VLBA Acquisition Memo # 108

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Area Code 617
692-4765

To: VLBA Data Acquisition Group

From: Alan E.E. Rogers,
Edwin F. Nesman

Subject: Phase Calibration Detection and Processing at the Sites

The phase calibration tones can be extracted at the sites using the dual detector in the decoder module (part of the formatter).

Tone Frequencies

The dual detector can extract complex amplitudes for

sample frequency/(8N) for 2-level

or sample frequency/(16N) for 3-level

where N is an integer >0 in the range 1 - 32,768

The Table shows the tone frequencies which can be both produced using the 10KHz L.O. increment and extracted by the tone detectors.

Systematic Error Sources

a) Images
Many Tone frequencies are unusable because the image of another rail falls on top of the extracted rail. The Table shows which rails have image corruption assuming a 2 MHz bandwidth and 1 MHz rail spacing (1 microsec pulse spacing).

b) Harmonics of the Tone Extraction "Local Oscillator"
In the 2-level mode the tone extractor uses quadrature square waves which have harmonic content which results in a spurious response. These spurious responses are harmless unless they happen to fall on another rail or rail aliased by the sample clock. When aliased the resulting errors are more serious as they produce errors when change with calibration tone phase.

c) Best Choice of Tone Frequency

10 KHz was chosen for MKIII geodetic/astrometric VLBI because the phase errors are small and this tone frequency can be extracted for all bandwidths down to 1 MHz.

Detection Sensitivity

The SNR for the tone extraction is given by

$$SNR = \left(\frac{2}{\pi} \quad (2\ BT)\ \frac{Trail}{Tsys}\right)^{1/2} \quad \text{for 2-level}$$

where B = Bandwidth
T = Integration Time

The ratio Trail/Tsys is the fraction of power in a rail to the power in the bandwidth window. For 0.1% power in a 2 MHz bandwidth and a 60°K system the rail strength is -148 dBm and the SNR is 160 in 10 second integration. Using both detectors the instrumental group delay for 4 X-band frequencies with 200 MHz r.m.s. spanned bandwidth could be derived with a 1 sigma error of 2 picoseconds in 20 seconds. The use of only one calibration tone near the D.C. edge of each individual channel should adequately correct all instrumental and cable drifts except those in the baseband converter baseband filters and samplers. It would be better to process a tone near the center of each band since this would correct for most of the baseband filter and sampler drift but the ideal 1.01 MHz tone frequency cannot be extracted by the simple detectors in the formatter and a 1 MHz tone is corrupted by images unless the rail spacing is increased from 1 MHz. However, the temperature 200 ps/degC coefficient expected for the baseband filter is reduced by the bandwidth synthesis process to less than 1 ps/degC for a 200 MHz spanned bandwidth. Another assumption in the use of a single rail is that the cable dispersion changes over a few MHz are small.

Tone Frequency KHz	Bandwidths MHz	Harmonic # for Static Error	Max. Static Error (deg)	Other Error Sources	Max Error from aliasing (deg)
4000	[16]			BBC Images	2.5
2000	16,[8]			BBC Images	2.5
1000	16,8,[4]			BBC Images	2.5
500	16,8,4,[2]	3	19	BBC Images	2.5
250	16,8,4,2,[1]	5	11	aliased harmonics	2.0
200	16,8,[4]			aliased harmonics	2.0
100	16,8,4,[2]	11	5	aliased harmonics	1.0
50	16,8,4,2,[1]	21	2.7	aliased harmonics	0.5
40	16,8,[4]			aliased harmonics	0.4
20	16,8,4,[2]	51	1.1	aliased harmonics	0.2
10	16,8,4,2[1]	101	0.6[0.2]	aliased harmonics	0.1[0.1]

Table. Tone Frequencies which can be processed and produced with 1 MHz rails and 10 KHz L.O. increment.

Notes.
1. For bandwidths in [] tones can not be processed in 3-level mode.
2. Errors in [] are for 3-level mode.
3. Aliasing errors are given for 2 MHz bandwidth and decrease by a factor of 2 for each factor of 2 increase in bandwidth. The VLBA 8-pole butterworth response was assumed for calculation of the strength of the alias sampled rail.