RISE Research Institutes of Sweden

Report on Activities to the 21th meeting of the Consultative Committee for Time and Frequency, June 2017

SP is now RISE – Research Institutes of Sweden

The RISE institutes Innventia, SP, and Swedish ICT have merged in order to become a stronger research and innovation partner. The process of creating the new RISE will take place gradually over the course of the years to come, but in the beginning of 2017 the three institutes have all change their name to RISE and the head office been located in Gothenburg, Sweden. The new RISE is organized in six divisions. The NMI with the national metrology laboratories, including Time and Frequency, is part of the RISE Safety and Transport division and the Measurement Science and Technology unit and located as before in the city of Borås, Sweden. The national time scale of Sweden UTC(SP) will keep its name.

1. Staff

The staff involved in time and frequency work at RISE is about 4-5 persons. The work includes time and frequency generation and dissemination, calibration, knowledge transfer and research as well as positioning, navigation, and atmospheric research using GNSS.

2. Clocks for TAI

RISE presently contributes to TAI with up to 28 clocks (19 CS and 9 HM) maintained at four different locations in Sweden. 6 clocks (4 CS and 2 HM) are located at the National time and frequency laboratory at RISE in Borås (about 60 km inland from Gothenburg on the west-coast) were UTC(SP) is maintained. 8 clocks (6 CS and 2 HM) are located at the RISE underground location in Stockholm [1] (about 450 km north-easts of Borås). 3 clocks (1 CS and 2 HM) are located at the Onsala Space Observatory, Onsala (about 60 km south-west of Borås) and the remaining 11 clocks (8 CS and 3 HM) are located at STUPI AB, a clock facility in Stockholm. The clocks located at the three remote sites are linked to UTC(SP) using GNSS code observations. All 28 clocks are supporting the rapid UTC time scale.

3. Time Scales

UTC(SP) is a real-time time scale and defined at the output connectors of an auxiliary output generator (AOG) that is phase-locked to a 5-MHz signal from one of the local clocks in Borås, usually a hydrogen maser. The output is steered so that the time and frequency offset between UTC(SP) and UTC are minimized. Besides UTC(SP), alternative time scales are maintained at the other Swedish clock facilities and laboratories. Different steering methods are available and used for the steering of the time scales:

1. A Kalman filter-based algorithm [2, 3], using clock differences of all available clocks (local and remote), estimates in real time the frequency offset and frequency drift relative to TAI of, in particular, the reference clock. UTC- and UTCr-data are used when available, after the fact, to update the clock states for more accurate steering.

Figure 1: RISE underground clock facility in Stockholm. Upper left picture presents the front wall of EMP protected building inside the cavern and the picture below presents a view of the inside of the underground plant with two identical time and frequency laboratories, separated by a wall with a window, both equipped with same amount of clocks, GNSS receiver and other timing instruments. The upper middle picture presents the outer compartment used for supply systems like climate and power. Electrical power is connected through shielded ducts and metallic leads penetrating the EM-shield are equipped with filters. (lower right picture). Each lab (lower left and lower middle picture) is climate regulated by redundant coolers and a central dehumidifier. DC UPS systems for distribution of 24V and 48V with battery capacities for > 1 hour of sustaining the operation of vital equipment (upper right picture).

2. If the reference clock has a very good short term stability and well predictable frequency drift, such as a HM, a small frequency adjustment applied to the AOG several times a day in order to compensate for the frequency drift may be used. A frequency offset adjustment is applied only when needed.
3. For many of the remote, alternative times scales, a simple daily frequency adjustment is made based on the calculated difference between UTC(SP) and the local time scales.

