Going Digital – The Transition from Mark IV to DBBC at Onsala

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Abstract The Onsala Space Observatory is currently equipped with both a VLBI Mark IV rack and a digital BBC (DBBC). The Mark IV rack at Onsala has been used operationally for both astronomical and geodetic VLBI for more than 40 years. In 2011, Onsala purchased a DBBC and we started to test it and to gain experience with the new device, both for astronomical and geodetic VLBI. The DBBC was upgraded several times and the Field System (FS) interface was implemented. We did parallel recordings, with both the old Mark IV/Mark 5A system and the new DBBC/Mark 5B+ system, during numerous geodetic VLBI sessions. Several R1, T2, and Euro sessions were correlated during the last two years by the Bonn correlator with Onsala being included both as an analog station (two-letter code On) and as a digital station (two-letter code Od). We present results from these parallel sessions, both results from the original correlation and results from the analysis of the corresponding databases.

Keywords VLBI, backends, DBBC, geodesy

1 Introduction

The Onsala Space Observatory has a long history in VLBI going back all the way to 1968, participating both in the field of geodetic and astronomical VLBI within IVS, EVN, and GMVA. At the moment, VLBI observations are carried out with two telescopes: a 25-meter telescope operating from 18 cm (L-band) to 5 cm (C-band) and a radome-enclosed 20-meter telescope in the frequency range from 13 cm (S-band) to 3 mm (115 GHz). In the foreseeable future these two telescopes will be joined by the VLBI Global Observing System (VGOS) twin telescopes. In 2011 the Mark IV rack was complemented with a DBBC VLBI backend. With the observing mode requirements for VGOS and the limitations of the old analog systems compared to digital backends, the transition to DBBCs is unavoidable. By adopting DBBCs at Onsala we had the opportunity to get hands-on experience with the evolving system and ensure that we can obtain satisfactory results with the system. Furthermore, maintaining the old Mark IV equipment provides challenges on its own.

The DBBC acquired in 2011 was a DBBC2 [1] and since then it has been upgraded several times. Zero-baseline tests have been conducted for both IVS and EVN, and with EVN the DBBC is operational since mid-2013. The aim is to have the DBBC in operation in the IVS sessions as well. Currently the equipment used consists of a Mark 5A connected to the Mark IV rack and a Mark 5B+ connected to the DBBC. Furthermore, we have a Mark 5C, which is used as an e-transfer machine, and a PC-EVN for real-time e-VLBI, which is to be replaced by FlexBuff as the future e-VLBI machine.

Recording in parallel with both Mark IV and DBBC setup during several geodetic VLBI sessions, correlated at Bonn, we obtained databases in which Onsala was included both as analog and digital station. We compared the results from these databases to find whether there were any differences, random or systematic, in both the raw delays and the derived geodetic parameters, i.e., station positions, earth orientation parameters, and zenith wet delays.

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2 Parallel Observations with Mark IV and DBBC

Numerous parallel observations with the Mark IV and DBBC were recorded during the period between 2012–2014. The session types included R1, R&D, EUR, and T2 sessions. The sessions are listed in Table 1.

Table 1 Sessions recorded in parallel at Onsala with Mark IV and DBBC.

Session type	Session name
IVS-R1	R1553, R1563, R1566, R1567, R1569, R1570, R1572, R1573, R1585, R1592, R1598, R1601, R1602, R1604, R1612, R1615, R1616
IVS-R&D	RD1201, RD1301, RD1303, RD1306
EUROPE	EUR118, EUR120, EUR123, EUR125
IVS-T2	T2090, T2093, T2094

