Initial Results from the MIKES-Metsähovi Time and Frequency Link for the VGOS Radio Telescope

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Abstract VLBI relies on the precision of Hydrogen maser clocks at each station to provide accurate time and frequency for their observations. Recent developments allow us to use distributed clocks via optical fiber links in order to provide these time signals at any remote radio telescope. Here in this paper, we discuss the distribution of the official Finnish UTC clock time to operate the new VGOS radio telescope at Metsähovi.

Keywords VGOS, Time & frequency link, White Rabbit switch, fiber-optic

1 Introduction

Correlation of data obtained by Very Long Baseline Interferometry (VLBI) radio telescopes located around the globe relies on very precise information about the arrival time of the radio signals. VLBI stations also require a very stable frequency reference (at 5 or 10 MHz) for operating most of their instrumentation. These stations use a local Hydrogen maser (H-maser) as a reference clock. We are developing a 'remote maser' concept for VLBI that synchronizes participant stations to the same reference clock via optical fibers [1]. In this paper, we report on the first results from a 50 km optical fiber time and frequency link between the National Metrology Institute VTT MIKES and the Metsähovi Geodetic Research Station.

1. Finnish Geospatial Research Institute FGI, National Land Survey
2. Technical Research Centre of Finland Ltd VTT, Centre for Metrology MIKES

In summer 2018 the Finnish Geospatial Research Institute (FGI), part of the National Land Survey of Finland (NLS), began the construction of a new VGOS radio telescope at Metsähovi. FGI had been participating in the IVS campaigns for over a decade already but did not have its own radio telescope. Instead, FGI rented observing time from the astronomical radio telescope of Aalto Metsähovi Radio Observatory (MRO). The construction of this new antenna will provide a new station dedicated 24/7 to global geodetic observations. More information about the status of the radio telescope at Metsähovi can be found at [2].

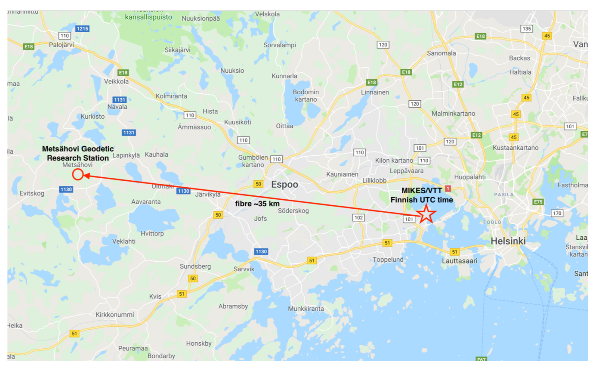


Fig. 1 Metsähovi is located 50 km from Helsinki. VTT MIKES is in Otaniemi, next to Aalto University and 40 km from Metsähovi. The official Finnish UTC time and frequency signal is provided to the station via an optic fiber.

The location of the new VGOS radio telescope at Metsähovi and VTT MIKES can be seen in Figure 1. Both institutes are separated by a distance of 40 km; however, they are linked with several pairs of dark fibers thanks to the Finnish University and Research Network (FUNET), part of CSC - IT Center for Science LTD. The link was originally installed to provide a 10 Gbps connection to the radio telescope.

2 Configuration

The experiments are conducted with the White Rabbit (WR) extensions to the Precision Time Protocol (PTP) [1]. The White Rabbit switch provides precision timing and high accuracy synchronization based on an Ethernet-based network. The so-called WRS master distributes the clock, 1 pps signal, and a fixed 5 or 10 MHz frequency signal to all the nodes in the network using a hierarchical architecture. The basic configuration used during the first tests is shown in Figure 2.