4. Remote Time and Frequency Comparisons

4.1. GNSS

RISE operates several GNSS receivers capable of producing both code- and carrier phase observables. GPS and GLONASS data (CGGTTS and RINEX) from two receivers (SP01 and SP02) synchronized to UTC(SP) are sent to the BIPM on a daily basis, thus supporting with GPS data also the rapid UTC time scale. Software provided by Pascale Defraigne of ORB [4] is presently used to calculate the CGGTTS-formatted data. The GPS-link of the receivers was relatively calibrated in a campaign among European laboratories in 2016 [5]. Other receivers installed in the laboratory, capable of observing in addition Galileo and Beidou satellites are presently evaluated (see also paragraph 7.9 below).

Figure 2: RISE roof-top installation with TWSTFT-antenna and GNSS antennas in the background (picture to left). RISE main GNSS antennas on a concreate pillar and a metal framework construction (picture to right). The main antennas and connected receivers are part of the IGS- and SWEPOS GNSS network. The antenna cables for the main antennas are temperature-stabilized using a water-pipe construction. The main time and frequency GNSS receivers (SP01 and SP02) are connected to the concreate pillar antenna.

4.2. TWSTFT

RISE operates since 2003 a TWSTFT-station that in combination with GPS carrier-phase data (i.e. TWGPPP) is the main time transfer link for RISE to UTC. TW-data are sent on a daily basis to the BIPM. The station was calibrated in a campaign among European laboratories using a mobile TW-station in 2016 [6].

5. Time Dissemination

5.1. NTP

RISE operates several local NTP servers [7] referenced to UTC(SP) for both IPv4 and IPv6, two at the facilities in Borås and two at the underground facility in Stockholm. RISE provides in a similar way an authenticated NTP-service that uses NTPv4 autokey. Besides the NTP servers at the RISE facilities, four traceable NTP nodes [8] with a total of 8 servers are established at Swedish national exchange points for Internet traffic. Those nodes are securely placed within mined spaces below the ground and are considered critical infrastructure. The system's timing is sustained by local time scales based on 2 CS clocks in each facility. The time scales are linked and compared on a daily basis to UTC(SP) using GNSS time transfer.

5.2. Time code via telephone modem

From RISE there is still a modem service available that serves UTC(SP) as European time code with latency estimation.

5.3. Speaking clock

A speaking clock service is distributed by TeliaSonera where RISE provides, in Borås, a system with traceable synchronization and speech synthesis.

5.4. Local 10-MHz reference distribution via fibre

RISE is responsible for maintaining 16 SI units (of the 17 within Sweden), and the realization of many of these requires an accurate and stable frequency signal. Furthermore, several testing and calibration facilities at RISE need traceable frequency for their accredited measurements. From the time and frequency laboratory, there are fibre optical connections used for disseminating a 10-MHz reference signal to these laboratories including among them the voltage primary standard laboratory and length and dimension laboratory.

6. Geodetic GNSS station

The time and frequency laboratory has several GNSS antenna systems available. The main antenna is placed on top of a concrete pillar and connected via a power splitter to several receivers in the laboratory. One of these receivers, SPT0, is a part of the IGS network as well as SWEPOS (a Swedish reference network of permanent GNSS stations). SWEPOS (www.swepos.se) is used in a number of applications. Among them the study of land uplift in Sweden (Onsala Space Observatory) as well as real time kinematic (RTK) positioning at the centimetre level (National Land Survey of Sweden). Time and frequency applications take advantage of a system implemented for antenna- and antenna cable temperature control.

7. Research and Development

RISE is presently active in the following areas:

7.1. Distributed Time Scale Algorithm

Today, the distribution of atomic clocks in Sweden includes about eight sites with similar timescale equipment for the realization of time scales steered to UTC. Of these, four core sites realize UTC(SP), which in principle act as distribution points for traceable common Swedish time and frequency. Further, several other sites, such as hosted by industrial partners, can provide clock data using time comparison with for instance GNSS. An ensemble time scale algorithm, which includes all available clocks at the different sites has been developed and tested. It is based on Kalman filtering, which allows estimating each clock's phase, frequency and frequency drift relative to UTC. In order to improve the robustness, link combination has been included into the time scale generation. Different link types can be used to redundantly link all the sites together, where one link is expected to carry the site to site calibration [9,10].

