VNIIFTRI, RUSSIA

Time and Frequency activity at the VNIIFTRI

Thermal beam magnetic state selector primary Cs standard

The time unit - the second - was legally realized during 2009-2011in Russian Federation basing on classical thermal beam magnetic state selector primary CS 102 standard. Since last CCTF meeting no considerable changes have happened in it's physical package and electronics. No efforts were applied to improve instrument.

So instrument operated more or less reliably and produced more few tenth determination of the unperturbed Cs frequency transition each year. The uncertainty type B for the instrument is estimated as $u_B \leq 3\times10^{-14}$. The average time unit difference between TAI and CS 102 for the period of 2009 - 2011 was about $(1\pm4)\times 10^{-15}$.

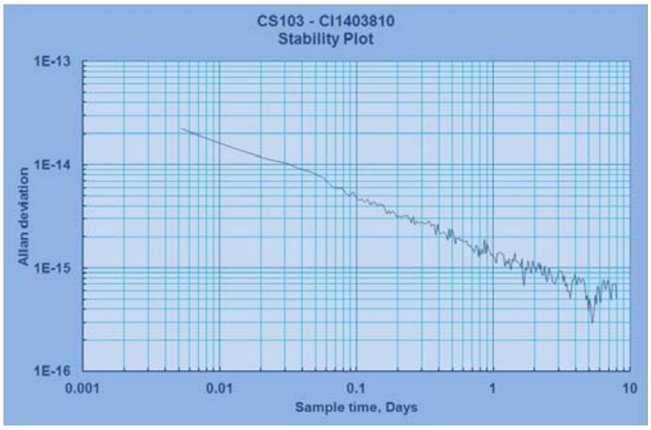
Investigations and status of fountain primary Cs standards.

The main efforts during 2009 – 2011 years have been concentrated on development and investigation of two fountain primary Cs standards. Today in new laboratory building in thermo controlled rooms we have two standards: CS 103 and CS 105 general view of which is depicted below.

CS 105

CS 103

At the end of the project in 2011 an accuracy of CS 103 was evaluated as 4.8×10^{-16}. But later for practical purpose we doubled the number of low density atoms. So at present CS 103 errors budget is evaluated as 6×10^{-16}. At present state the accuracy of CS 105 is evaluated as 1×10^{-15}. Our recent comparison of SI time unit reproduced by CS 103 during MJD 56104-56139 relative to that published in Circular T 295 coincided within $(8\pm7)\times10^{-16}$.



The following picture presents Allan frequency deviation of Cs 103 relative to H-maser clock # 1403810 measured for the same period.

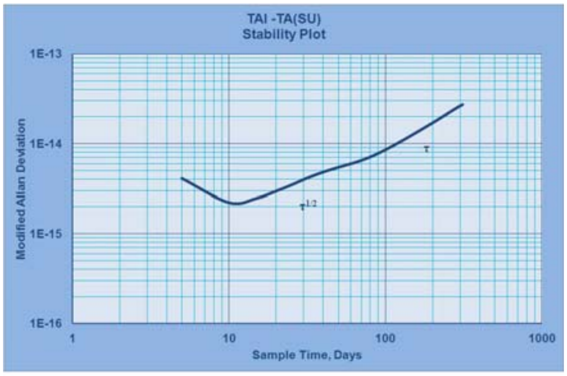
UTC(SU) time scale maintenance

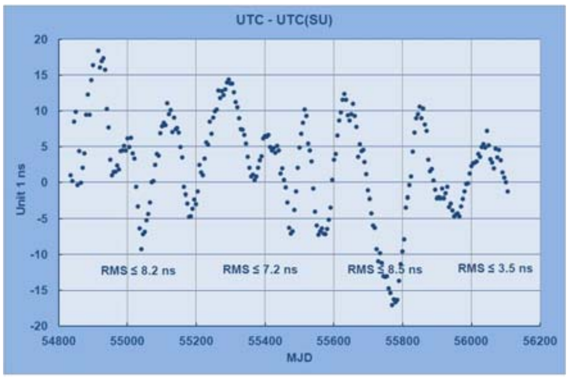
The mainframe of time keeping instrumentation consists of H-maser ensemble. During 2009-2011 no considerable changes have happened in time keeping instruments - usual maintenance of H-maser's and inter comparison technique. Two time scales: coordinated UTC(SU) steered to UTC and free running TA(SU) continued to generate in conformity with algorithm introduced on MJD 53369 (30 DEC 2004).

Because of TA(SU) have been based purely on free ensemble of H-masers clock ensemble manifested inevitable residual frequency drift. Despite this frequency instability of TA(SU) as compared to TAI $\sigma_y(\tau)$ 2-4$\times10^{-15}$ $10 \le \tau \le 30$ days.

UTC(SU) time scale have been steered to UTC at one month basis with RMS difference UTC-UTC(SU) $\le$ 7-8 ns at least for last five years.

Two following pictures demonstrate the above mentioned features.



