VLBI Digital-Backend Intercomparison Testing (Draft)

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Introduction

On 4-5 May 2009, the first intercomparison zero-baseline correlation testing was done between digital backends (DBEs) that have been independently designed at different organizations. The results of this testing are the first step in a more thorough investigation that also includes actual VLBI observations.

The DBE systems

Three systems were brought together at Haystack for testing:

1. A European 'dBBC' system configured with polyphase filter bank (PFB) firmware. The dBBC was accompanied by Gino Tuccari of INAF/IRA.
2. A Chinese 'CDAS' (Chinese Digital Data Acquisition System), configured with 8 tunable dual-sideband digital BBCs. The CDAS was accompanied by Drs. Wenren We, Li Bin, Wu Yajun and Zhu Renjie of Shanghai Observatory.
3. A Haystack 'DBE1' system based on the Berkeley-designed hardware and Haystack firmware, configured with PFB firmware. The DBE1 was accompanied by Haystack staff Arthur Niell, Chris Beaudoin and Alan Whitney.

Test setup

The test was setup for 'zero-baseline' testing as shown in Figure 1.

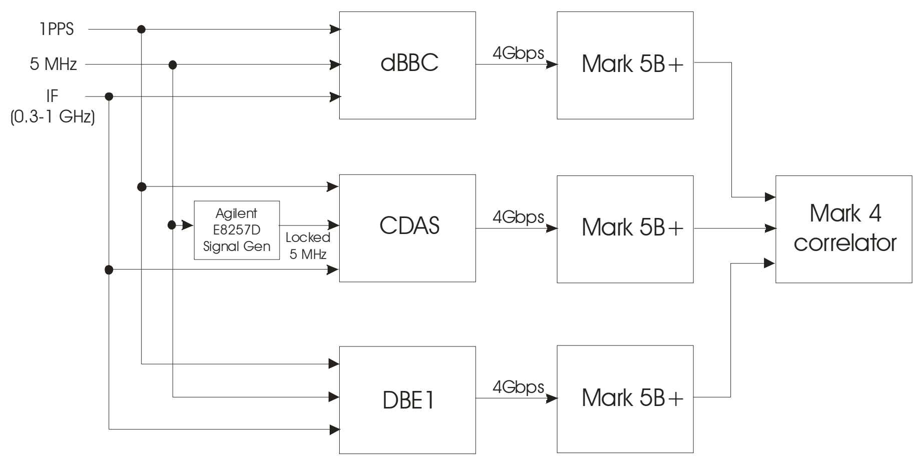

Figure 1: Setup for zero-baseline intercomparison testing

The CDAS required a 10 MHz reference, which was supplied via a Agilent E8257D signal generator that could accept a 5 MHz reference and create a locked 10 MHz reference signal suitable for the CDAS. A standard TTL 1PPS signal was distributed to all units for synchronization purposes. A common broadband-noise IF signal was provided to all units, and each unit had its own internal 512-1024MHz anti-aliasing Nyquist filter. The sampling frequency in all units was 1024 MHz.

The dBBC and DBE1 were configured to produce 15 useful 32MHz-bandwidth output baseband channels (LSB with respect to the input IF), centered at the IF-equivalent frequencies of 528, 560, 592, 624, 656, 688, 720, 752, 784, 816, 848, 880, 912, 944, 976 and 1008MHz.

The CDAS supports 8 flexible-LO digital BBCs, each producing a USB/LSB sideband pair (two adjacent 32MHz channels). The LO frequencies were set so as to match the frequencies of the dBBC/DBE1 channels. However, since the PFB units produced only LSB channels (determined by selection of Nyquist sampling zone 2), only 8 CDAS channels could be cross-correlated with the dBBC and DBE1 units (since the Mark 4 correlator cannot process mixed sideband data).