7.2. Passive Utilization of TWSTFT

TWSTFT is an active method that is restricted in the number concurrent users. In order to extend the use of TW to other users a common clock method has been developed [11]. Rx only stations can compare their local clocks by observing the same signals that are transmitted by the active network. The active network also provides time series of estimates of pseudo ranges from passive stations to the satellites that are necessary to correct the common clock observations. Orbit determination is based on the measurements of the active network and provides an extended Kepler model. Methods have been developed in order to detect orbit manoeuvres. Research has so far concentrated on a post processing method that allows the utilization of common clock measurements for increasing the number of measurements between the NMIs by possibly reducing the concurrent number of signals in space. The real potential of the method is however the possibility to use TW signals for real-time time transfer

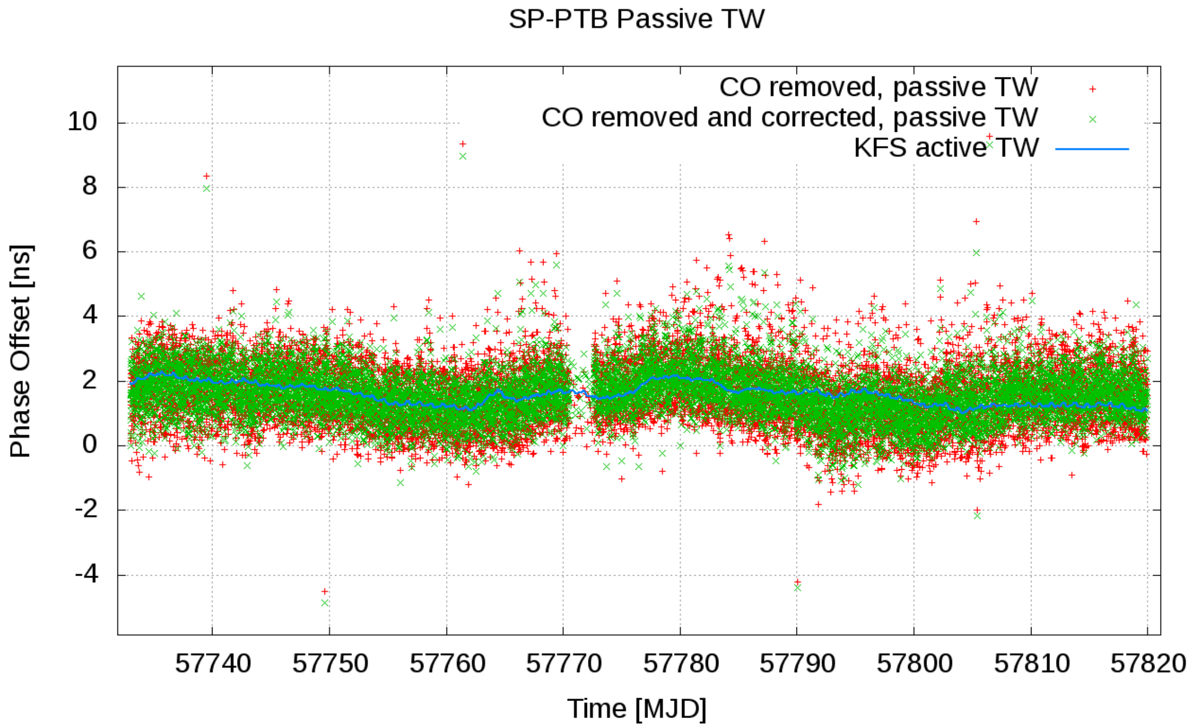

Figure 3: Example of time transfer by passively utilizing common clock TWSTFT measurements. The graph shows the time difference between UTC(SP) and UTC(PTB) for about 90 days between December 2016 and March 2017. The blue solid trace is the Kalman filtered version of the active TWSTFT link as estimated from the ITU data published at the BIPM. It is the best estimate for the time offset of the times scales between both institutes, with an uncertainty of about 1.0 ns. Common clock measurements were achieved by following the PTB schedule at one of the receiver channels at SP. The common clock difference between the observations at SP and PTB are mainly the sum of the clock difference, the geometric difference to the antenna phase center at the geostationary satellite T11-N, and numerous differential delays caused by the atmosphere and tides on the solid Earth. The latter can be corrected to a high degree by modeling using ground based environmental measurements. The geometric difference however, is varying largely due to diurnal satellite motion and has to be estimated using orbit determination. For each observation epoch create an extended Kepler orbit descriptions that is able to describe and predict the motion of the satellite. For this the regular measurements of the active European TWSTFT network are used. The common clock differences, reduced by geometry, atmospheric delays and an arbitrary calibration offset (CO), are shown as red points in the graph. Depending on the source of the common clock an additional individual bias of up to one nanosecond are present in the passive solution. We assume that such biases are caused by code interference and are a feature of the SATRE modem used by all stations. Estimating and removing these biases result in the green points show in the graph. Typical differences to the filtered active solution are below 1 ns RMS.

