Operational studies of the Onsala Twin Telescopes

L. Chin Chuan, R. Haas, K. Le Bail

Abstract We present an overview of recent operational studies at the Onsala Space Observatory, focusing on the Onsala Twin Telescopes. The overview includes the so-called single-dish Tsys measurements covering the entire VGOS frequency band from 3 to 15 GHz, measurements with invar systems installed in late 2023, monitoring pcal amplitudes and phases, and first test observations using potential future frequency setups for observations of the European Space Agency (ESA) Genesis satellite.

Keywords Onsala, Twin Telescopes, VGOS, Genesis

1 Introduction

The Onsala twin telescopes (OTT) continue to participate in local and global VGOS observations. There is still potential to improve the observations, such as carefully avoiding unwanted radio frequency disturbances within the VGOS bands and understanding how the telescopes deform with temperature variations. At Onsala, we take the initiative to monitor the OTT systems and the local radio environment. The measurements and monitoring are presented in the following sections.

L. Chin Chuan, R. Haas, K. Le Bail
Chalmers University of Technology, Department of Earth, Space, and Environment, Onsala Space Observatory, Onsala, SE-439 92, Sweden

2 Tsys measurement at multiple directions

Tsys, also known as the system temperature, represents the total noise of a receiving system. It includes the noise (or power) from the radio source, the atmosphere, the receiver, and reflections from the surrounding environment. We dedicated a session of slightly more than 24 hours to monitoring the Tsys at the zenith position. Then, we dedicated another day to measure it in different directions. The expectation is that the Tsys stays stable if the environmental noise is low in that particular direction. In the following, we present the results of the Tsys monitoring sessions from 2.9 to 15.2 GHz.
Figs. 1 and 2 show the median Tsys as a function of frequency for Oe and Ow, respectively. The standard deviation colour bars show the stability of the Tsys measurement for the ”frequency channels” over 96 cycles, wherein each channel is 32 MHz wide, similar to the current VGOS recording practice. Each cycle consists of three samples at 10-second intervals.

From the plots, we understand that when there is a spike in the median Tsys at a particular frequency channel, the environment at that frequency is generally radio-noisier. As expected, we can see a lot of unwanted radio signals interfering with the systems in the lower frequency band below 4 GHz, especially at Ow. It might be due to that Ow has a more sensitive feed than Oe, as the same trend manifests when the antennas point in different azimuth and elevation directions, as shown in figs. 3 and 4. The red arrows indicate the frequency from low to high.

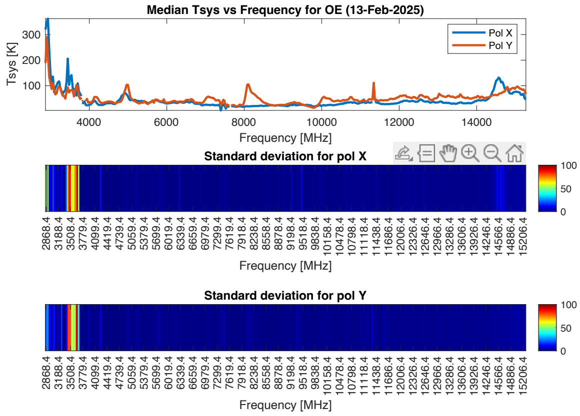

Fig. 1 Median Tsys and its standard deviation for Oe over the frequency range 2.9–15.2 GHz when pointing at zenith.

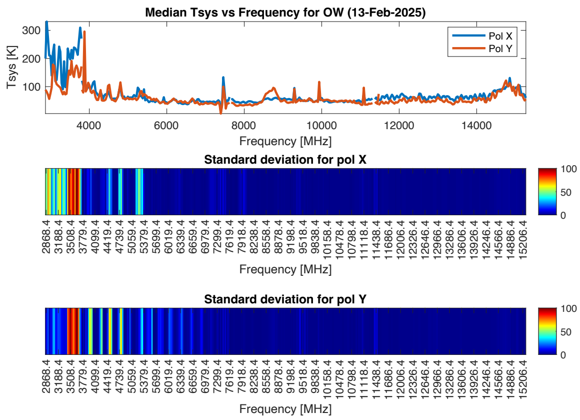

Fig. 2 Median Tsys and its standard deviation for Ow over the frequency range 2.9–15.2 GHz when pointing at zenith.

