New or recently-modified fourfit features

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Many features have been added to fourfit over the past 12 months. This document describes in a bit more detail the newest features to be found in version 3.7 of fourfit. Detailed syntax of all features, as well as brief descriptions can be found in the online fourfit documentation:

http://www.haystack.mit.edu/tech/vlbi/hops/fourfit.txt

Run line parameters:

-P option – controls polarization processing. L is used as a synonym for X or H, while R is used as a synonym for Y or V. The allowable values are:

>   **-P all** (or not specified) – do each product that has been correlated, sequentially.

>   **-P LL** (also RR, LR, or RL): do the specified product only.

>   **-P LL+RR+LR+RL** (or any subset): do a coherent sum of the indicated products, not taking into account anything other than manually specified delays and phases. Parallactic angle is <u>not</u> used.

>   **-P I**: pseudo Stokes I mode, which is used to maximize snr for VLBI2010. The polarizations are assumed to be linear, and a combination that mimics Stokes I to first order in the D terms is formed. Brian Corey and Bill Petrachenko developed the equation that is used:

$$I \approx (X_a {\times} X_b + Y_a {\times} Y_b) cos\Delta + (X_a {\times} Y_b - Y_a {\times} X_b) sin\Delta$$

>   where Δ is the differential parallactic angle. Differential Faraday rotation also contributes to Δ, but it is not known, and is thus ignored by fourfit. The parallactic angle is not calculated in the hardware correlator, and is only available when using difx.

Control file parameters:

dc_block – if true, it causes the data in the lowest-frequency spectral (sub) channel to be overwritten with zero. The default value is false, which differs from the implicit traditional value, wherein it was always discarded. In an era of analog video-converters, with an A/D converter per VC, a significant amount of DC is

seen, so discarding the channel makes sense. With a PFB-based backend, though, the A/D DC bias doesn't show up in the output channels, so there is no reason to throw away the bottom of the band, hence the default of false.

delay_offs – this parameter allows offsets (in ns) to be made on a per-channel basis, similar to the normal pc_phases correction. If there are two polarizations, it is applied to both.

interpolator – the original fourfit used the fine-fitting algorithm from frnge, which (due to memory & processor restrictions) fit along the singleband delay, multiband delay, and delay rate axes one dimension at a time, in an iterative round-robin fashion. Under certain conditions this can cause a lack of fit continuity across a single band (say) delay boundary.

The code now supports a simultaneous fit in all 3 dimensions, on a 5x5x5 grid of evaluated coherent sums. In most cases the difference is slight. The default is the old method (*interpolator iterate*). The new code is invoked with *interpolator simul*. The interpolator actually used is printed at the lower right of the fringe plot.

ionosphere – in TEC units (10^16 electrons/m^2), typically specified on a per-station basis, applied differentially on a baseline within fourfit. A complete fringe fit at multiple points for trial values of the ionosphere is done, and the code finds the interpolated maximum. A range of coarse values is specified by ion_win and ion_npts, the maximum within the range is found, then a second pass fine search is done around the maximum. The resulting fit value can be found on the upper right of the fringe plot. An example of the fitting process with 19 coarse points spread over a TEC from -10 to +10 is shown in Figure 1.
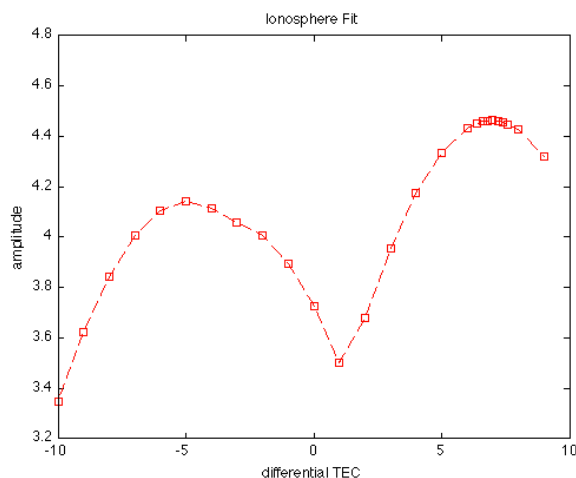

Figure 1 Ionospheric fit example

ion_npts – the number of points in the coarse ionosphere search

ion_win – the window in TEC units over which the coarse points are distributed

optimize_closure – When true, the fine fringe search is modified so as to minimize the contribution of non-closing delay errors to the closure phase; this can result in poorer single-baseline fits. The difference is whether to use the sbd or mbd residual to correct the phase to the DC edge. This parameter only has an effect for SSB data, as DSB data are distributed symmetrically about the DC edge, and it would cancel out. Since the mbd is used to go from the DC edge to the overall reference frequency, any mis-closing error made using mbd to go to the DC edge would exactly cancel out. Instead, if non-closing sbd's are used, then the difference between them and the mbd's introduces a phase error when extrapolating to band edge.

