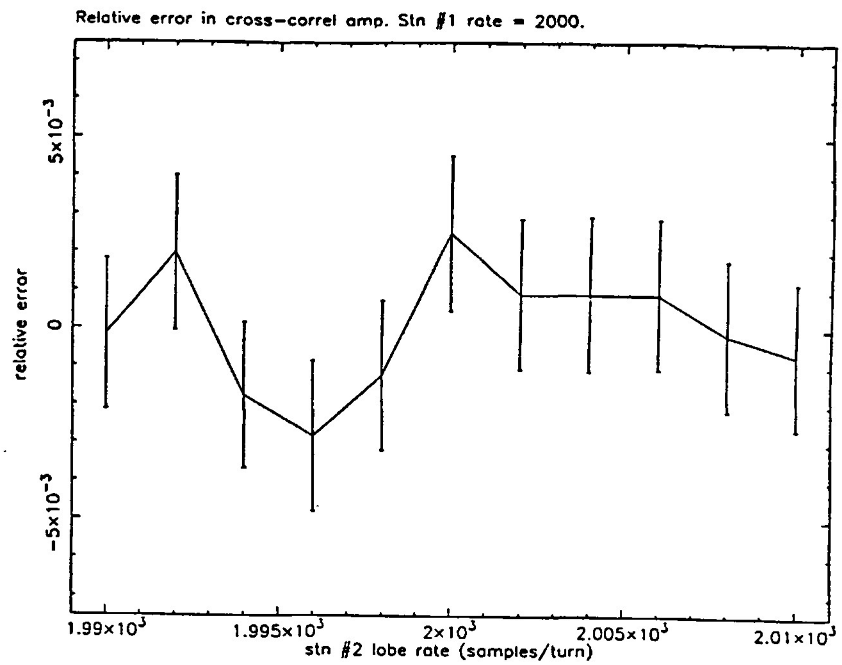
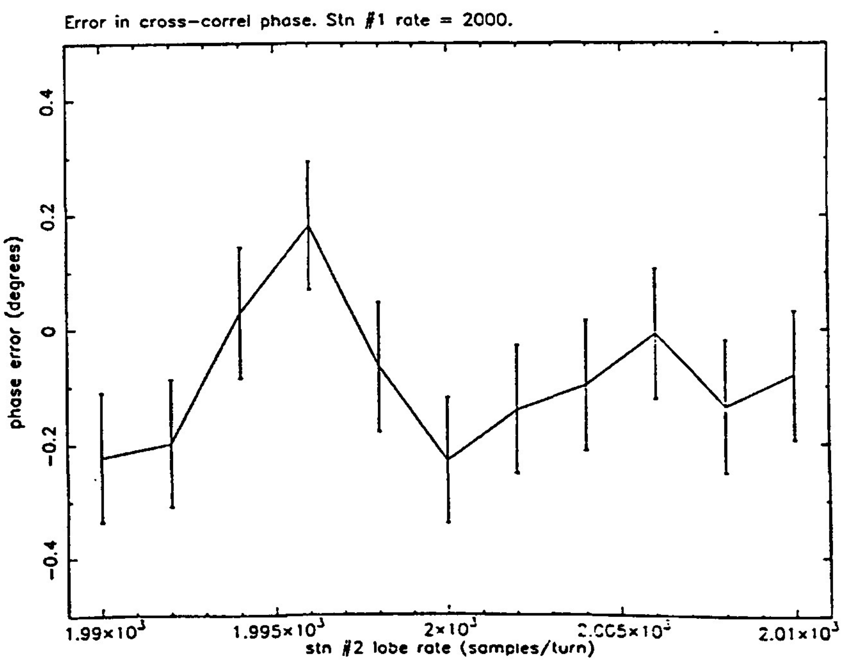


