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The First Geodetic VLBI Field Test of LIFT: A 550-km-long Optical Fiber Link for Remote Antenna Synchronization

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Abstract We present the first field test of the implementation of a coherent optical fiber link for remote antenna synchronization realized in Italy between the Italian Metrological Institute (INRIM) and the Medicina radio observatory of the National Institute for Astrophysics (INAF). The Medicina VLBI antenna participated in the EUR137 experiment carried out in September 2015 using, as reference systems, both the local H-maser and a remote H-maser hosted at the INRIM labs in Turin, separated by about 550 km. In order to assess the quality of the remote clock, the observed radio sources were split into two sets, using either the local or the remote H-maser. A system to switch automatically between the two references was integrated into the antenna field system. The observations were correlated in Bonn and preliminary results are encouraging since fringes were detected with both time references along the full 24 hours of the session. The experimental set-up, the results, and the perspectives for future radio astronomical and geodetic experiments are presented.

Keywords Optical fiber, clock synchronization, metrology

1 Introduction

A coherent fiber link for application in very long baseline interferometry (VLBI) for radio astronomy and geodesy has been realized thanks to the LIFT (the Italian Link for Time and Frequency) project [1]. The map of the present LIFT backbone is shown in Figure 1. A dedicated fiber (dark fiber) is used from INRIM to Bologna, where the signal is split: one of the arms reaches the European Laboratory for Non Linear Spectroscopy in Florence (LENS) and the other arm extends the link to the Medicina Observatory. The last 30 km of the link, from Bologna to the radio telescope, are shared with the data channel with a DWDM (Dense Wavelength Division Multiplex) architecture. The system already demonstrated to be capable of operating for several hours without interruptions and without loss of coherence [2]. For the VLBI application it is mandatory to guarantee long-term operation so one of the aims of the experiment was to test in the field some technical improvements, such as automatic polarization adjustment.

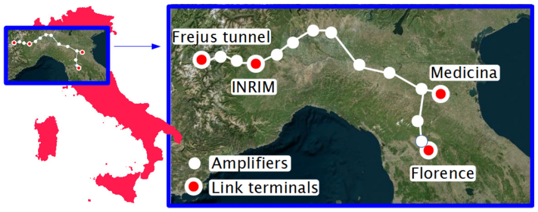

Fig. 1 The present LIFT backbone.

Conceivably, a fiber-based network of multiple antennas connected to a single clock can be envisaged, with improved spectral purity and long-term stability.

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This will be useful for high-resolution VLBI and could open the possibility of direct fringe comparisons in addition to the well-established protocols where the data are processed at a correlator. This experiment opened the possibility of replacing the local hydrogen masers at the VLBI sites with optically-synthesized Radio Frequency (RF) signals. This could improve the VLBI resolution by providing more accurate and stable frequency references and, in perspective, by enabling common-clock VLBI based on a network of telescopes connected by fiber links. We planned an experiment at Medicina during a measurement campaign that took place in September 2015. In Section 2 we present the experiment set-up, in Section 3 the EUR137 Experiment, and in Section 4 the conclusion and the perspectives for further developments.

2 Experiment Set-up

The optical link to Medicina is based on the distribution of an ultra-narrow linewidth laser at 1.5 μm along a phase-stabilized telecom fiber, which does not affect the uncertainty of the delivered frequency at the 10^{-19} level of accuracy (in terms of relative frequency) [1]. To inject the signal of the H-maser at INRIM into the optical link, an optical frequency comb is used. At Medicina, the received light is regenerated by phase-locking a local diode laser. The obtained signal is then used to phase-lock a second optical frequency comb that generates a 100-MHz RF signal. A detailed description of the setup and its characterization can be found in [2]. The signal synthesized from the comb is then processed and sent to a low-noise digital frequency divider which generates both the 5 and 10 MHz RF signals and a Pulse Per Second (PPS) signal needed for the instrumentation of the radio telescope (i.e., as references for the local oscillator of the RF receivers and for the synchronization of the acquisition systems). Particular attention has been devoted to the detection and processing electronics, to ensure that its instability does not affect the overall system performances. To efficiently compare the performances of the local and the fiber-delivered clocks during a VLBI campaign, we added an electronic system to the radio telescope instrumentation which is capable of switching between the two references (Figure 2).