3 Invar measurements of the OTT towers

In December 2023, invar measurement systems were installed in the OTT telescope towers to measure their structure deformation caused by temperature changes. The invar measurements monitor the temperature-induced vertical deformation of the towers, which primarily shows a seasonal signature, as demonstrated in Figs. 5 and 6.

The difference of both the raw invar measurements, sampled at 1 Hz, or averaged over different time intervals, is roughly 1 mm between the coldest months (January 2024 and 2025) and the hottest months (July and August 2024). We can also see in these two figures that the invar measurement system at Oe appears to be noisier than the one at Ow in the

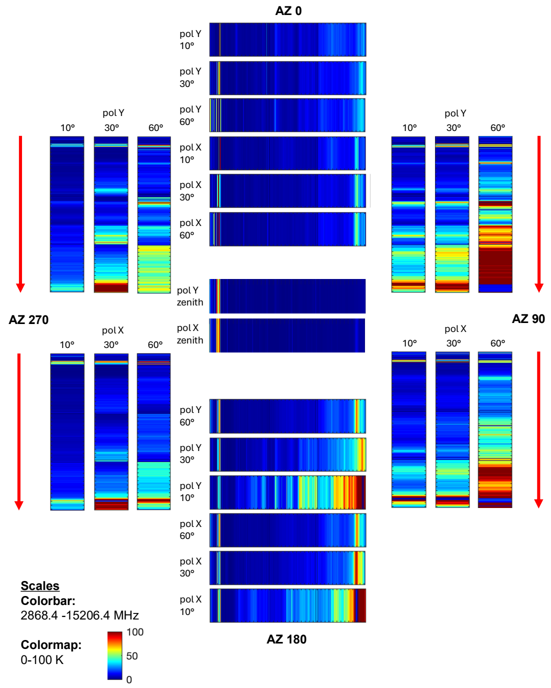

Fig. 3 Standard deviations for Oe Tsys in four azimuth directions and three elevations each azimuth from 2.9 to 15.2 GHz.

short-duration periods, which is suspicious because the invar measurements should not be affected by antenna movements during observation. To investigate this phenomenon further, we dedicated a 34-hour long experiment to test the invar measurement system responses when the antenna is steady, when the antenna changes only in azimuth, and when the antenna changes only in elevation.

Table 1 Standard deviations in millimetre of the invar reading responses for Oe and Ow in seven situations: antennas not moving; antennas move in azimuth while elevation=90 degree, then elevation=45 degree; antennas move in elevation while azimuth=0 degree, then azimuth=90 degree, azimuth=180 degree, azimuth=270 degree.

Station	steady	el=90	el=45	az=0	az=90	az=180	az=270
Oe	0.090	0.110	0.111	0.094	0.090	0.091	0.093
Ow	0.092	0.096	0.098	0.095	0.098	0.098	0.098

Table 1 shows the standard deviations of the invar measurements in seven different situations. We see that both telescopes exhibit comparable levels of

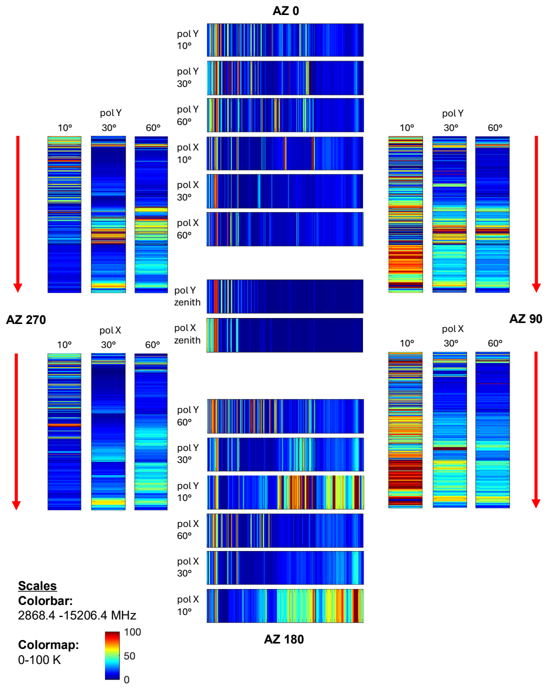

Fig. 4 Standard deviations for Ow Tsys in four azimuth directions and three elevations each azimuth from 2.9 to 15.2 GHz.

