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"Multiband Delay Error"

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Multiband Delay Error - 1

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(everybody welcome to pitch in)
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1. Introduction

Following the proposal by Bill Petrachenko that significantly better delay precision can be obtained for the same total SNR by using more than two frequency bands, e.g. S/C/X/Ka, the VLBI2010 Report based many of its recommendations on the assumption that such an increase in per-observation precision can be achieved. However, if this approach is to be pursued, it is necessary to evaluate the actual precision that can be attained when effects such as instrumental errors and source structure are included.

In this memo we will try to enumerate the effects that need to be included and to outline a model for estimating the delay and calculating the errors due to the different effects. This effort is aimed at the errors within a scan and targets the geodetic observable, so the length of a scan will generally be less than a few minutes, and scans as short as a few seconds are being considered.

All of the discussion has been about delays. What is the value of delay rates to the geodetic solution, and should the accuracy of the delay rate estimation affect choices made regarding the delay? For one example, the variation with elevation of the delay rate residuals is used by Tom Herring's *solvk* to calculate the stochastic variance/time to be used as a parameter in estimating the change with time of the zenith delay (assumed to be the wet component) during a (24 hour) session.

This approach also makes the estimation of the amplitudes both ambiguous and more difficult.

1. Should an amplitude be estimated for each band?
2. How should the estimated polarization information be presented?

Such source parameters are important for the CRF component of the IVS program, as well as for evaluation of the system performance for the geodetic results.

2. Effects

2.1. Feed

a. Polarization
   The proposed broadband feed is linearly polarized. Therefore to remove the effect of differential rotation, all polarization products must be correlated. What are the phase vs. frequency characteristics of the feed in both polarizations?
b. Phase center
   Does the phase center vary with frequency? Does it vary with antenna orientation or temperature? How much? How does this affect the estimation of the delay? Is there a phase dependence on focus position? How constant is it?

2.2. Instrumental delays across a band and among bands (different cable lengths?)

(this might should be part of next section)
Although we should use fiber, testing may be done on an existing system.
Do we have to solve for band-to-band offsets in any case at the 4 psec level?

2.3. Receiver (RF to IF, i.e. into the DBE)
Phase dispersion in MMIC (or other LNA)
Phase dispersion across receiver band
How stable is dispersion with time, temperature, orientation?

2.4. Source structure phase
a. What is the error due to phase variation with (u,v)?
within a band (assuming large spacing between frequency bands compared to the width of a band)?
across bands?
b. Effect of "position" difference among bands.
Can the position be modeled as varying linearly with frequency? (Use X-band frequency for reference position to be consistent with current S/X catalogues?) This can only be used at the correlator if given as apriori information.

2.5. Ionosphere correction
Is quadratic approximation sufficient?
Is apriori information necessary or helpful, e.g. from GPS TEC?

2.6. Atmosphere correction
Is simple mapping function and apriori ZHD and ZWD sufficient?
Is apriori information necessary or helpful, e.g. from NWM as given on Johannes web site? If so, the data would have to produced as apriori information from a forecast in order to be able to use for RealTime or NearRealTime correlation. Just another bookkeeping problem.

2.7. Loss of data in channels or entire band
RFI
Non-detection due to unusually high Tsys, weak or resolved radio source, other?
How does loss of data affect mbd?
Can calibration of the phases be linear enough to keep any bias (due to the loss of data) below an acceptable level (e.g. 4 psec, 1 psec?)?
Is any additional uncertainty due to the loss of data correctly calculated? (next section)

3. Delay rates?

How much value should be placed on delay rates?
How should uncertainty in delay rate be estimated?

4. Delay (phase) model

Here is a first cut at a simplified phase delay model

$$\tau(\overrightarrow{B},f) = \tau_g + \tau_{atm} + \tau_{inst}(f) + \cdots \quad \frac{1}{2\pi f}[\phi_{iono}(f) + \phi_{SS}(\overrightarrow{B},f) + \phi_{pol}(antenna_1, f) + \phi_{pol}(antenna_2, f) + \cdots ?] \tag{4.1}$$

where $\vec{B}$ is the baseline, and the frequencies will be the individual frequencies within each band, i.e. as many frequencies as there are recorded channels. Of course some effects will be grouped, such as common delays within a band due to a common cable length. In addition the different polarizations will have to be indicated, and the effects of polarization impurity will have to be included.

The correlator will remove a model for the geometric delay and for the atmosphere delay. For now assume that any residual error is linear in frequency and time. The residual unmodeled delays, i.e. the effects which have to be either corrected before correlation, estimated from the correlation coefficients, or worried about later are then:

$$\Delta\tau(\overrightarrow{B},f) = \tau_{inst}(f) + \cdots \quad \frac{1}{2\pi f}[\phi_{iono}(f) + \phi_{SS}(\overrightarrow{B},f) + \phi_{pol}(antenna_1, f) + \phi_{pol}(antenna_2, f) + \cdots ?] \tag{4.2}$$

Although written as a delay in order to present the effects to be modeled, the estimation of the delay will be in terms of the correlation coefficients for each of the frequencies and polarizations as a function of time through the scan. (Here will follow a very messy set of equations relating amplitudes and phases to correlation coefficients at many frequencies and in all four polarizations, assuming that is the best way to estimate the delay (and amplitudes and polarization information.)

5. Uncertainty in the estimates of delay, delay rate, amplitudes, and polarization

How should the uncertainties be calculated?

- from number of bits and frequency distribution as is currently done?
- taking into account the non-linearity within a scan, i.e. the scatter of the post-fit residuals for the scan?

How should the uncertainty be calculated?

What is the contribution from each of the individual error sources?

5.1. Feed

5.2. Instrumental delay

5.3. Receiver

5.4. Source structure

5.5. Ionosphere correction

5.6. Atmosphere – probably effect of fluctuations within a scan rather than rate of change of zenith delays and mapping functions

5.7. Loss of data in channels or entire band