The new Time and Frequency Laboratory for the Sardinia Radio Telescope

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Abstract

A time laboratory was established at the Astronomical Observatory of Cagliari more than one century ago, aimed for time-tagging scientific observations. At present, this laboratory is facing up a deep refurbishment in order to cope with the much tighter specifications on phase noise, time resolution, and frequency stability required by the new scientific applications planned for the Sardinia Radio Telescope. As a result of the participation to millimeter Very Long Baseline Interferometry and pulsar timing experiments of SRT, the new Time and Frequency laboratory will be called to provide extremely low phase noise and highly stable frequency references.

1. Introduction

The Sardinia Radio Telescope (SRT) [1-3] is a project managed by Italian National Institute for Astrophysics (INAF) and Italian Space Agency (ASI) characterized by a very large collecting area with a 64-m diameter primary mirror, becoming the largest Italian antenna, and in the top-five list in the World. SRT, is in the final phase of the construction 35 Km North of Cagliari and it is expected to be inaugurated in middle 2011. From a technological point of view, the Sardinia Radio Telescope project consists of a general purpose, fully steerable, wheel-and-track parabolic radio telescope capable to operate with high efficiency in the 0.3 - 115 GHz frequency range. The SRT design has been optimized to reach many different scientific objectives spanning over various disciplines: Radio Astronomy, Geodynamics, Deep Space tracking of interplanetary missions. SRT will make both single dish observations as well as the ones arranged in a connected network mode like the Very Long Baseline Interferometry (VLBI). Then together with the other two Italian radio telescopes located in Medicina (Bologna) and Noto (Siracusa), it will be possible to setup a self consistent, fully Italian, VLBI network.

The main aim of the authors is to connect, in a true meaningful scientific way, the long history of the timing laboratory of the Astronomical Observatory of Cagliari into an updated time and frequency (T&F) configuration suitable to cope with the outstanding research activities planned for SRT. As a matter of fact and in spite of very tight economical constrains, the laboratory has been carefully operated over so many decades, keeping it updated with the most advanced technologies. The instrumentation now available at the laboratory is devoted to time-keeping, serving the Bureau International des Poids et Mesures (BIPM) for the construction of the Coordinated Universal Time (UTC). Looking into the future, we want to extend the past capabilities of the timing laboratory into a new configuration supporting all the new science planned with SRT and asking for quite different requirements in terms of phase noise, time resolution, and frequency stability. We expect soon the delivery of a new hydrogen maser (from T4Science) to be utilized as the master frequency standard of the station and of some other dedicated hardware. We foresee the start of a quite new activity in this field as all the SRT station will move on from its first light configuration stage.

2. Time-keeping activity

Since the foundation of the Astronomical Observatory of Cagliari, at the end of the XIX century, many efforts has been addressed to get the most advanced clocks for the time-tagging of the scientific observations mainly devoted to investigate the polar motion of the Earth [4]. A pendulum clock was used for many decades, then in the sixties the

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laboratory was equipped with a quartz oscillator (TRACOR) and in the seventies with an atomic cesium clock (EBAUCH B-5000). At that time, the time laboratory started to build a local time scale, and to join the BIPM, as a second Italian node of the network (the first node is the Istituto Nazionale Ricerca Metrologica).

Nowadays, the time-keeping activity is maintained with two (a master and a slave) commercial cesium clocks (HP-5071A), characterized by excellent long-term stability which are recording the local time scale almost continuously since 1996. The synchronization to the UTC is provided by the multi-channel, multi-frequency receiver TTS-4 connected to GPS, GLONASS, and GALILEO. The Fig. 1 sketches the differences between the local time and the UTC for the two cesium clocks in the last fifteen years. The dark line shows the time scale generated by the master, UTC(CAO), while the grey one represents the slave. The gaps in the diagram are due to many causes like for example a move in other laboratories or maintenance operations to the cesium tubes or to the GPS receivers. The statistical uncertainty of the master cesium clock computed in the Circular-T, along year 2010, is 1.5 nanosecond, whereas the relative weights in percent (averaged over 2010) assigned by BIPM to Cagliari's clocks are 0.26% for the master and 0.66% for the slave. These data are available in the FTP server of the Time, Frequency and Gravimetry Section of the BIPM website [5].