For normal geodetic processing this parameter should be false (which is the default), as each single band really had a different characterstic delay that should be corrected for with the sbd when going to band edge, prior to the fit across all frequencies.

pc_delay_l
pc_delay_r – In the block diagram in Figure 2, which depicts the VLBI2010 system, it can be seen that the pcal only imperfectly corrects for instrumental phase and delay effects. It is injected prior to the low-noise amplifier in the front-end, and in principle everything that happens to the signal after that point can be corrected by examining the embedded pcal information. However there are differerent pathways for the two linear polarizations from the feed to the injection point. Also, the pcal signal is split, and follows different paths to the injection point.

The pc_delay_l and pc_delay_r parameters are designed to correct for this uncalibrated portion of signal path. The baseline pcal phase difference is corrected appropriately for each of the four Stokes polarization products. For example, the LxR product phase is corrected by

$$(\tau_{rem}^R - \tau_{ref}^L) \times (f - f_r)$$

where f_r is the reference frequency. These two delay values, which are specified in ns, can be determined once by looking at strong fringes on an unpolarized source (with good coordinates); the values should then be relatively stable unless the frontend setup is changed.
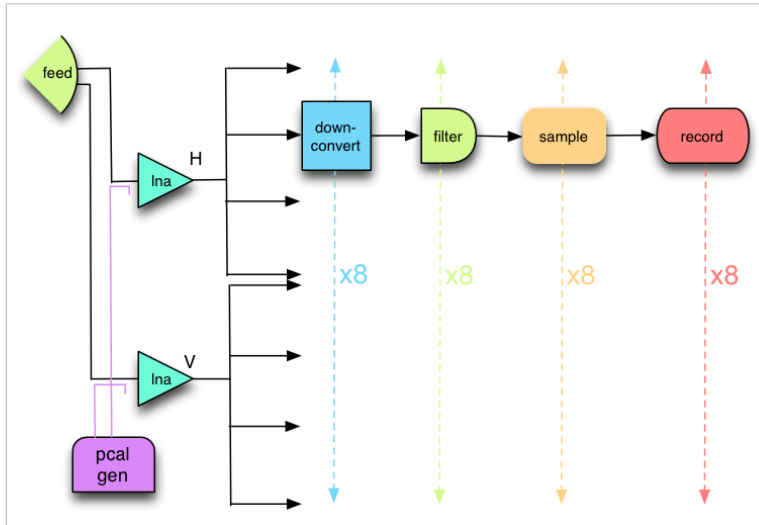
Figure 2 Block diagram of VLBI2010 signal paths

pc_phases_l
pc_phases_r – normally manual or additive pc phases are done on a per-channel basis. In the presence of dual polarization, though, this level of control is not fine enough, since the LCP signal will likely follow a different processing path than the RCP signal. This vector parameter allows phases to be specified for only the L (= X or H) and R (=Y or V) channels, in a manner completely analogous to *pc_phases*.

pc_mode – multitone mode is now recommended, and further information about it can be found in a memo at:

http://www.haystack.mit.edu/tech/vlbi/hops/multitone_phasecal.pdf

Since multitone mode with pc_period set is a superset of ap_by_ap mode, the ap_by_ap mode is now deprecated, and some combinations of parameters are no longer supported with it.

pc_period – averaging period (in accumulation periods) of multitone mode (see memo above)

pc_tonemask – a mask used to exclude correlated tones from the multitone delay solution (see memo above)

samplers – the current software has no way infer from the vex file what samplers were used to feed each of the frequency channels. With this keyword we can specify this information. It specifies from 1 to 8 sampler pools, by using the channel identifying characters. In multitone mode (only) this sampler information is used to more accurately do the phase cal correction. The central concept is that a PFB backend introduces very little differential error into channels from a

common sampler. Thus the most accurate pcal correction is one in which all tones in all of the channels handled by a sampler are used to determine the instrumental delay of that pathway, and then that one delay is used to correct the phases for all of those common channels.

station_delay – approximate a priori delay from the pcal injection point down to the digitizers (in ns). This delay is used to determine an absolute delay from the pcal values (in multitone mode), which have an ambiguity of 1 us (for 1 MHz rails), or 200 ns (for 5 MHz rails). This is important because the cross-power spectra are corrected (in multitone mode) point-by-point across the spectrum by the difference in extracted pcal delays. If one of the stations is on the wrong ambiguity then the coherent summed amplitude is affected. This parameter is primarily used for VLBI2010, where the cable delays of 200-300 ns may be large compared to the 200 ns ambiguity spacing. There is a default value of 150 ns, which would result in multitone fit delays in the range from 50—250 ns.