The set-up used for the experiment was composed by the standard VLBI backend, local and remote H-maser Time and Frequency (T&F) references with the switching unit, and the Field System control software. The VLBI backend is composed by a sampling equipment DBBC (Digital Base Band Converter), a data formatting unit (FILA10G) [3], and a recording unit (Mark 5C, http://www.haystack.edu/tech/vlbi/mark5/). The switch between the two references is controlled through the IF3 switch-box driven by the observation schedule, when an ad-hoc procedure is called, inserted in the original schedule. The long-term correction of the local H-maser is obtained through a dedicated Global Positioning System (GPS) receiver (on the left in Figure 2) which also provides the initial synchronization of the reference PPS signal generated by the local H-maser. The latter signal is also used for the initial synchronization of the remote PPS only after every possible unlocking of the optical link, i.e., the unlocking of the servo loops on the laser sources, or the optical combs, or link noise compensation. Since the reference switching breaks the DBBC synchrony, a resynchronization is necessary after each switch and a consequently automatic FILA10G time counter adjustment, provided by means of a dedicated GPS antenna (on the right in Figure 2), just for this purpose.

3 EUR137 Experiment

In order to test the remote clock, we used the International VLBI Service for Geodesy and Astrometry (IVS, [4], [5]) Europe experiment (EUR137), already scheduled for September 7, 2015. Since for this experiment Medicina station was not scheduled, we decided to add it to the official schedule in the so-called “tag-along” mode. We established to use both time standards (optical link and local H-maser) throughout the experiment. We split the session into two different sub-sessions, based not on time but rather on two sets of sources that were observed alternatingly as shown in Table 1. This gives us the possibility to have two 24-hour long observations with both reference clocks.

The data recorded at six European stations (namely DSS65, MEDICINA, METSAHOVI, NYALES20, ONSALA60, and WETTZELL) were sent to the Bonn correlator. The EUR137 experiment was correlated using the Bonn DiFX correlator [6]. In the correlation,

