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Abstract We give a brief overview on the status of the Onsala twin telescopes (OTT), two years after their inauguration. The different components of the VGOS systems are briefly described, and the development towards routine operations.

Keywords VGOS · Onsala twin telescopes · DBBC3

1 Introduction

The Onsala twin telescopes (OTT) (Fig. 1) are two identical VGOS telescopes that were designed by MT Mechatronics GmbH. The OTT were installed during 2015/2016 in a distance of 75 m from each other. The ceremonial inauguration took place in May 2017 in connection to the 23rd Working Meeting of the European VLBI Group for Geodesy and Astrometry (EVGA) (Haas et al., 2019). Within the International VLBI Service for Geodesy and Astrometry (IVS) the OTT are known as ONSA13NE and ONSA13SW, with 2-character abbreviations OE and OW, respectively. The telescopes have a ring-focus design with a main reflector diameter of 13.2 m. As all VGOS telescopes they have fast slewing speeds: 12 and 6°/s in azimuth and elevation, respectively. The RMS surface accuracy of the main reflectors was determined to be 82 µm and 102 µm for OE and OW, respectively (Lösler et al., 2017), which is fulfilling the VGOS requirements.

Fig. 1: The Onsala twin telescopes at night, with OW (left) and OE (right). Photo taken by Armin Corbin in early 2019.

2 The signal chain

The OTT are equipped with cryogenic broadband receiving systems that were built at Onsala and are to a large degree identical (Pantaleev et al., 2017a). However, they have two different feed horns. OW is equipped with an Eleven-Feed of type 2017EFiC-2-14C-8P. It has hybrid couplers to reduce the needed number of low noise amplifiers from eight to two. The design is compact and wide band, with an opening angle of 65°, dual linear polarized covering a frequency range of 2 – 14 GHz. The intention when designing the system was to achieve compatibility with the legacy S/X systems. OE is equipped with a Quad-Ridged Feed Horn (QRFH) that was purchased

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from Caltech. The type is QRFH-60S-6-3 which was customized for an opening angle of 60° and a frequency range of 3 – 18 GHz. The intention when designing this system was to avoid the RFI-polluted lower S-band frequencies. The two receiving systems are interchangeable so that both OTT should be able to co-observe in mixed-mode with legacy S/X systems, however, not simultaneously.

The backends are located in the observatory control room at the 20 m radome enclosed telescope, approximately 500 m straight line distance from the telescopes. The radio frequency (RF) signals are sent from the telescopes via optical fibres which are approximately 1 km long since they are burried 70 cm below the soil surface and cannot follow the straight line. The cable length variations are monitored with cable delay measurement systems (CDMS). Each of the telescopes is equipped with four RF-over-fibre (RFoF) transmitters each located on the receiver trolley, two for vertical and two for horizontal polarization. Due to a high level of radio frequency interference (RFI) in the lower end of the frequency range and potential problems with saturation, the polarizations are split into a low (2.0 – 6.0 GHz) and a high frequency part (3.8 – 18.0 GHz). The corresponding RFoF receivers are located in the control room, close to the backends.

The OTT use one DBBC3 backend (Tuccari et al., 2018) each. These DBBC3s are of type DBBC3-8L8H, i.e. equipped with 8 IF-modules with 4096 MHz bandwidth each. There are eight analogue conditioning modules, called GCoMo, each covering 4 GHz of RF-input. The RF-signals are fed into the DBBC3s according to Tab. 1. Since the highest frequency band (11.4 – 15.2 GHz) is not yet used for VGOS test observations, RF-band (3.8 – 7.6 GHz) is currently split and fed into the two middle modules. However, the systems are prepared to cover higher frequencies in the future, see the range marked in red in Tab. 1.

Table 1: RF input to the DBBC3s. For the current VGOS test experiments, Band-3 and Band-4 are fed with the same frequency range. However, all systems are prepared to be fed with a higher frequency band (red) in the future.

RF-band	OW - Eleven-Feed Bandwidth (GHz)	OE - QRFH Bandwidth (GHz)
Band-1	2.0 – 3.8	3.0 – 3.8
Band-2	3.8 – 7.6	3.8 – 7.6
Band-3	3.8 – 7.6	3.8 – 7.6
Band-4	7.6 – 11.4	7.6 – 11.4
	(11.4 – 15.2)	(11.4 – 15.2)

3 Pointing and sensitivity

Soon after the official inauguration in May 2017, first light was achieved with both OTT and radio source signals could be detected. Following this, during the summer of 2017 the work continued to derive pointing models. Fig. 2 depicts the current level of pointing residuals for both telescopes. The RMS residuals for OE are 14.8 arcsec and 10.3 arcsec in elevation (E) and orthogonal to elevation (xE), and for OW 15.6 arcsec and 13.2 arcsec, respectively.