FIGURE 2

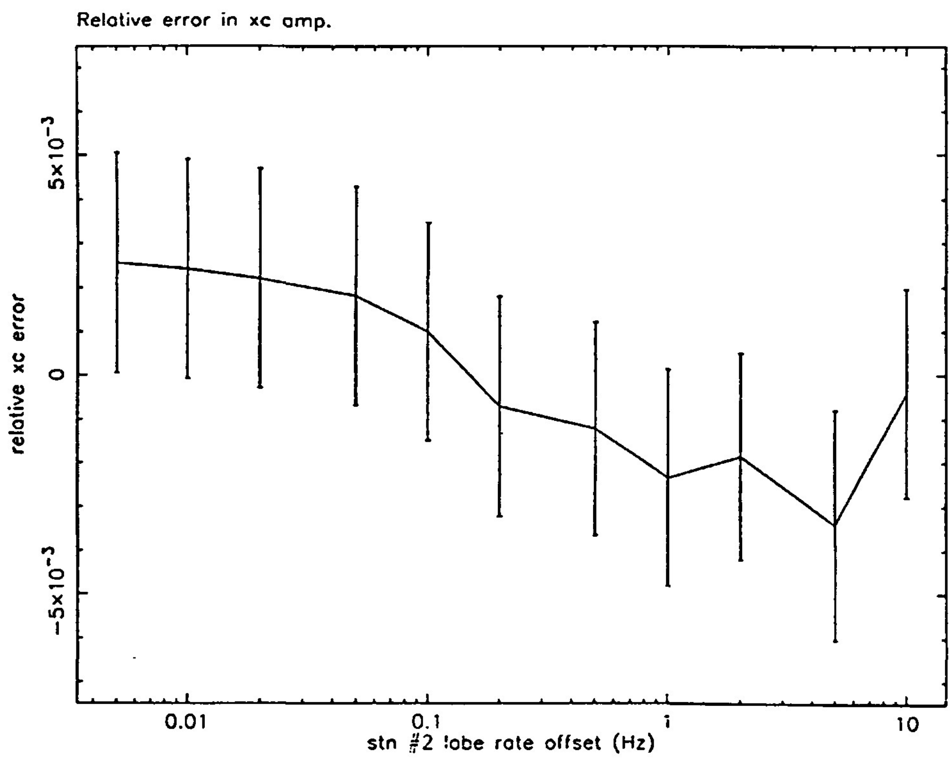


Relative error in cross-correl amp. Stn #1 rate = 2000.
relative error
5x10^-3
0
-5x10^-3
1.99x10^3
1.995x10^3
2x10^3
2.005x10^3
2.01x10^3
stn #2 lobe rate (samples/turn)



Error in cross-correl phase. Stn #1 rate = 2000.
phase error (degrees)
0.4
0.2
0
-0.2
-0.4
1.99x10^3
1.995x10^3
2x10^3
2.005x10^3
2.01x10^3
stn #2 lobe rate (samples/turn)

FIGURE 3.


Relative error in xc amp.
relative xc error
5×10^{-3}
0
-5×10^{-3}
0.01
0.1
1
10
stn #2 lobe rate offset (Hz)