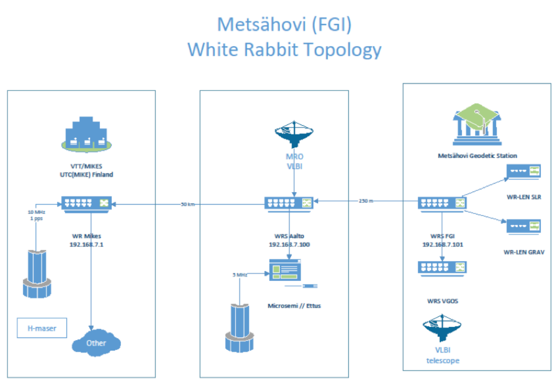


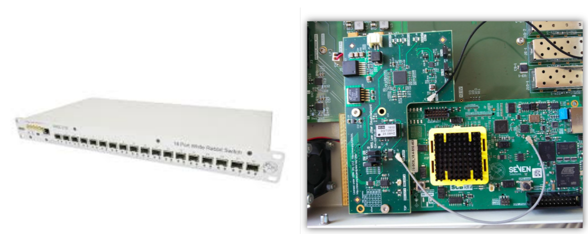
Fig. 2 Current set up to distribute the standard Finnish UTC time and frequency reference to the Metsähovi station and to the future VGOS radio telescope.

The WRS master is located at VTT MIKES and is directly connected to one of their Hydrogen masers. The WRS master distributes the time and frequency signals via optic fiber to a number of WRS nodes (also known as WRS slaves). For instance, the two WRS existing at Metsähovi are configured as WRS slaves. There is a pair of dark fibers that directly links VTT MIKES to Aalto MRO. These fibers are shared for the 10 Gbps data transmission connection and the time and frequency link. Additional fibers between MRO and FGI were installed in order to extend the White Rabbit network within Metsähovi facilities. The FGI and MRO facilities are located within a radius of 300 m.

[1] www.sevensols.com

The White Rabbit units are configured with a Dense Wavelength Division Multiplexing (DWDM) Small Form-factor Pluggable transceiver (SFP) in bi-directional mode, allowing proper transfer of the optical wavelengths over long-distance fibers. The round-trip time of the optical link was monitored over a period of one year. The first estimations indicate that asymmetry of the link contributes less than 500 ps to the uncertainty of time-transfer.

The standard configuration of a White Rabbit switch (see Figure 3 (i)) was upgraded with the Low Jitter Daughterboard (LJD) modification to the WRS (see Figure 3 (ii)) [3]. The installation of the LJD board improves significantly the stability of the internal clock of the standard WRS. The measurement set up at Metsähovi is shown in Figure 4.



(i) (ii)

Fig. 3 (i) Standard WRS capable of the distribution of time and frequency signals up to 15 nodes. (ii) Modification to the WRS, which improves the stability of the clock and frequency signal.

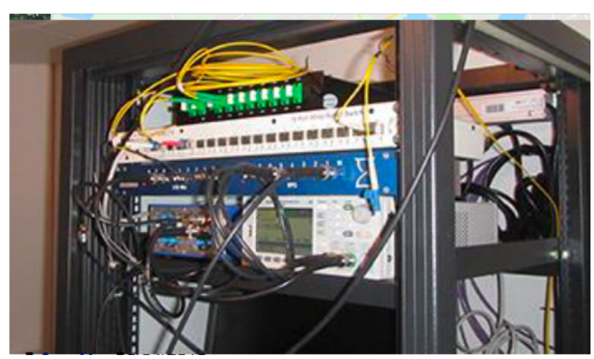
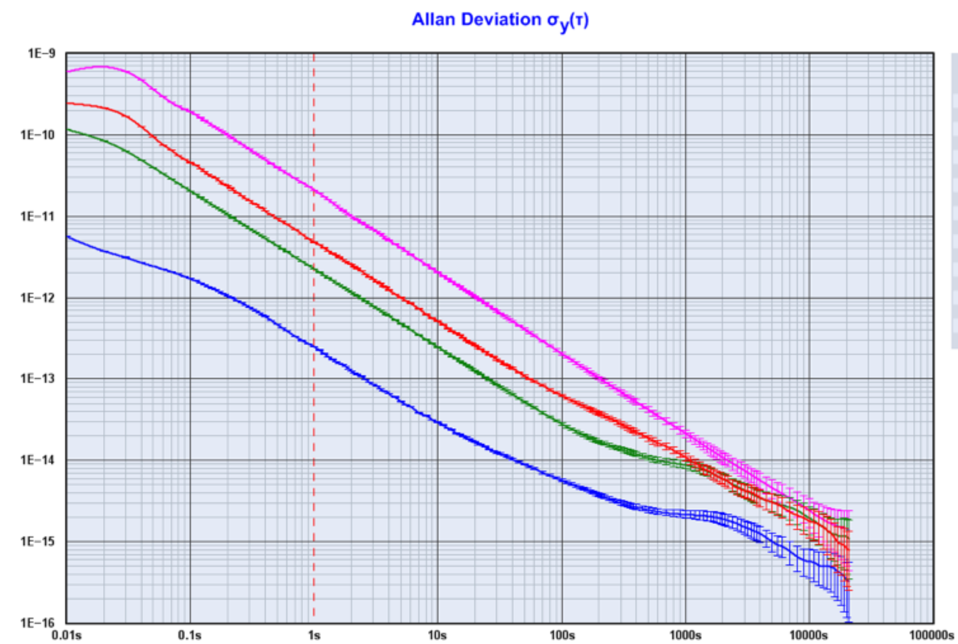