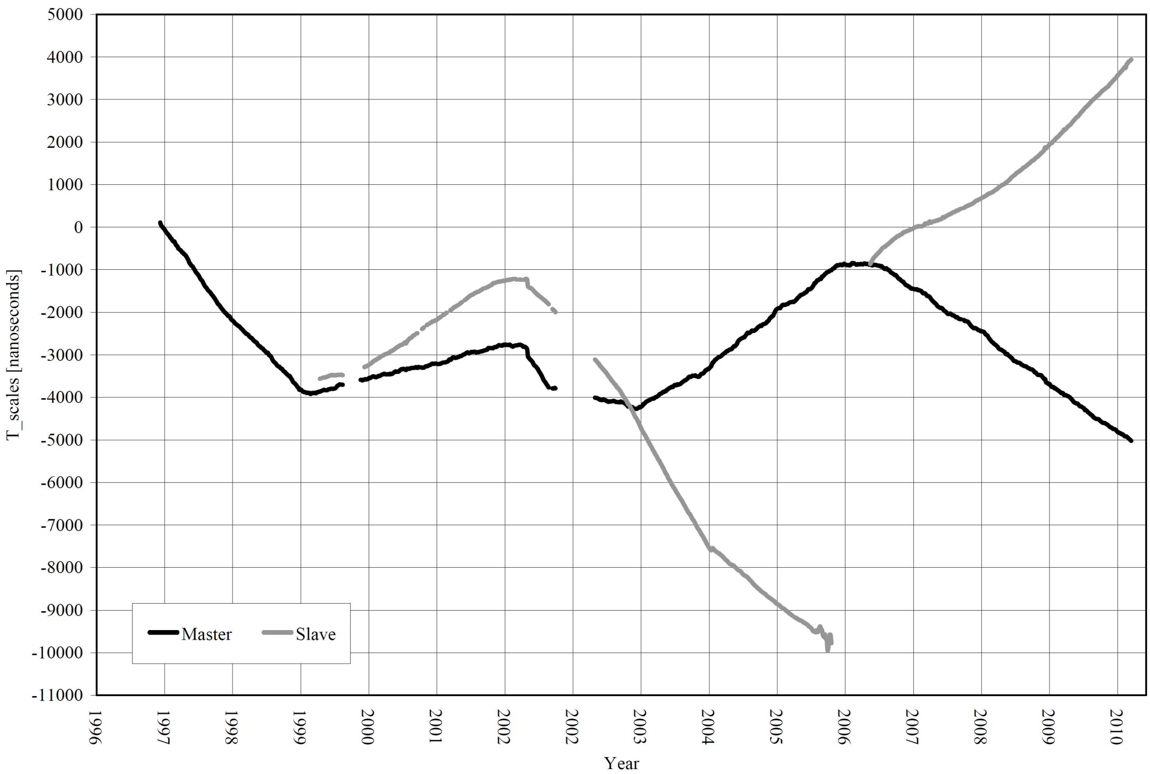

Fig. 1 – Differences between UTC and local time scale computed for the master cesium by BIPM (black curve) and for the slave cesium by an electronic counter (grey curve).

3. The new role of the T&F laboratory within the Sardinia Radio Telescope

VLBI is a well established technique that has applications in Radio Astronomy, Geophysics and even timing. Observatories spread around the World participate to common observing sessions of the same celestial objects over different radio frequency bands. According to the configuration details of the VLBI experiment, from the correlated flux of the interferometric product among the data streams collected at each Observatory, it is possible to extract information on:

- the particular structure of a celestial radio source down to the size of the most compact radio astronomical objects like Active Galactic Nuclei and their jets;

- the three dimensional spatial coordinates of each antenna with respect to an almost perfectly inertial reference frame (made of Quasar radio sources) and then on all the orbital parameters of the Earth considered as a solid body (like polar motion, length of the day, etc.) or its internal deformations (like tectonics movements) that characterize the modern Geophysics;
- and finally an extremely precise comparison among the atomic time scales generated at each site, starting from the local frequency standard.

At present the cross correlation process can be made even in real time having been able to connect the Observatories with very wide band optical fiber links (typically 1 Gb/S), so the expected final information can be delivered not very late after closing an observing session.

Concerning the T&F applications, the needed frequency stability can be extremely high, because such experiments are essentially phase comparisons made up to sky (observed) frequencies of 100 GHz and over integration times of a few hours, let is to say they require Allan Variances of a few parts into 10^{-15} at 1000 seconds. Now only active hydrogen masers can reach this kind of stability with units commercially available at a reasonable cost. Moreover, a SRT backend will be dedicated to the timing of millisecond Pulsars, allowing a more direct comparison with such extremely accurate time references over time scales longer than a year.

SRT, other than a VLBI station in its simplest configuration, will have many more application fields: its active (transmitting) tracking capability of Deep Space spacecraft will open new frontiers in Space Radio Science experiments, with tests of General Relativity, studies of the internal structures or possible atmosphere of the visited planetary objects and many more.

We plan to be able to cross compare all the atomic frequency standards available in the laboratory and also to provide the hardware needed to distribute over all the station the time and frequency reference signals that are suitable to support the various discipline sciences planned for SRT, with the best confidence levels on reliability and performance.

4. The scheme and the instrumentations of the T&F laboratory

In the next months, it is planned to move the T&F laboratory currently installed in the headquarter of the Astronomical Observatory of Cagliari (Lat. 39d 8m 9s N - Long. 8d 58m 22s) to the SRT's site (Lat. 39d 29m 50s N - Long. 9d 14m 40s). Currently, we are carefully investigating all the possible strategies available to extract scientific information from such big movement of the T&F laboratory.

