VLB ARRAY MEMO No. 472

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To: VLBA

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Subject: Correlated Flux Calibration Techniques for VLBA

A) 2-level data

Following the conventional method:

In order to convert the normalized correlation ρ to correlated flux F we have

$$F = 2K\rho\left(\frac{T_{s1}T_{s2}}{A_1A_2n_1n_2a_1a_2}\right)^{1/2}$$

where	K	= Boltzmann's constant
	A_1, A_2	= antenna apertures
	n_1, n_2	= aperture efficiencies
	T_{s1}, T_{s2}	= "on source" system temperatures
	a_1, a_2	= atmospheric attenuations

The efficiencies as a function of antenna elevation are normally measured by observing some strong calibration sources at each antenna. The system temperatures are usually measured by injecting a calibrated noise source into the receiver and measuring the total power. If this is a switched noise source the system temperature Ts is

$$Ts = Tcal\ [Poff/(Pon-Poff)]$$

where the noise in this measurement is

$$\frac{\sigma_T}{T} = \frac{2}{(BT)^{1/2}}\frac{Ts}{Tcal}$$

for equal switch cycles. So that with a 2% cal a 1% measurement of system temperature can be made in 1 minute at 2 MHz bandwidth. The performance can be improved with a 10% cal which is on for only 10% of the time (for the same average 1% degradation in interferometric SNR) results in a 1% measurement in only 5 seconds and a 50% cal on 2% of the time results in a 1% measurement in only 1 second. The performance degrades with reduced bandwidth so that at 62 KHz with a 50% cal on for 2% requires 30 seconds to acquire a 1% measurement. The technique of using a switched noise source with variable duty cycle, also known as noise adding radiometry, should provide continuous calibration with adequate accuracy. It doesn't require a high accuracy square law detector in a system which includes an accurate attenuator (in the I.F. distributor) to calibrate the detector (or measure the system temperature via the "Y" factor method) and adjust the levels so that the detector is not required to handle a very large dynamic range.

B) 4-level data

With 4-level data the power level at the input to the A/D converter needs to be maintained at a level which optimizes the interferometric SNR. This "ALC" function can however be conducted independently from the noise adding radiometry provided the ALC follows the detector or the ALC attenuator is adjusted only on switching cycle boundaries so that the (Pon-Poff) of equation 2 is measured under constant attenuation for each radiometry cycle. A normalized correlation coefficient can be measured in the same way as done in the VLA correlator.

C) Use of the "phase calibrator" (coherent pulse generator) to measure system sensitivity variations

The injection of a coherent signal into the front-end can be used to measure the system sensitivity. The method is not absolute and requires calibration. This method which is available in the MkIII S/X system has not been extensively used for no particular reason - except perhaps that accurate correlated flux measurements are not a primary goal for geodetic VLBI. The precision of the method is very good. For example, if the total power contribution of the "phase cal" measured over a broad bandwidth is 1% then the noise in the measurement of voltage of a phase cal rail is

$$L^{1/2} (2BT)^{-1/2}$$

where L is the digitization loss factor ($\pi/2$ in the 2-level case). Thus the system temperature can be measured with a fractional precision of

$$L(2Bt)^{-1} \frac{Ts}{Tcal}$$

or to within 1% in only 10 milliseconds for a 1 MHz bandwidth. A pulse calibrator is probably not the best coherent source (although it is nice and simple to build), a pseudo random signal like that suggested many years ago by the Canadian group would be a better choice.

D) Larry's Method (Array Memo 471)

Larry D'Addario suggests that the variations in system temperature presumably caused by variations in spill-over and atmospheric attenuation can be measured by following the variations in baseband attenuation needed to maintain constant level at the A/D converters. This method will probably work quite well in most experiments.

E) Recommendations

1) Inject a noise source of about 10% which can be switched with variable duty cycle+. We will need this to provide absolute calibration between thermal calibrations.

2) Provide a stable voltage controlled attenuator at baseband which is under microprocessor control and can be calibrated using an accurate diode switched step attenuator in the I.F. distributor. [Mechanically switched attenuators (like the Weinschel 3200 series) might be acceptable if the operation of this attenuator is relatively infrequent - say no more often than once per minute].

3) Provide a square law detector and total power integrator for each baseband channel at the input of each A/D converter.

4) Include a coherent pulse generator or phase cal which can be injected into each front end.

With these items the system can be calibrated by Larry's method, noise adding radiometry and coherent cal method. Which method works best might depend on the type of observation, for example:

a) Under conditions of stable receiver gain, Larry's method might excel.

b) If the receiver gain is not as stable as projected due to intermodulation from out of band interference or other causes, the NAR method might be superior.

c) Under conditions of strong, impulsive interference (from radar, for example) the "coherent cal" method should continue to work when other methods will fail.

+If we prefer to avoid the complication of a variable duty cycle - a fixed 10% duty cycle would be a good choice.