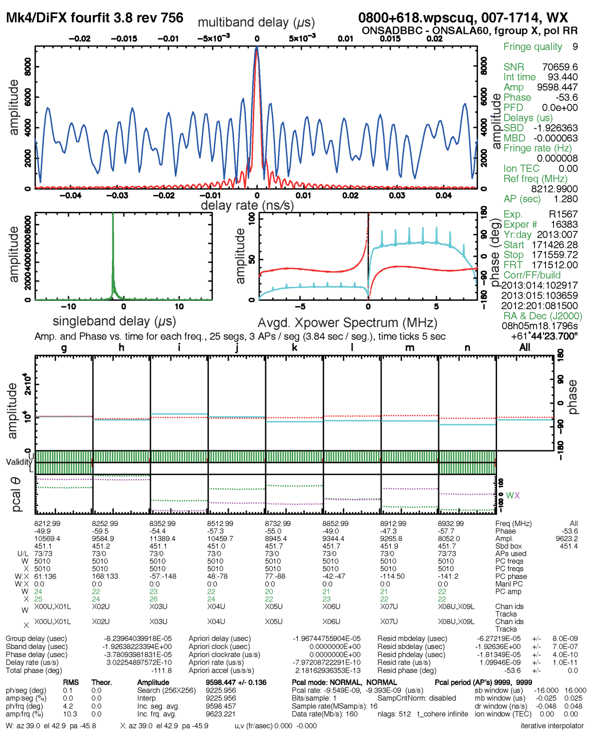

Fig. 1 Fringe plot for X-band for the R1567 zero-baseline test.

Zero-baseline tests were conducted for these sessions using the DiFX installation at Onsala. Fringe plots for X- and S-band for one such zero-baseline test (R1567) are shown in Figures 1 and 2. Furthermore, as mentioned earlier, in several cases both the Mark IV/Mark 5A and DBBC/Mark 5B+ data from the sessions were sent to Bonn for correlation. The Bonn correlator did fringe-testing and as a result produced databases in which the analog and digital data were added as separate Onsala stations, ONSALA60 (On) and ONSADBBC (Od). From here on the analog and digital stations will be referred to as On and Od, respectively.

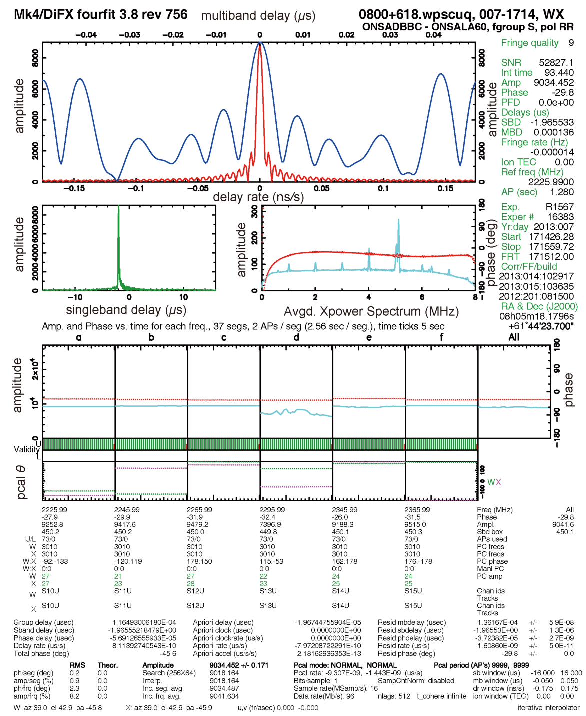

Fig. 2 Fringe plot for S-band for the R1567 zero-baseline test.

3 Correlation and Analysis

The sessions that were recorded in parallel and correlated at Bonn were used as a basis in the comparison analysis. The analyzed sessions are listed in Table 2. In total, six sessions were used in the analysis, which covered a time period of approximately 13 months.

All sessions were analyzed using the Calc/Solve VLBI analysis software [2]. Both On and Od were included as separate stations in these databases. The databases were processed in two ways to yield results for the session: either On or Od was turned off. The

Table 2 Analyzed sessions with Onsala as analog and digital station.