Fig. 4 Current set up arranged at Aalto Metsähovi radio observatory where the time and frequency signals provided by the VTT MIKES are being compared with the local Hydrogen masers.

Three White Rabbit LEN extension units were purchased this year for testing purposes. The units are a



Tau	Sigma(Tau)
1s	4.80E−12
2s	2.56E−12
4s	1.24E−12
8s	6.27E−13
10s	5.12E−13
20s	2.57E−13
40s	1.35E−13
80s	7.38E−14
100s	6.28E−14
200s	3.80E−14
400s	2.23E−14
800s	1.33E−14
1000s	1.09E−14
2000s	5.93E−15
4000s	3.48E−15
8000s	2.12E−15
10000s	1.80E−15
20000s	8.20E−16

Trace	Notes	Input Freq	Sample Interval	ADEV at 1s	Duration	Acquired	Instrument
h3-h4-24h		5.000 MHz	0.010 s	2.48E−13	1d 0h 0m 0s	8640000 pts	Symmetricom 3120A
h3-std-24h		10.000 MHz	0.010 s	2.11E−11	1d 0h 0m 0s	8640000 pts	Symmetricom 3120A
h3-lj-24h		10.000 MHz	0.010 s	2.25E−12	1d 0h 0m 0s	8640000 pts	Symmetricom 3120A
hm-wrl-24h		10.000 MHz	0.010 s	4.80E−12	1d 0h 0m 0s	8640000 pts	Symmetricom 3120A

Fig. 5 Allan deviation of the H-maser vs. Standard WR (pink), H-maser vs. WR-LEN (red), and H-maser vs. WRS with the modified Low Jitter Board (green), and the H-maser (blue). The analysis was conducted with a Symmetricom 3120A phase meter.

cost-effective solution to extend internally at FGI the 10 MHz and 1 pps or IRIG-B signal between the different scientific instruments at Metsähovi. The dimensions of these units are relatively smaller than standard WR switches, and their performance is slightly higher.

3 Results

The 1 pps signal was closely monitored for the last year and a half. The 1 pps signal provided by the standard WRS and the WRS + LJD have been compared with the local Hydrogen masers. Statistics of the signals are extracted every minute for all possible measurement sets. The real-time information can be followed from the VTT MIKES web site [2].

Comparisons of the frequency signal (5 and 10 MHz) with the local H-masers were also conducted. The phase noise and Allan deviation analysis have been analyzed regularly over periods of 24 to 100 h using a phase meter. We used the Symmetricom 3120A for these tests. Figure 5 shows the Allan deviation of the H-maser compared to the standard White Rabbit switch (in pink), the H-maser vs. the WR-LEN (in red), the H-maser vs. the WRS + LJD (in green), and finally two of the H-masers from Aalto Metsähovi (in blue). The performance of the WRS + LJD is one order of magnitude better than the standard WRS and one order of magnitude worse than a Hydrogen maser. The results show that the random errors are reduced to the level of 1e-12 at 1s (0.5 Hz BW). This performance is perfectly suitable to fulfill the requirements for VLBI Global Observing System (VGOS) and sufficient for all but the most demanding applications [4].