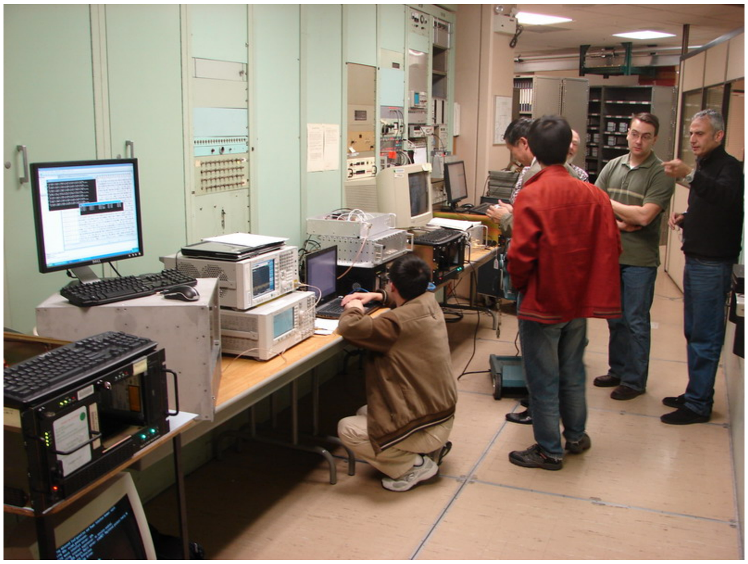

Figure 2: DBE intercomparison test setup at Haystack Observatory

Testing procedure

The testing procedure was straightforward:

1. All DBE units were synchronized to the common 1PPS signal.
2. IF levels were set appropriately for each of the units.
3. Each DBE unit connected to a Mark 5B+ with a VSI-H interface operating at a 64 MHz clock rate.
4. All Mark 5B+ units were set to identical UT times.
5. Simultaneous recordings at 4 Gbps were made on each of the three Mark 5B+ units.
6. Cross-correlation was done on the Mark 4 correlator with the assistance of Mike Titus.

Testing results

The testing of the units went well, with only the usual sort of small hiccups that occur when such tests are done. It was fortunate that we had three DBE units to test, as it greatly eased diagnosing the effects of a particular DBE unit; without three units, testing would have been much more difficult. Various tones were injected for some tests in order to ensure that the units were grossly performing as expected, but there were no standard phase-cal tones available, and it proved difficult to set levels that were acceptable across the whole IF band; therefore, no phase-cal tones were used for the testing reported here.

dBBC to DBE1 Results

Figure 3 shows a standard ‘frnge’ printout from the Mark 4 correlator of a zero-baseline correlation between the dBBC and DBE1. Normal correlations are seen in all 15 channels. There is an observed phase-rolloff, primarily attributed to the differences in phase-rolloff near the edges of the analog Nyquist filters; this is normal and expected, and can be compensated for by adding filter-specific phase corrections for each Nyquist filter (we did not attempt to do this). The timing difference between the two units, as shown in the correlation results, is about 0.5 microsecond, well within acceptable limits.

We believe these results indicate full compatibility of these two units, though some static phase adjustments will normally need to be assigned to compensate for Nyquist-filter phase rolloff.

dBBC/DBE1 to CDAS Results

Figure 4 shows the ‘frnge’ zero-baseline cross-correlation results of the same test between the DBE1 and CDAS units (though only 8 channels were correlatable, as noted above). Note that the single-band delay function (graph labeled ‘singleband delay’ on the horizontal axis) is multi-peaked, indicating different relative delays between different channels. When the channels were ‘frnged’ individually, it became clear that there were three discrete delays among the 8 correlated channels, at relative delays of approximately -40, -134, and -6 nsec. Similar results were obtained in correlation between dBBC and CDAS.

The results in Figure 4 use only 1-bit sample. This is due to the fact that the CDAS is basically built to provide 4 bits/sample and there was no way to re-normalize the output to 2 bits/sample with a proper sample distribution. As a result, all data involving the CDAS was correlated with only 1 bit/sample.

<u>Summary and recommendations</u>

We judged these tests to be quite successful and thank everyone who participated. Several recommendations arose from these tests:

1. For compatibility reasons, it would be highly useful if the sideband type (LSB or USB) can be easily chosen on an individual channel basis. Such a capability would greatly increase the useful of these DBEs when operating with legacy analog systems, or when PFB units are operating on baselines that include flexible digital baseband converters (such as the CDAS).
2. We were impressed with the construction and operation of both the dBBC and the CDAS. A few minor problems were found with the CDAS which need attention before it can be used in mainstream VLBI observations:
    a. All signal-processing paths through the CDAS must have the same digital delay.
    b. Proper 2 bits/sample interpolation must be implemented.
    c. The external 1pps signal should be actively used only once (when the unit is synchronized); the external 1pps may be left connected for monitor purposes, but the unit should operate normally even if the external 1pps is disconnected.