Observing date	Session name
2012 October 01	IVS-R1553
2012 December 10	IVS-R1563
2013 January 02	IVS-R1566
2013 January 07	IVS-R1567
2013 July 01	IVS-R1592
2013 Novermber 18	IVS-R1612

databases were calibrated using cable and weather data extracted from the individual station log files. There were no gross errors apparent in either of the log files in any of the sessions. A small, noise-like difference could be seen in the cable calibration data, but it is negligible because the differences between the cable calibration data were within 1.5–3 μs RMS, which is less than 0.1% of the total values. We first resolved ambiguities, clock breaks, and possible other issues with the sessions. Then we estimated station positions, earth orientation parameters, and zenith wet delays by switching either On or Od on/off. Station positions were estimated for digital and analog Onsala, and—due to post-seismic motion—for TIGO and Tsukuba. The clocks and the troposphere were modeled as piecewise linear functions with 60-minute intervals. Then the set of parameters associated with On and Od were compared to determine whether there were any significant differences in the results. In addition, we translated the database version 2 into NGS format to compare the raw delays for On and Od.

To assess whether the differences were noticeable, we computed a weighted RMS difference for station positions, UT1–TAI and rate, polar motion, and atmospheric parameters. The On–Od difference values are listed in Table 3.

Table 3 WRMS differences between the estimated parameters.

On–Od	WRMS differences
Up	8.2 mm
East	1.3 mm
North	3.5 mm
UT1–TAI	0.98 μs
$-\Delta$LOD	1.14 μs
Xpol	11.0 μas
Ypol	11.6 μas
dX	8.9 μas
dY	10.3 μas
ZWD	3.2 mm

In general, there is a relatively good agreement between On and Od in the estimated parameters. There is, however, a noticeable fluctuation in the station position when comparing the two solutions. The largest variation was found in the vertical coordinate; it was about 1 cm. The east and north coordinates show better agreement, with East being the best. As can be seen from Figure 3, this difference is mostly due to fluctuation, which is scattered around the zero-line. This indicates that it is likely that there is no systematic bias between the station positions from On and Od. Almost all the differences fall within the error limits with respect to zero.

The estimates for UT1–TAI and rate, as well as polar motion and nutation, all lie within their limits of uncertainty from zero. The difference in ZWD was within 20 mm with approximately 91% of the values within one standard deviation from zero. The distribution of differences in the hourly ZWD estimate is illustrated in Figure 4. Session R1553 has the largest deviation from zero, and has also the greatest offset in the station position, with a distinct deviation in the North-component. This indicates that there might be unresolved problems within that session.

Table 4 Biases and standard deviations of the observed delays between ONSADBBC–ONSALA60.

Od–On	Bias [ns]	Std. dev. [ps]
IVS-R1553	−657300.04	32.0
IVS-R1563	−657350.06	26.8
IVS-R1566	−657350.09	14.4
IVS-R1567	−657300.08	11.6
IVS-R1592	−657300.08	19.4
IVS-R1612	−657350.03	16.4

Table 5 Biases and standard deviations of the differences between observed delays on the baselines (ONSADBBC–WETTZELL)–(ONSALA60–WETTZELL).

(Od–Wz)–(On–Wz)	Bias [ns]	Std. dev. [ps]
IVS-R1553	−1900.03	33.9
IVS-R1563	−1950.08	65.1
IVS-R1566	−1950.08	20.8
IVS-R1567	−1950.08	14.8
IVS-R1592	−1950.07	21.2
IVS-R1612	−1900.02	17.3