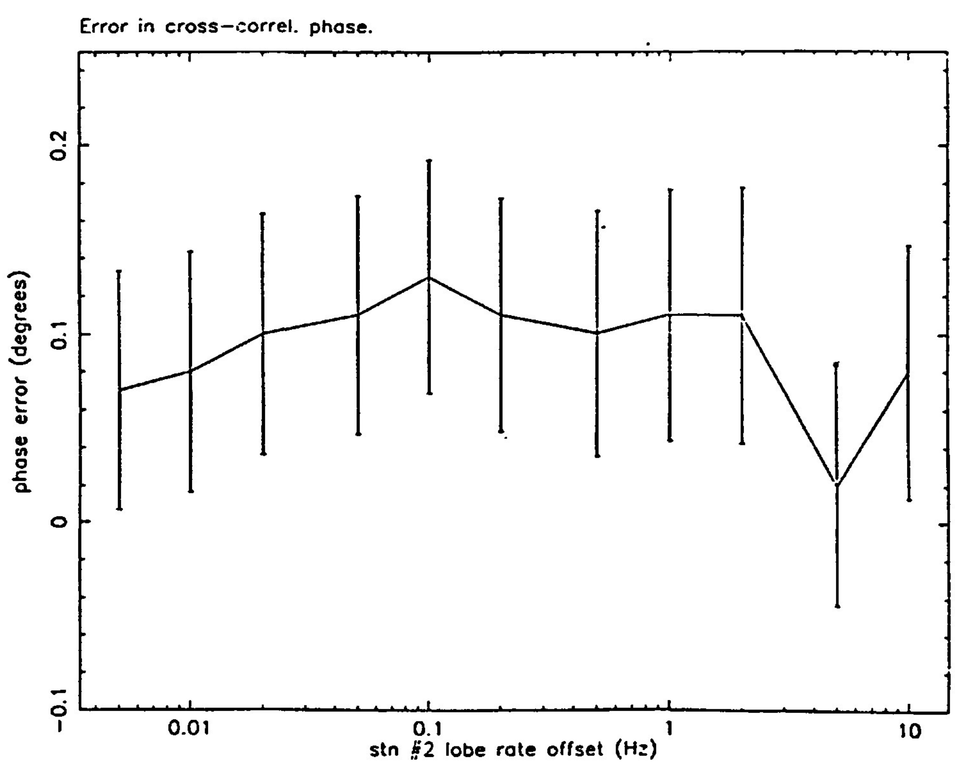

Error in cross-correl. phase.
phase error (degrees)
0.2
0.1
0
-0.1
0.01
0.1
1
10
stn #2 lobe rate offset (Hz)

FIGURE 4.

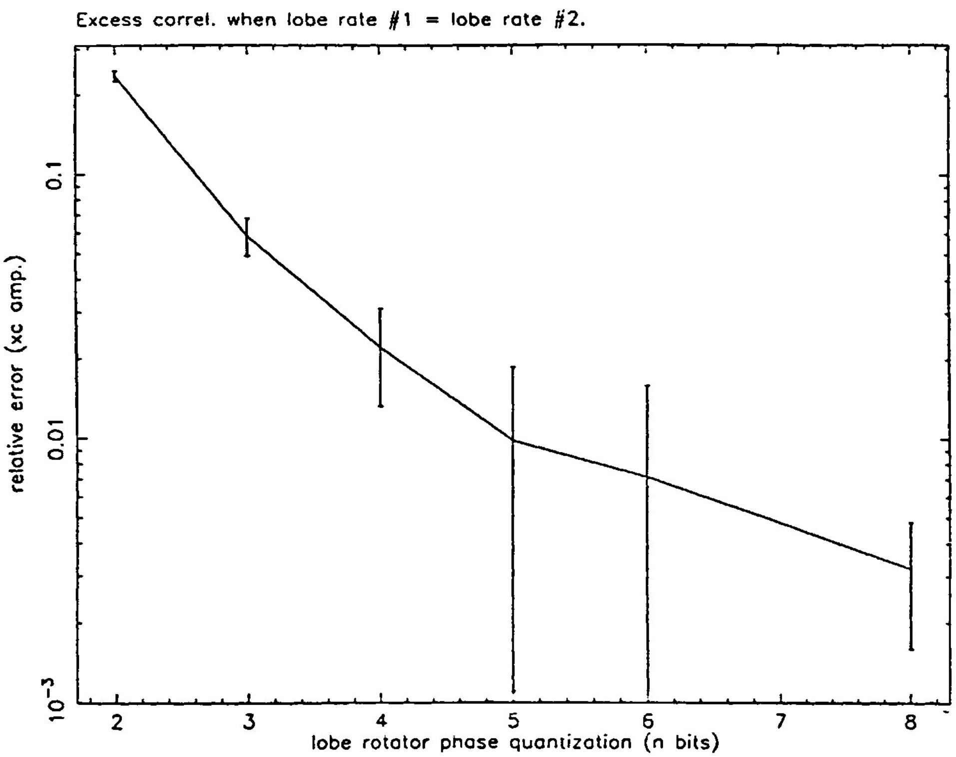

Excess correl. when lobe rate #1 = lobe rate #2.
relative error (xc amp.)
0.1
0.01
10^{-3}
2
3
4
5
6
7
8
lobe rotator phase quantization (n bits)

FIGURE 5.