It was gratifying to see three functioning DBE units all working together. The problems discovered were minor and will be quickly corrected. The next step is to conduct a set of test VLBI observations, which we plan to do at the earliest convenient opportunity.

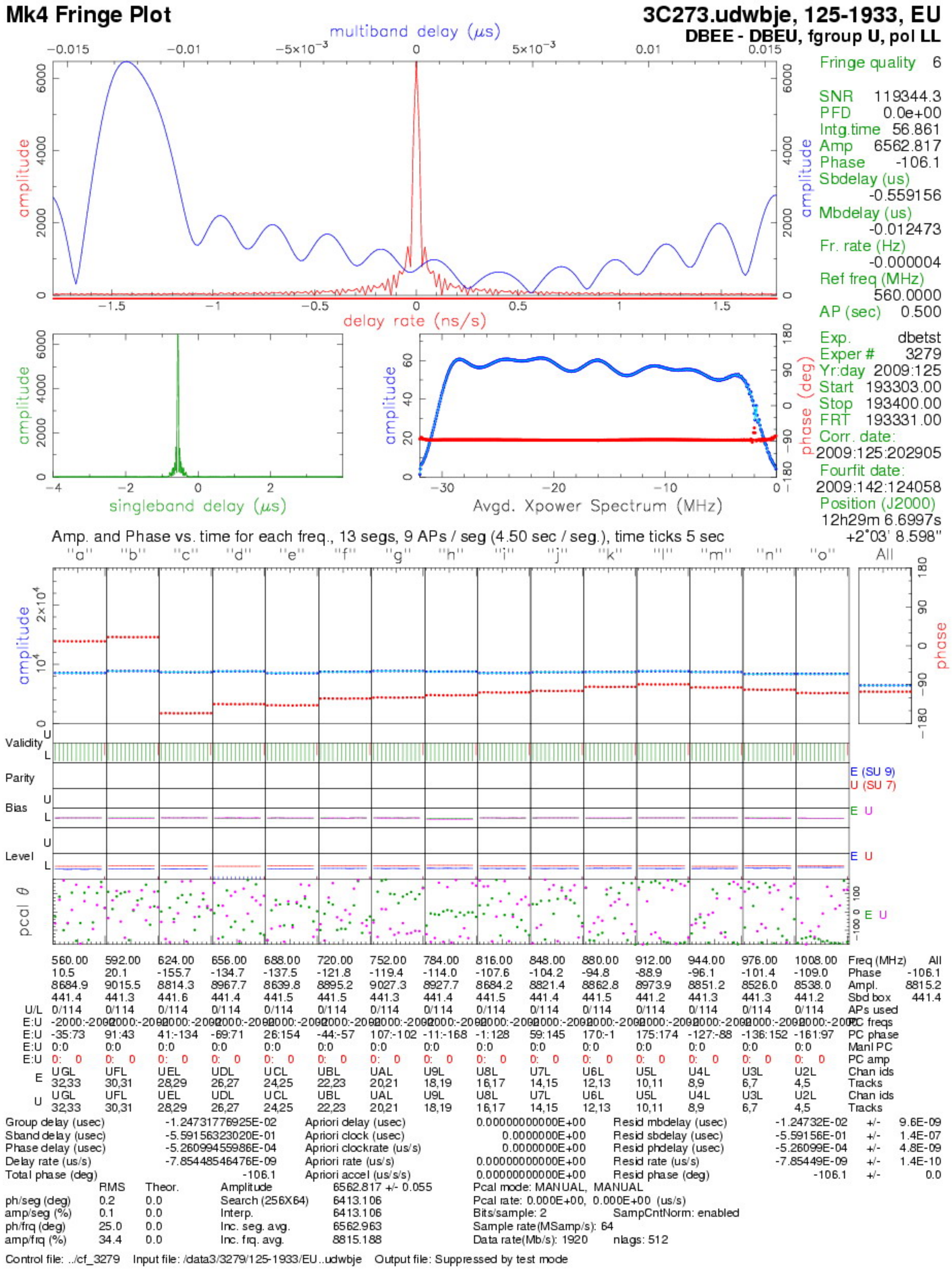

Figure 3: 'frnge' plot from zero-baseline test between dBBC and DBE1

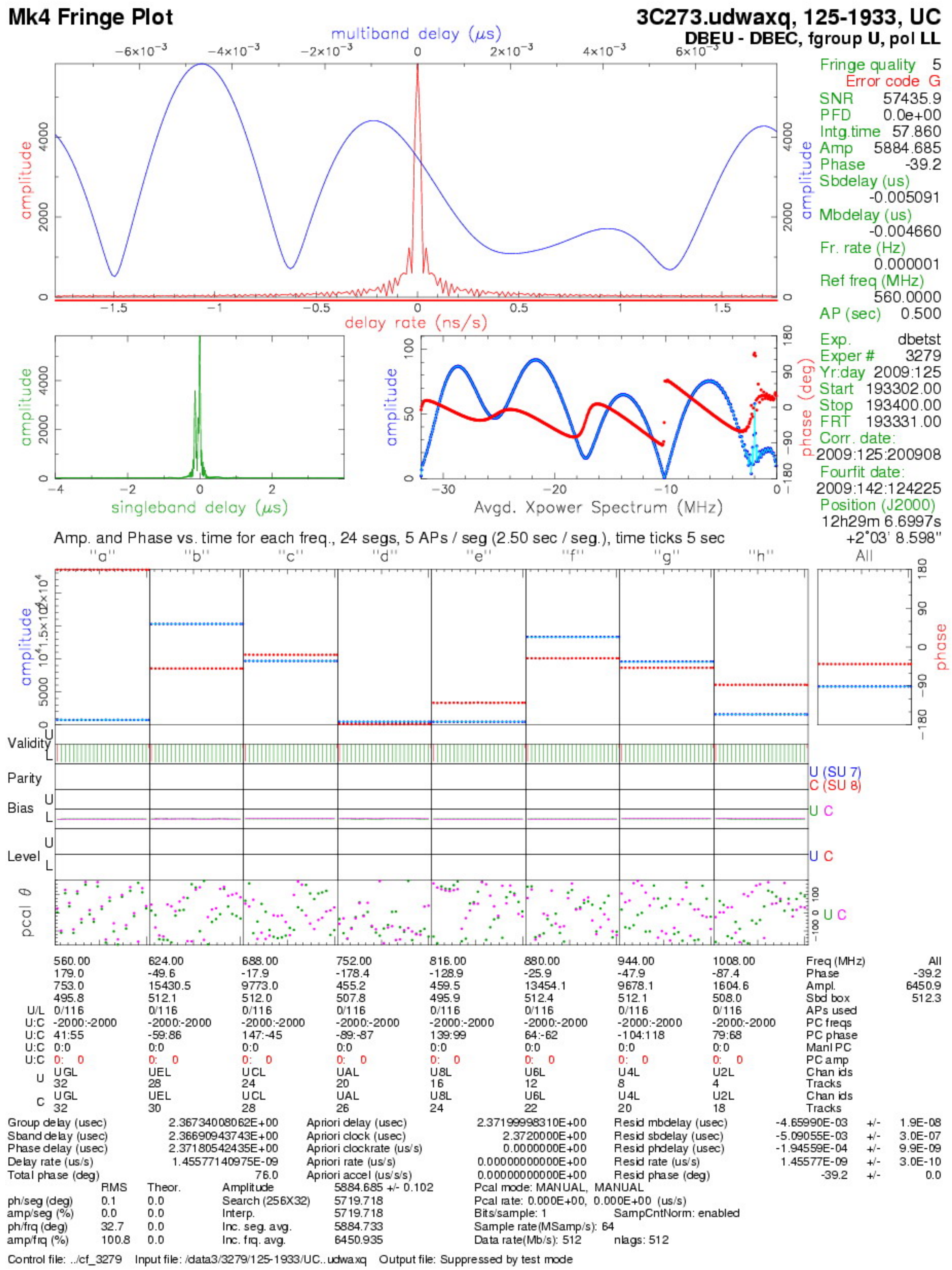

Figure 4: 'frnge' plot from zero-baseline test between DBE and CDAS. Note multiple peaks in 'singleband delay' plot.