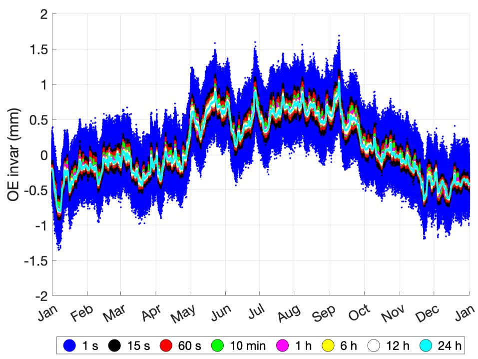

Fig. 5 Invar readings for Oe from January 2024 to January 2025.

uncertainty when the antennas are standing still. The standard deviation for Oe increased by about 22 % when the antenna moved in azimuth while the elevation was constant, in contrast to only 4 % when it moved in elevation while keeping the azimuth constant. On the other hand, the standard deviation of Ow

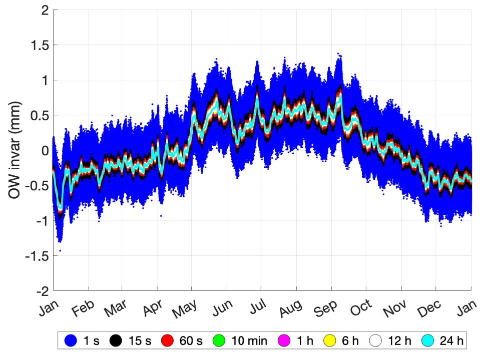

Fig. 6 Invar readings for Ow from January 2024 to January 2025.

increased by about 5 % when the antenna moved, regardless of direction.

4 Phase cal signal monitoring

It is crucial to have a functional phase cal system in VLBI for a coherent combination of several observation channels. At the Onsala Space Observatory, we plan to monitor the phase cal amplitudes and phases of the OTT systems for every session soon. In Fig. 7 we present as an example the phase cal amplitudes and phases extracted using the m5pcal tool directly from the raw data recorded from a 24-hour VGOS session (vo5022). We average the second, third, and fourth tones of the outputs, as they are the strongest tones of our 5 MHz phase cal systems. The figures presented are for demonstration of the visualised outputs. Hence, we selected only one polarisation in band A (3.0–3.5 GHz) since the phase cal signal is strongest at low frequencies for the OTT. More detailed results are presented in Table 2.

In a comparison of the two stations presented in Fig. 7, we see that Oe has a relatively more stable phase cal with flatter amplitudes and less prominent short-term variations in the phases over 24 hours. However, the phase is still very clearly affected by the ambient temperature. The Ow phase cal amplitude became very unstable between 07:30 and 21:30 UT in two upper frequency channels in band A, which could be a result of local radio frequency interference that more strongly affected the Ow telescope, as