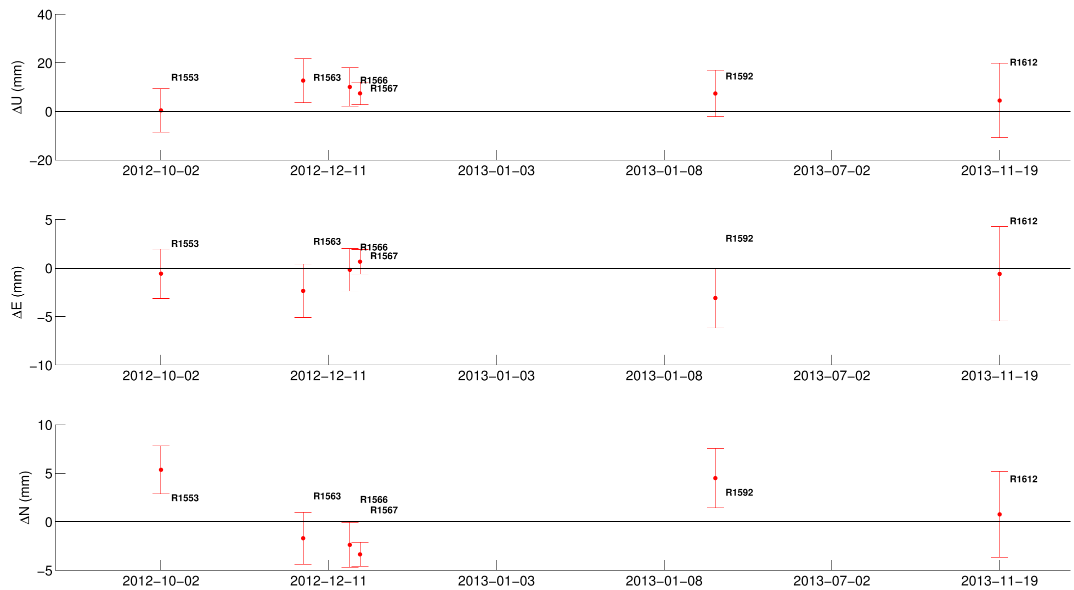

Fig. 3 Differences between On–Od in the East, North, and Up components.

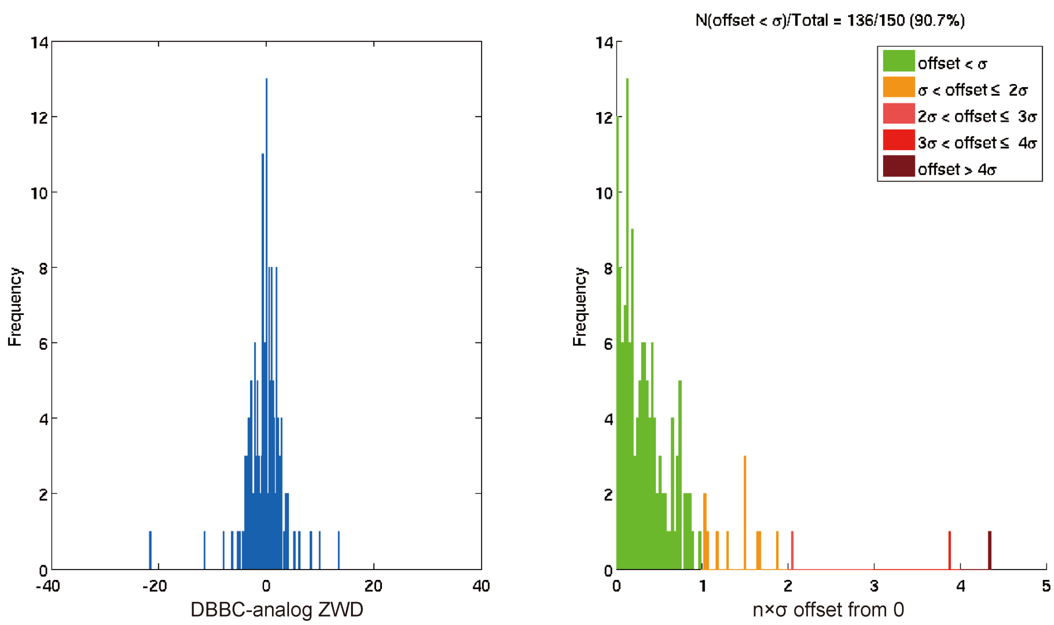

Fig. 4 (left) Distribution of differences in the ZWD estimate between Od and On. (right) Distribution of the level of significance of the Od–On differences.