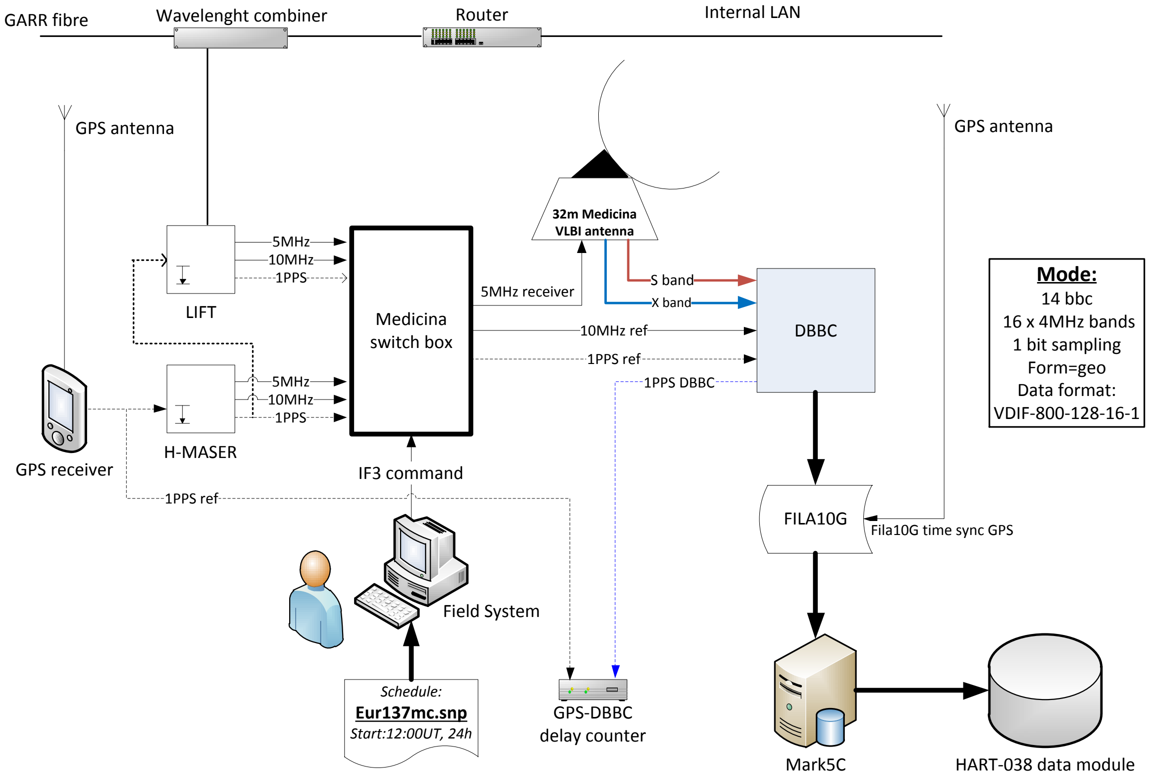

Fig. 2 Schematic experimental set-up.

Table 1 Observed sources.

Clock 1 (H-Maser)	Clock 2 (LIFT)
0059+581	OJ287
0552+398	1803+784
0229+131	1751+288
0119+115	1749+096
1849+670	3C274
0823+033	1128+385
3C418	0716+714
CTA26	0202+319
0017+200	0642+449
1418+546	1726+455
1741-038	0016+731
0454-234	1334-127
0727-115	1519-273
1156+295	

the observations performed at Medicina with the two different clocks were treated as two different VLBI stations: MEDICINA and MEDILIFT. This gave us the opportunity to compare the two geodetic outputs. Following all the standard correlation and post-correlation steps, we created a Mark IV database and analyzed it with νSolve [7]. The MEDILIFT observations had more problems (as opposed to MEDICINA) that were mainly due to the clock behavior: some jumps together with some planned resets at INRIM caused clock breaks. In Figure 3 the MEDILIFT group delay residuals with unresolved clock breaks (on the left) and the residuals (on the right) after setting up eight breaks are presented, respectively. Actually there were more than eight breaks, but between some intervals there were only a few observations leading to singularities. Thus, these observations were removed.

In Figure 4 the final residuals for MEDILIFT (on the left) and MEDICINA (on the right) baselines with full parametrization are displayed: 2nd degree polynomial + one-hour CPWLF (Continuous Piece Wise Linear Functions) clocks, one-hour ZWD (Zenith Wet Delay), 24-hour horizontal tropospheric gradients, station positions for MEDICINA and MEDILIFT, PM (Polar Motion), UT1 (Universal Time), and nutation offsets.

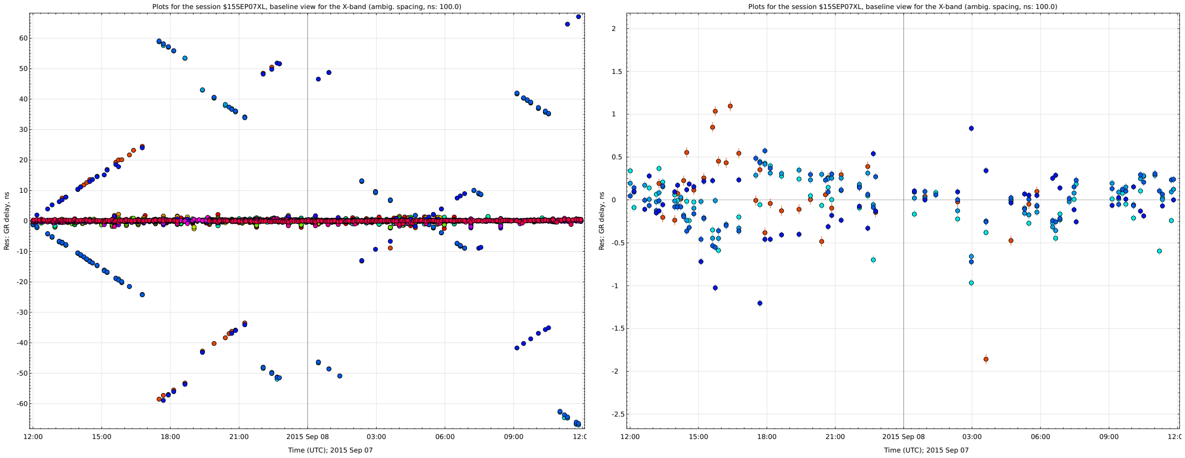

Fig. 3 Group delay residuals for MEDILIFT baselines with unresolved (on the left) and resolved (on the right) clock breaks (in ns).