between an unlimited number of users outside the active network and as a mean to resiliently distribute UTC(k) realizations.

7.3. Realization of a Traceable multichannel 50 Hz Voltage and Current Reference for Phasor Measurement Units (PMU) Calibration in Power Grid Applications

Synchronized phasor measurements are dependent on a common time base, such a UTC, which typically is realized using GNSS to a sufficient level of accuracy. However, the absolute calibration of internal delays of PMUs is not trivial, because the difference of the characteristics and the frequency between the electrical signals measured at 50 or 60 Hz and the signals (10 MHz, 1PPS) used to trace time and frequency to UTC. Research is underway to bridge both signal domains by using direct sampling and generation of waveforms and waveform analysis. The overall goal is to reach phase angle uncertainties below 100 ns for the low frequency reference signals and to provide a calibration facility for PMUs.

7.4. Very long baseline interferometry (VLBI)

RISE time and frequency group cooperates with the geodesy group at the Onsala Space Observatory (OSO). A major space geodetic technique at the Onsala site is VLBI, which is among other things is used for the rapid determination of earth orientation parameters (EOP). As VLBI is a delay measurement system, clock comparisons were an early application of it, but the complexity of the system and the experimental use is in general unpractical for continuous time comparisons. During recent years and with the ambition of the Global Geodetic Observation System (GGOS), VLBI has seen a renaissance as a technique and its use for precision intercontinental time and frequency comparisons is again a viable option. RISE has been involved in using VLBI measurements for time and frequency transfer applications. We are working towards a real-time method of VLBI observations using state space filtering. This combines well with rapid EOP work done at OSO and the ambition of VGOS (V for VLBI), which is being implemented at the site with two new telescopes. In the future, VGOS will provide real-time measurements, which can be used to provide time and frequency transfer at unpreceded levels of precision.

7.5. Authenticated NTP and traceability

RISE continuous to work on research regarding the improvement of NTP, its authentication and robustness. The RISE NTP server park is based on a denial of service proof design at 10 Gbit/s Ethernet that allows replying to all received valid NTP packets. The timing design makes it possible to trace all individual packets to the UTC(SP) as they are transmitted to the network. The traceability of time of events is an important issue for many applications and is for instance regulated for the European finance sector. Research is ongoing to achieve appropriated dissemination of UTC(SP) close to concerned users and achieve traceability. Remote NTP service traceability was developed and is implemented for several clients [12].