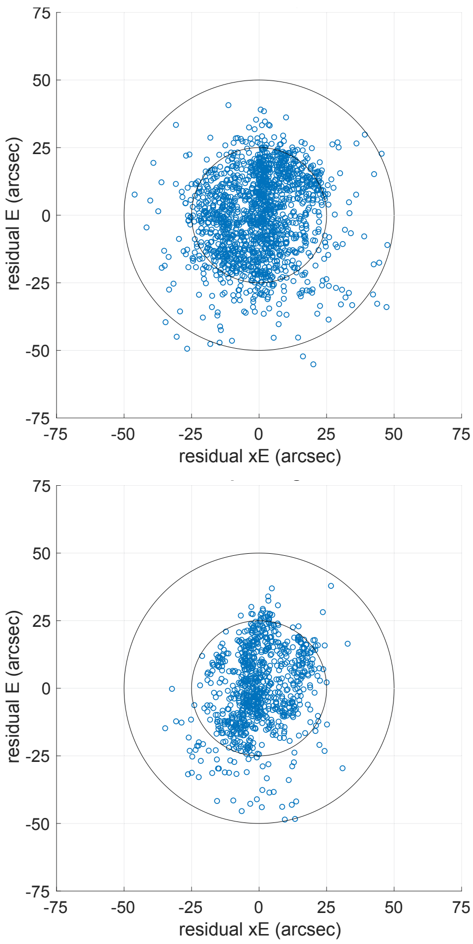

Fig. 2: Pointing residuals for OE (top) and OW (bottom).

In the autumn of 2017 first interferometric tests were done. In a test on 25 September, fringes were found for some RF bands for OE, and on 5 October also for OW. Both systems were adjusted and finally on 13 November 2017 fringes were found in all 4 RF-bands for OE. It took until 8 February 2018 before the same was achieved with OW.

Extensive measurements were performed to characterize the OTT system performance at the frequencies currently used for VGOS test sessions. Fig. 3 depicts system equivalent flux density (SEFD) measurements. In general, except for the lowest frequency range, around 3.0 – 3.5 GHz, which is affected heavily by RFI disturbances, the goal of 2000 Jy is achieved with both systems. However, there are also RFI around 5.2 GHz and 5.8 GHz for horizontal polarization.

A complete monitoring of the broadband sensitivity, i.e. not only the current VGOS frequencies, is planned for the future.

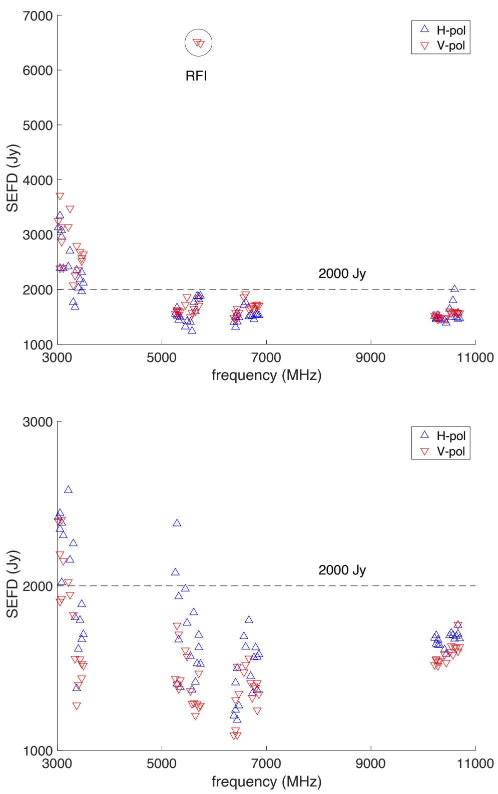

Fig. 3: SEFD measurements for OE (top) and OW (bottom).

4 Data recording and transfer

The OTT use Flexbuff computers as recorders. Currently there are two such machines, with 330 TB and 432 TB storage capacity, respectively. The backend systems can be flexibly connected to any of the recorders. Extensive tests have verified that recordings of up to 50 Gb/s are possible. Fig. 4 gives an overview of the current connectivity of the OTTs. The connectivity to the outside world is using two 10 Gb/s links, but can easily be upgraded to 100 Gb/s if necessary.