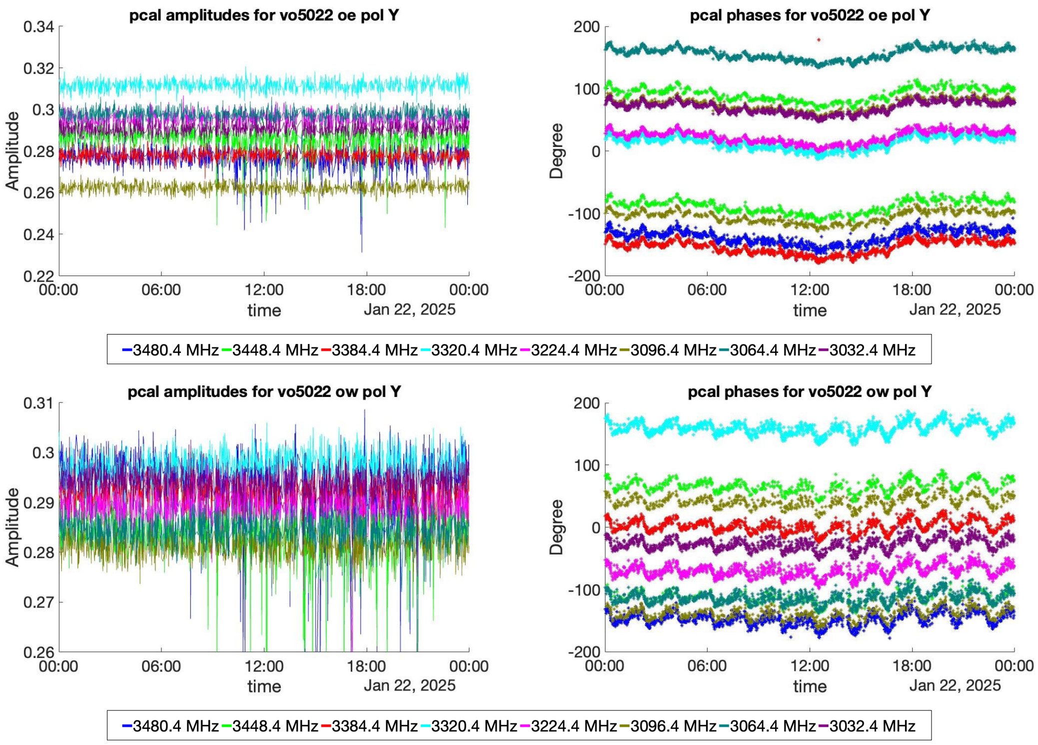

Fig. 7 Phase cal amplitudes (left column) and phases (right column) averaged over tone 2, 3 and 4 for vo5022 Oe (top row) and Ow (bottom row) in band A, polarisation Y.

shown also in the Tsys experiment in Section 2. More research is needed to explain the cause of the short-term seasonal variation in the phases of Ow and the reasons why the second and sixth frequency channels alter by 180 degrees in phase every scan.

Table 2 presents the RMS values of the phase cal amplitudes, the corresponding uncertainties in percentage, and the uncertainties of the RMS phases for both Oe and Ow. Only band A and band D are shown for comparison of the lowest and highest frequencies observed during the session. The average amplitude in band D is lower than in band A, and the average uncertainty is significantly higher. The same characteristic is even present within the same frequency band. For the phases, the RMS is irrelevant to this investigation. However, the uncertainty in the phase gives the impression of how stable the phases are for each frequency channel. As mentioned previously, the alternating phases for channels 2 and 6 also manifested in the tabulated results. Band D channels also have more variable phases than band A. We also see that the amplitudes are generally lower for Ow than for Oe in band D, and so are the corresponding uncertainties. However, Ow seems to have less variable phases in comparison.

5 Genesis frequency setup tests

An upcoming European Space Agency (ESA) mission, Genesis, whose purpose is to combine and co-locate all four space geodetic techniques on one satellite platform to achieve a more accurate Terrestrial Reference Frame (TRF), will allow observations with VGOS radio telescopes (Delva et al., 2023). Genesis should send signals in four frequency bands: 3.1–3.3 GHz, 5.25–5.57 GHz, 8.2–8.4 GHz, and 9.3–9.8 GHz. As an initial test, our aim was to place (5+9+5+13) channels of 32 MHz bandwidth each per polarization in these frequency bands. Due to the requirements to observe 2n channels with the VDIF data format, 8+16+8+16 channels per polarisation must instead be observed.

Table 2 The RMS values of the phase cal amplitudes, the uncertainties of the RMS amplitudes (U_a) and the uncertainties of the RMS phases (U_p) for Oe and Ow.