7.6. White Rabbit (WR)

White Rabbit is a fruitful combination of IEEE1588 (PTP) and SyncE, and is today the most mature method for time and frequency transfer using IP technologies and optical fibre networks. The design is optimal for campus networks and works well on distances of a few kilometres that support the original topology of White Rabbit. Longer baselines needed for (inter)national time transfer need adaption of the transmission paths, which is reducing the accuracy of the method. RISE is working on establishing local links using WR and is researching the characteristics of WR time transfer in none optimal transmissions paths, such as WDM networks with dispersion compensation. Modelling of errors sources is a possible way to compensate for the non-reciprocal delay changes. We are also in the progress of investigating the possibilities of application of WR in coherent networks, such as the new Swedish NREN Sunet-C.

7.7. One-way fibre frequency transfer with real-time correction

The technique using one-way broadcasting of frequency over two wavelengths, with real-time post-compensation of phase variations at the receiver, has been evaluated and improved since its first publication 2009 [13,14,15]. The technique has been awarded a Swedish patent in 2011, and approved for US and European patents in 2013 [16].

7.8. Two-way coherent frequency transfer in a commercial DWDM communication network

A nationwide fibre optic communication network utilizing state-of-the-art technologies with data modulation both in the polarization and in multi-level amplitude and phase is being deployed in Sweden. Since there is a limited amount of clients connected to the network, each client will be assigned a personal wavelength. With a network that is all-optical through an advanced utilization of dynamically reconfigurable optical add and drop multiplexers, each wavelength can theoretically be connected to any other client within the network, enabling broadcasting on allocated wavelengths. The coherent modulation formats also enables signal recovery through electronic digital signal processing after detection, and no optical dispersion compensation is thereby installed. This new network scheme enables a brand new implementation of frequency and time dissemination in the network. These optical add-drop installations allow for future efficient frequency and time signal broadcasting from reference nodes operated by distributors such as RISE to users connected to the network.

Time and frequency transfer in the new network is using a two-way scheme [17], but a major improvement compared to coherent frequency transfers in previous network [18,19,20] is that there are no needs for Dispersion Compensation Fibres (DCF), since the network is fully coherent and utilizes phase modulation. An experimental fibre connection is established between RISE in Borås and Chalmers University of Technology (Chalmers) in Gothenburg. The one way fibre length is about 60 km and implemented in SUNET (Swedish University Computer Network). The aim of the system is to providing the ability to distribute monitored ultra-stable frequency with a future traceability to UTC(SP) to multiple users within the network. The time and frequency laboratory at RISE is using an optical frequency comb and an ultra-stable laser as backbone for this method. The performance of the laser is unique in Sweden and several end-users would benefit from access to this type of equipment in their areas of research.

7.9. GNSS software

Prototype software for providing GNSS link data in the CGGTTS format has been developed at RISE, with the aim of supporting commercial undertakings. It takes as input observational data in RINEX version 2 and 3 formats. At present the systems GPS, GLONASS, Galileo, and Beidou are handled.

We have also developed software for manipulating the content of the RINEX files. The observational data are adjusted to mimic the reception at an alternative position, but still producing the same clock data solution as the original file. The software is useful e.g. for costumers not wanting to reveal their antenna positions, but still contributing with observational timing data. Another feature of the software is the possibility to alter the clock reference in the RINEX files, which is useful for referencing the RINEX underlying clock data directly to a national reference instead of to the reference clock of the receiver.

7.10. Other GNSS applications: Positioning, Navigation, and Atmosphere

Research and development in a wide range of GNSS applications is carried out at RISE. One area with special attention during the last years has been the influence of the observations from the receiving antennas and their near-field environment. Studies in this field are presently carried out together with the National Land Survey of Sweden and the Onsala Space Observatory [21,22]. The assessments are primarily focused on geodetic and atmospheric applications, but carrier phase time and frequency transfer will also benefit from the updated antenna models derived.

The current road transport system has problems with safety, efficiency and size. Future ITS (Intelligent Transportation Systems), where vehicular communication systems, including GNSS data, play a key role, are envisioned to alleviate these problems and allow for a safer and more efficient coordination of vehicles. Information about RISE latest research within this area can be found here [23,24].

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