Multiband delay differences between Mk4 hardware and DiFX software correlations

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We compare the multiband delays (MBDs) and SNRs for 16 scans correlated on the Haystack hardware and software correlators, hereafter referred to as the Mk4 and DiFX correlators.

**Summary of results:** Comparisons were made between correlators and also within each correlator for different a priori models. The smallest MBD scatter is for DiFX vs. DiFX, and the largest for Mk4 vs. Mk4. The scatter is quantified in terms of the standard deviation of the ratio between MBD difference and undifferenced MBD standard error, or dMBD/$\sigma_{mbd}$. The mean value of this quantity for S- and X-band is 0.15 for intra-DIFX, 0.52 for intra-Mk4, and ~0.41 for Mk4 vs. DiFX, with a tendency for X values to be higher than S. Mk4 and DiFX SNRs agree within a few percent.

The details….

**Recorded data:** The scans were recorded during R1543 from 08:30 to 09:30 UT on July 24. The observing mode was S/X wideband, 16 Msample/s/channel, 1 bit, 256 Mb/s total. Data were e-transferred from Bonn to Haystack by Simone Bernhart and Jason Soohoo. The stations are N = Ny Alesund, T = Tsukuba, V = Wettzell, and Y = Yebes 40m.

**Correlation:** In order to test the sensitivity of the output observables to choice of a prioris (clocks, station and source positions, etc.), correlation was done twice on each correlator, first with the original a prioris from Bonn, then with the clock rates changed for three stations, always with an AP length of 1 second. The rates were changed by +1, +2, and -1 ps/s for V, N, and T, respectively. Because the clock reference epoch was 17:00 UT on the preceding day, the rate change also changed the clock offset at the time of the scans by ~0.06 µs per ps/s change in rate. These two sets of aprioris are labeled 'A' and 'B'.

For the 2$^{nd}$ DiFX correlation (DiFX B), only three playback units were available, and Tsukuba was dropped from the correlation.

**Fringe-fitting:** All fringing was done with *fourfit*, following *difx2mark4* conversion with DiFX. The control file, which was identical to the Bonn original with two exceptions, was the same in all four cases. The exceptions were:

1. 'start -8' was used to make the data accepted by *fourfit* (start and stop times and #APs) as nearly identical as possible between the four correlations. In the end, the start and stop times for each scan/baseline/frequency were identical for all correlations, and the #APs accepted in each channel was the same except in a few scans where they differed by one AP.
2. Yebes data were omitted during the first 25 seconds of scan 206-0837 because the antenna was off source.

Of the 132 type-2 files generated from the non-DiFX-B correlations, all but two had QCs of 8 or 9. Those two were omitted from the analysis.

**Observables:** The total multiband delays, SNRs, and other quantities were extracted from the type-2s with scripts that ran CorAsc2 on the type-200 and -208 records in each file. All the desired quantities are available in an alist file, but its 1-ps quantization for the total MBD is too coarse for the present study, where the MBD standard error is as small as 1.5 ps.

The total MBD used here is the MBD referred to the reference station clock, i.e., Mk3-style and not geocentric MBD. This MBD varies with reference clock offset as total rate times clock offset. An A-B MBD difference can therefore be affected by the ref clock model change. No correction was made for this effect here because in all cases it was negligible.

**MBD differences:** The MBD difference (dMBD) time series for the six pairs of correlations are shown on pages 3-8, with X-band plotted as a blue '×' and S-band a red circle. The lefthand panels show the differences, baseline by baseline, while the righthand panels show the difference divided by the (undifferenced) MBD standard error $\sigma_{mbd}$.

As is almost always found in such comparisons, the scatter in dMBD scales with standard error. For each correlator pair and each frequency, the standard deviation of dMBD/$\sigma_{mbd}$ was calculated,with the results shown in the table below.