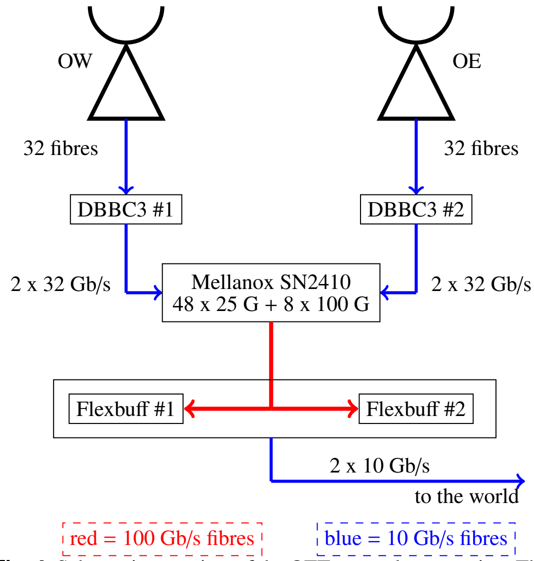

Fig. 4: Schematic overview of the OTT network connection. The two Flexbuffs have currently 330 TB and 432 TB storage capacity, respectively.

5 VGOS operations

We are very thankful to Ed Himwich for his support to integrate the DBBC3 control into the VLBI Field System (FS). The OTT operations can now be performed completely with the Field System FS 9.12.12 VGOS branch. This includes:

- configuration of the DBBC3 backends
- direct communication with the antenna control unit
- control of data recording
- control of the cable delay monitoring system (CDMS), including phase cal (PCAL)

There is one FS per OTT-system. They are interchangeable and can be accessed remotely. The telescopes themselves can be monitored via live-feed cameras, both in the control room as well from the outside. Additional monitoring of numerous telescope status parameters is possible via the in-house software ”Bifrost”. The data recording is monitored during observations with spectra and sampler statistics information that are displayed graphically on the FS screen.

During 2017, we participated in 6 VGOS test (VT) sessions of 24 h length, either with one or both systems. The VT-sessions are observed currently with 8 Gb/s and are correlated at Haystack observatory. There were problems with weak fringes and the level of the phase-cal signals, so that no useful VGOS databases resulted. In 2018 we participated with OE in total in 18 of the 24 h VT sessions. One of these sessions was observed with both OTTs. While the PCAL situation improved during 2018, there were problems with the DBBC3s. These problems caused data loss and no VGOS databases could be produced. In 2018 a lot of work was spent on improving the stability of the DBBC3s. Finally, the last VT-session in December 2018, which was also observed with both OTTs, was problem-free. Besides the international VT-sessions, we also observed with OE in 10 shorter sessions (4–6 h) with the European VGOS partner stations Wettzell and Yebes. These European VGOS (EV) sessions are correlated in Bonn. We also observed 6 sessions of various observation length together with Kashima, the so-called OK-sessions with different frequency setup than the standard VT-sessions and 16 Gb/s recording. A list of the 2017/2018 observations is provided in Haas et al. (2019b).

After the steep learning curve in 2017/2018 with continual system improvements, the situation became stable in early 2019. We participate in both the bi-weekly VT-sessions as well the EV-sessions, and the performance is in general good and stable. The first VGOS databases that could be analysed are `19JAN07VG` and `19JAN222VG`.

6 Further aspects

During the summer of 2018 a photogrammetric survey of OE was performed with an unmanned aerial vehicle (UAV). The aim was to investigate the elevation-dependent variations of the focal length (Lösler et al., 2019a) and to derive a model for signal path variation (SPV) in the telescope optics due to gravitational deformation (Lösler et al., 2019b).

The OTT were also equipped with a temperature and humidity monitoring system. Temperatures are monitored in different levels and directions in the telescope towers, inside the telescope azimuth and elevation cabins, and at various places along the optical fibres.

Furthermore, a local geodetic survey network with 6 concrete pillars was established around the OTT and a first epoch survey was performed (Heep, 2018). This is the basis for a classical local-tie survey which is planned for 2020.

In early 2019 first short baseline interferometry measurements were performed between the OTT and ON, the Onsala 20 m telescope, using X-band observations (Marknäs, 2019), see Tab. 2.

Table 2: Baseline length (L) and standard deviation (σ) in the Onsala telescope cluster, derived from local interferometric measurements at X-band performed in early 2019 (Marknäs, 2019).

Baseline	L (m)	σ (mm)
`OE - OW`	74.9612	± 0.2
`OE - ON`	468,6819	± 0.5
`OW - ON`	540.3115	± 0.4

7 Conclusions and outlook

A little less than two years after their official inauguration the OTTs have become operational. They are used operationally on a regular basis for VGOS observations. Data observed in the IVS VT-sessions are sent to the correlator at Haystack observatory and VGOS databases for post-processing are produced. Data observed in the European EV-sessions are sent to the correlator at Bonn. The plan is to continue to contribute to VGOS observations, both on the international and the European level.

One important aspect for the upcoming months will be to start to also observe in the so-called mixed-mode, using both the OTT and the Onsala 20 m radio telescope that is used for IVS S/X legacy observations. Further steps are to do additional local interferometry observations with the Onsala telescope cluster and to perform a classical local-tie survey and determination of the reference points.

On the system level, work will continue to fine-tune the pointing models, to derive gain curves, and to calibrate the OTT.

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