At the SRT site, the T&F laboratory will be placed in a new building where many modern technical solutions have been taken in order to create the right environment to preserve as much as possible the performance of the resonators. For example the atomic resonators (rubidium, hydrogen maser, and cesium) will be placed in a dedicated thermo-controlled room with a tight maximum thermal gradient allowed equal to 0.1 °C. Additionally, the hydrogen maser will be supported by a special anti-vibration basement.

The hydrogen maser will provide two frequency signals (5 and 10 MHz, later on when 100 GHz observations will start, also the 100 MHz will transmitted to the receivers), the 1 PPS and the IRIG code. Due to the large distance between the antenna and the laboratory, the signals are routed via fiber optics to the antenna. Specific attention has been addressed to identify the appropriate electrical-optics transceivers. As a matter of fact, several electronic instrumentations (for instance time interval counters and phase noise analyzer) are available within the laboratory for the characterization and the test of any devices related to time and frequency. In particular a new double conversion system with a third offset oscillator will allow to make Allan variance and phase noise measurements of any couple of atomic standards both with digital counters or in the analog configuration we have implemented long time ago [6].

Even if VLBI does not strictly need an hardware synchronization of the local time scale to UTC, we are considering to compensate for the expected drift of the hydrogen maser with respect to the local time UTC(CAO). The BNC 575 digital delay unit, with its 250 ps resolution, will be very well suitable to accomplish this task, under the automatic control of a custom program running on a computer. Future activity will prove what is the best strategy for all the user needs.

Finally, the Fig. 2 contains the general scheme of the T&F laboratory where main electronic equipments and connections are reported.

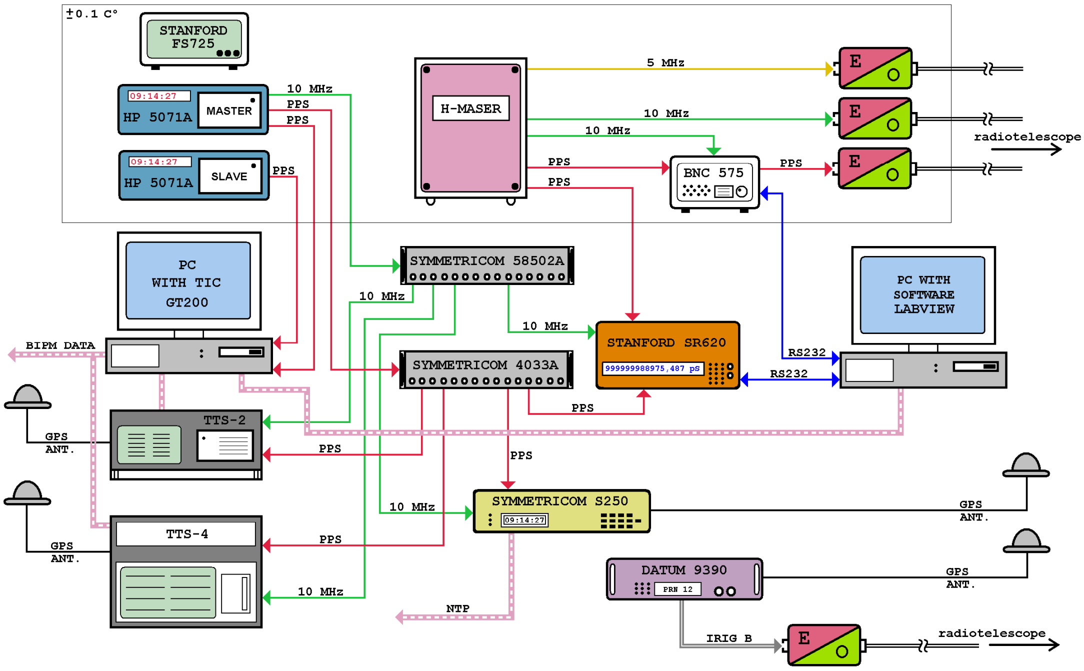

Fig. 2 – Schematic layout of the main equipments available at the T&F laboratory including both atomic resonators and ancillary devices.

5. References

1. http://www.srt.inaf.it/.

2. G. Grueff et al., "Sardinia Radio Telescope: the new Italian project," *Proceedings of SPIE Ground-based Telescopes*, Glasgow (UK), 2004, vol. 5489.

3. G. Tofani et al., "Status of the Sardinia Radio Telescope Project," *Proceedings of SPIE Ground-based and Airborne Telescopes II*, Marseille (FR), 2008, vol. 7012.

4. H. Enslin, E. Proverbio, "Time Determination, Dissemination and Synchronization," *Proceedings of the Second Cagliari International Meeting*, Cagliari (IT), 3-6 June 1974. Edited by H. Enslin, E. Proverbio: 3T Edizioni anastatiche, 1975.

5. http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication

6. R. Ambrosini, M. Caporaloni, "A simple and versatile phase comparison method can accurately measure long term instability," *IEEE-Transactions on Instrumentation and Measurements*, IM-37, 127 (1988).