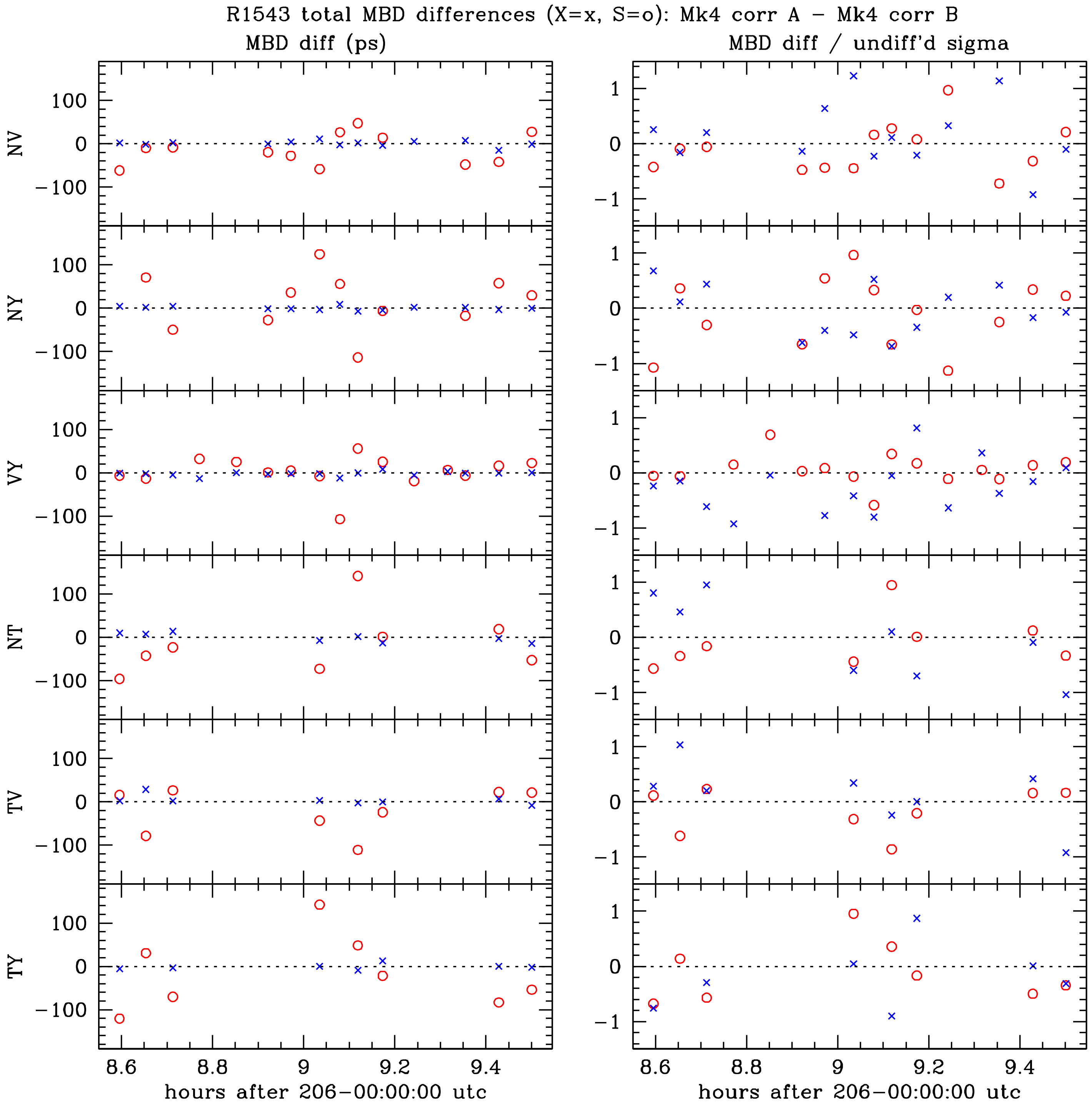
| *page no.* | *correlation #1* | *correlation #2* | *X-band dMBD/$\sigma_{mbd}$ std dev* | *S-band dMBD/$\sigma_{mbd}$ std dev* |
|---|---|---|---|---|
| 3 | Mk4 A | Mk4 B | 0.58 | 0.46 |
| 4 | Mk4 A | DiFX A | 0.40 | 0.43 |
| 5 | Mk4 B | DiFX A | 0.50 | 0.35 |
| 6 | Mk4 A | DiFX B | 0.46 | 0.34 |
| 7 | Mk4 B | DiFX B | 0.50 | 0.34 |
| 8 | DiFX A | DiFX B | 0.17 | 0.13 |

The table quantifies what is obvious qualitatively in the plots: By far the smallest scatter in dMBD/$\sigma_{mbd}$ occurs for DiFX vs. DiFX, and the largest for Mk4 vs. Mk4.

Less obvious from the plots is the larger dMBD/$\sigma_{mbd}$ scatter at X than at S in five cases. Perhaps this is just a fluke, but if it is real, one possible origin could be a component to the scatter that is independent of SNR. Such a component would become more visible in dMBD/$\sigma_{mbd}$ at high SNR due to the smaller $\sigma_{mbd}$. Separate S and X plots of dMBD/$\sigma_{mbd}$ vs. SNR do not indicate the presence of any such component, however.

On page 9 are six plots of X-band dMBD vs. SNR. While these plots provide no new information that couldn't be gleaned from pages 3-8, they are useful for comparing with similar plots in previous studies of correlation repeatability or correlator differences. For instance, page 10 is an excerpt from a Mk3 vs. Mk4 comparison we presented at the 2002 IVS GM. These same types of plots are included in the Mk3/Mk4 study by Alex Nothnagel et al. (IVS 2002 GM) and in the VLBA hardware/software comparison by David Gordon (IVS GM 2010).

**Signal to noise ratio:** SNR time series are plotted on pages 11-16, in the same correlator order as the MBD differences. Lefthand panels are $\log_{10}$(SNR), and righthand are the SNR ratios between the two correlations.


R1543 total MBD differences (X=x, S=o): Mk4 corr A − Mk4 corr B
MBD diff (ps)
MBD diff / undiff'd sigma
NV
NY
VY
NT
TV
TY
hours after 206−00:00:00 utc
hours after 206−00:00:00 utc