When the observed delays are compared between On and Od as well as among On, Od, and a third station, the unbiased values lie approximately under 50 ps with even scattering. The delays on the ONSADBBC-ONSALA60 baseline obtained from the converted NGS cards for each database are illustrated in Figure 5. There was a constant bias of approximately -657 μs present in each database with standard deviations from 12–30 ps. In addition to the constant term, three of the databases had a 50-ns ambiguity with respect to the other four. The constant biases are absorbed into the clock parameters in the analysis. The biases and standard deviations are listed in Table 4. A similar inspection was done with On,

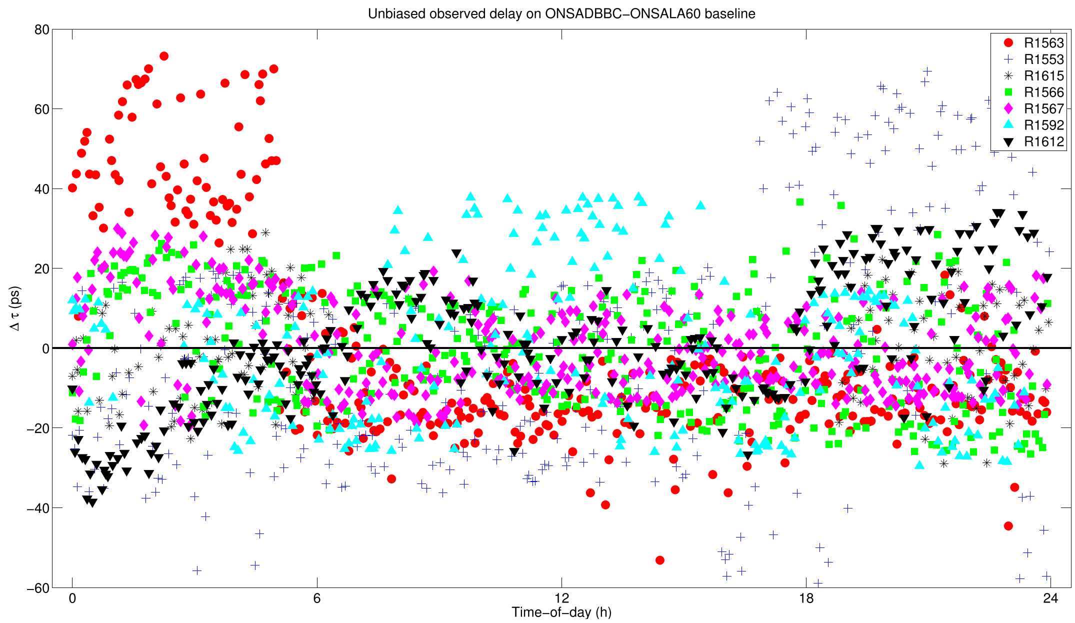

Fig. 5 Unbiased observed delays on the zero-baseline ONSADBBC–ONSALA60.

Od, and WETTZELL. The approximate bias between the differences is within −1900 ns to −1950 ns with standard deviations ranging from 15 ps to 65 ps. The biases and standard deviations for the differences between (Od–Wz)–(On-Wz) are listed in Table 5.

4 Conclusions

The differences between Od and On are relatively small. Due to the small number of sessions in which both On and Od are correlated, the sample size is relatively limited. No systematic errors could be discerned from the estimates obtained in this analysis. The DBBC at Onsala has performed reliably in numerous IVS sessions and no significant differences between the analog and digital backend have been found in the zero-baseline tests. Based on these sessions the values for the raw observed delay between Od and On differ in the range of ±20 ps. The non-systematic nature of the differences suggests that the source for errors is likely in the analysis and parametrization rather than in the instrumentation.

References

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