			OE			OW		
Band	Pol	Chan	RMS	U_a (%)	U_p (°)	RMS	U_a (%)	U_p (°)
A	X	1	0.29	2.79	11.95	0.28	2.51	11.36
A	X	2	0.28	2.74	99.34	0.29	1.73	117.52
A	X	3	0.29	1.35	11.06	0.30	0.82	10.26
A	X	4	0.29	1.15	10.81	0.29	1.03	10.08
A	X	5	0.30	1.49	10.78	0.28	1.67	10.61
A	X	6	0.27	1.03	90.68	0.28	0.86	94.48
A	X	7	0.30	1.17	9.88	0.28	0.92	10.11
A	X	8	0.29	1.22	9.61	0.30	0.98	9.76
A	Y	1	0.28	1.78	11.31	0.29	2.26	10.52
A	Y	2	0.29	1.85	91.06	0.28	1.70	90.34
A	Y	3	0.28	0.96	13.88	0.29	0.88	9.97
A	Y	4	0.31	0.80	10.72	0.30	0.91	9.94
A	Y	5	0.30	1.01	10.13	0.29	0.98	10.06
A	Y	6	0.26	0.84	90.17	0.28	1.12	90.27
A	Y	7	0.30	0.87	9.56	0.28	1.00	9.70
A	Y	8	0.29	0.89	9.48	0.29	0.93	9.40
D	X	1	0.23	8.01	39.88	0.17	13.84	32.15
D	X	2	0.22	8.30	98.76	0.09	15.91	108.16
D	X	3	0.21	8.50	37.71	0.10	18.42	27.47
D	X	4	0.20	8.41	38.94	0.12	20.60	48.10
D	X	5	0.23	7.52	37.19	0.14	16.41	30.56
D	X	6	0.23	6.56	105.37	0.14	13.40	111.36
D	X	7	0.23	7.05	36.62	0.16	13.78	28.52
D	X	8	0.22	6.95	36.68	0.16	12.35	27.67
D	Y	1	0.23	7.75	39.29	0.15	20.14	45.88
D	Y	2	0.31	7.31	93.71	0.15	17.67	91.59
D	Y	3	0.11	11.27	37.29	0.17	13.49	17.60
D	Y	4	0.15	9.91	38.80	0.18	12.20	27.59
D	Y	5	0.24	6.47	36.68	0.17	14.06	23.84
D	Y	6	0.24	6.52	110.50	0.18	12.21	113.72
D	Y	7	0.18	8.77	36.26	0.18	11.70	25.75
D	Y	8	0.23	7.43	35.75	0.16	11.57	24.97

We can achieve this channel allocation using the DDC_V_v126 firmware of the DBBC3 and correlate it in two steps, i.e. band A+B+C and then band C+D, due to the current limitation in HOPS to process only up to 64 channels. We may also modify the channel placement for greater compatibility with current VGOS observations, using (8+8+8+8) channels of 32 MHz bandwidth each per polarisation. Of these, the (5 + 8 + 5 + 8) channels per polarization that were within the Genesis frequency range were used for correlation and fringe fitting; see Fig. 8.

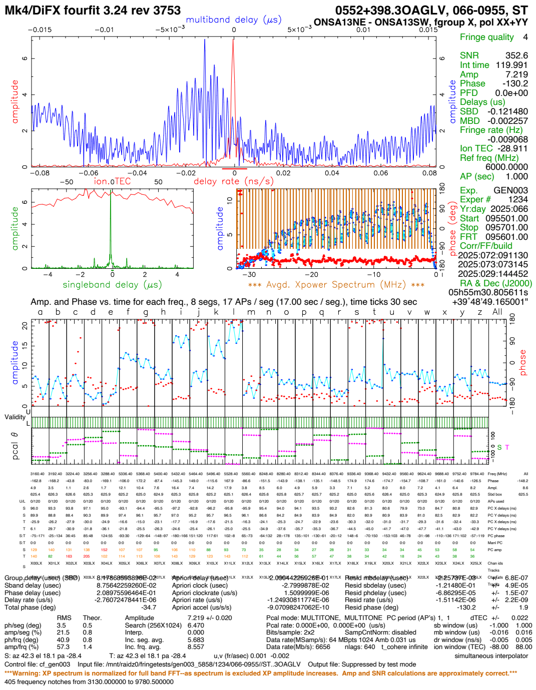

Fig. 8 Genesis test with recording 64 × 32 MHz channels using DBBC3 DDC_V_v125 firmware. Out of these, 10, 16, 10, 16 channels from each frequency band, respectively, were used for correlation and fringe fitting.

6 Conclusions and outlook

We are putting continuous effort in the presented areas, i.e. checking the electromagnetic environment around the observatory and its effect on VGOS observations, testing the stability of the antennas with respect to the ambient temperature, monitoring the quality of pcal amplitudes and phases during VGOS observations, and testing for potential frequency setups for upcoming VGOS observation modes.

References

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