4 Future Work

A high-performance remote maser concept is currently being developed at VTT MIKES. This new frequency

[2] http://monitor.mikes.fi/mets_aalto/

transfer technique [5] is under design in order to improve the current performance of WR-PTP and reduce the random errors to the 1e-13 level, that of active H-masers used worldwide for continuous timekeeping. The concept can be simplified to the schematics shown in Figure 6. A Morion MV317 voltage controlled oscillator is operated 'symmetrically' in a phase-locked loop (PLL), which compensates for drifts in the optical fiber link. Phase detection is done at the highest frequency present in the system. Frequency multipliers/dividers and a clean-up oscillator could be added to the remote end.

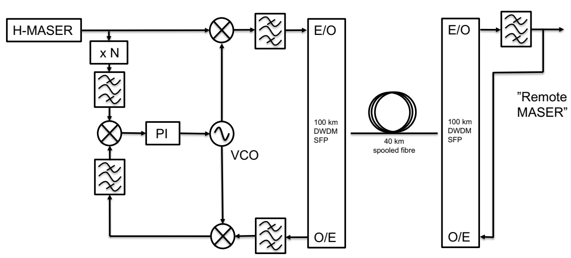


Fig. 6 A Morion MV317 voltage controlled oscillator is operated 'symmetrically' in a phase-locked loop, which compensates for drifts in the medium (fiber). Phase detection is done at the highest frequency present in the system.

Initial tests were conducted in the laboratory with satisfactory results. The system consists of a receiver and transceiver transmission over a spool of 40 km of fiber. The Allan deviation of the reference or noise floor is shown in black, the performance of an H-maser is shown in blue, and finally the received signal after the fiber spool is shown in red.

Further experiments will start in the fall of 2018, when the system will be deployed over the fiber between the radio telescope and the VTT MIKES. Successful results on these tests are expected by the end of 2019. The time is in agreement with the current schedule of operations for the VGOS radio telescope.

5 Conclusions

The definitive goal is that this time transfer project will support the geodetic measurements at the Metsähovi Geodetic Research Station. The new link, together with the atomic clocks of the Aalto MRO, also improves the

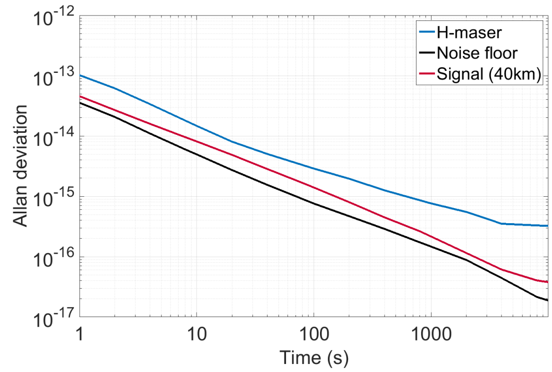


Fig. 7 Allan deviation of the reference or noise floor (black) and the received signal after propagating 50 km in a fiber spool (red). Also shown is the performance of the H-maser (blue). For the measurements all signals have been divided down to 10 MHz.

time and frequency precision for all the instrumentation at the station. Finally, the link opens as well new opportunities for connecting the UTC (MIKE) atomic time scale to other international geodetic observation networks such as IGS.

Future work will continue to exploit the White Rabbit technology for the time and frequency link of a geodetic station, while focusing on improving the concept of the high-performance remote-maser concept.

References

1. Clivati et al., A coherent fiber link for very long baseline interferometry IEEE Trans. Ultrason., Ferroelect., Freq. Contr., 2015, 62,
2. Zubko, N., Molera Calvés, G. et al.,'Status Update of the Metsähovi VGOS radio telescope', PoS IVS GM 2018.
3. M. Rizzi et al., "WRS Low Jitter Daughterboard", Open Hardware repository, https://www.ohwr.org/projects/wrs-low-jitter
4. Wallin, A.E. et al., Improved systematic and random errors for long-distance time-transfer using PTP White Rabbit, EFTF2018.
5. Fordell, T., Wallin, A.E., "A simple High-Performance Remote-Maser concept", ETFT2018.