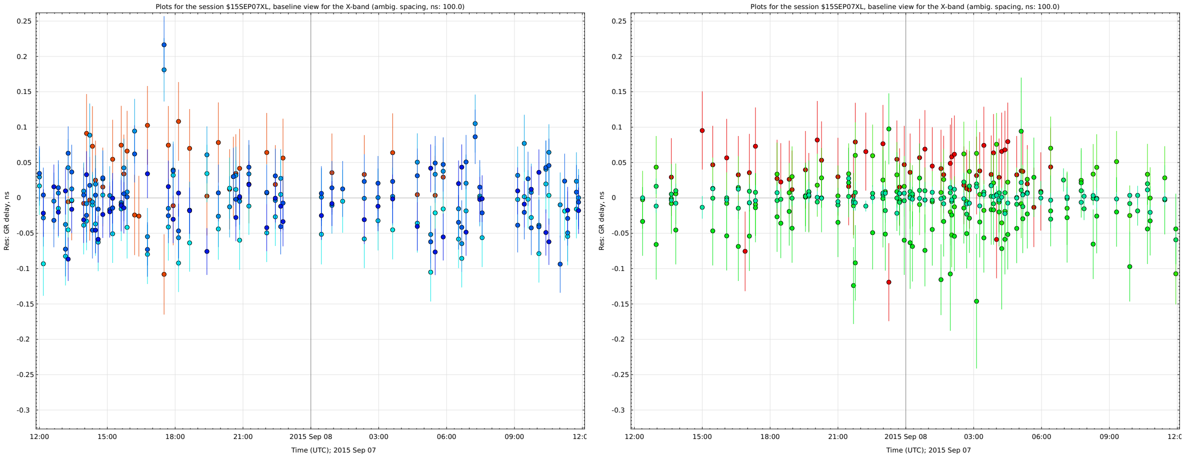

Fig. 4 Final νSolve solution for MEDILIFT (on the left) and MEDICINA (on the right) baselines (in ns).

For MEDILIFT the visible gaps are due to outlier handling.

The problems related to the clock behavior lead to difficulties in the data analysis of the baselines containing MEDILIFT. Resolving the clock breaks gives reasonable results, but the solutions for MEDICINA and MEDILIFT are different, in spite of dealing with the same station. The residuals of the MEDILIFT observations are somewhat larger than those of the MEDICINA observations. This, however, might be due to the imperfect estimation of the clock breaks in νSolve and needs further investigations. Furthermore, the coordinates obtained from the two different data series differ by a few centimeters, mainly in the height component, which reflects obviously on the tropospheric delay. The data are still under analysis for a full assessment of this difference and the related uncertainty.

4 Conclusions

The IVS EUR137 24-hour experiment demonstrated the feasibility of using the LIFT optical fiber link to distribute the time from INRIM in Turin to the Medicina Observatory. Some technical issues were encountered when making it possible to observe with both clock standards (local and remote clocks). Problems with the observations done with the remote clocks have been found during the data analysis. A key point is to improve the robustness of the remote clock for extended times. We have planned new experiments for 2016, involving the other INAF antenna in Noto and possibly in coordination with the ASI radio telescope in Matera (ASI), to further test the stability of the system. A newly funded project will possibly extend the fiber link to the Matera geodetic observatory and allow for possible common clock experiments as early as the beginning of 2017. In the future, a fiber-based network of multiple antennas connected to a single clock can be expected. This experiment opens the possibility of replacing the local hydrogen masers at the VLBI sites with optically-synthesized RF signals.

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