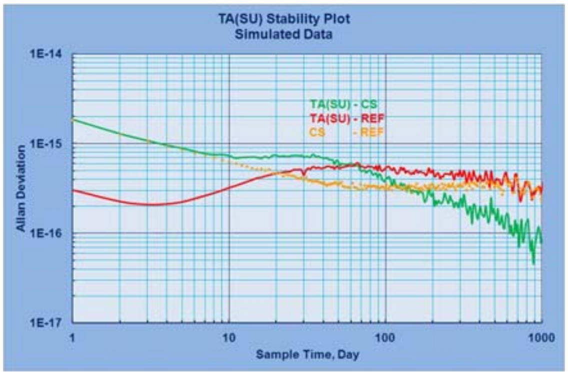


Implementation of two primary caesium fountain standards with uncertainty comparable to long term stability of the clock ensemble into operational instrumentation complex of VNIIFTRI time laboratory in 2012 drastically changed possibilities for time algorithm to maintain atomic time scale TA(SU) and coordinated time scale UTC(SU).

The new time algorithm and a proper software have been developed. The main principles realized in the time algorithm:

- keeping of the time unit reproduced by primary VNIIFTRI caesium fountain standards is realized by continuously operating H-maser ensemble;
- the time unit in TA(SU) corresponds to that reproduced by primary caesium fountain standards CS 103 and CS 105;
- atomic time scale TA(SU) is autonomous and independent;
- the national scale of coordinated time UTC(SU) is referred to TA(SU) as a high stable source and by frequency steering corrections based on Key Comparison CCTF-K001.UTC data realizes time steering to UTC.
- time constant in algorithm is one month for estimation clock rates relative to caesium fountain standards - TA(SU) maintenance, and one month for estimation of time difference (UTC – UTC(SU)) - UTC(SU) steering procedure.

The algorithm and software have been tested basing on simulated data. Statistical properties of simulated data were in compliance to real that of participating H-masers, caesium fountain standards, UTC, and operational time link. All stimulated data have been referred to ideal reference frame – REF. Brief results of tests are presented below.

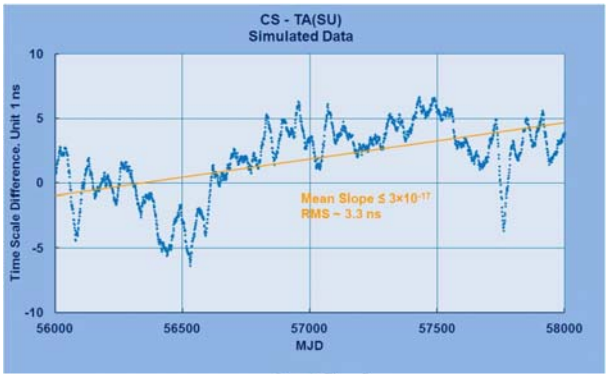


Because of at moment of test we have no reliable data on caesium fountain standards flicker floor level we've introduced this as $\sigma_y(\tau)$ 3×10^{-16}.

"Short" term stability (1 – 3 days) of TA(SU) - REF is determined by intrinsic H-masers instability and statistical averaging over ensemble. This result have been obtained by subtracting clocks frequency drift based on drift prediction for two previous months H-maser's comparison across caesium fountain standards.

Then there is a bump at about one month which is in conformity to automatic frequency control theory and used value of time constant 1 month. For much more greater times stability estimations of TA(SU) - REF and CS - REF coincide and reach caesium fountain standards flicker floor level.

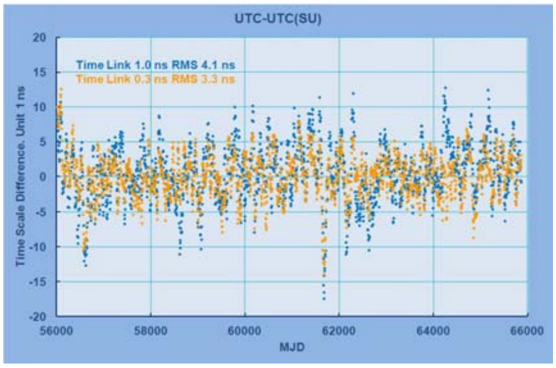
Stability estimations TA(SU) - CS for short time is limited by caesium fountain standards stability itself, has an above mentioned bump at 1 month and for greater sample times demonstrate TA(SU) steering features relative to CS. In any case time algorithm stability analysis based on simulated data enables to expect marked improvement in TA(SU) stability up to level considerably better than $\sigma_y(\tau)$ 1×10^{-15}.



For task of this investigation one may treat CS as a clock and calculate time difference TA(SU) and CS. This demonstrate TA(SU) - CS steering ability RMS $\leq$ 3 ns. On other hand averaged TA(SU) and CS time unit difference $\leq 3\times10^{-17}$. The latter result demonstrates TA(SU) ability to keep time unit reproduced by primary caesium fountain standards without any degradation at least at level of stated CS 103 $u_B \leq 5\times10^{-16}$.

The other result of tests is UTC – UTC(SU) time difference. For this purpose we first of all stimulated REF – UTC sequence basing on the following assumptions:

- UTC based on TAI, which by turn on EAL;
- current EAL stability is defined in Circular T;
- for sample times more than 30 days TAI stability exceeded that of EAL due to steering corrections and manifested stability level about $(1\text{-}2)\times10^{-16}$;
- UTC(SU) link uncertainty u_A to UTC is currently limited by 1 ns, and in future in case of TWSTFT link by ~0.3 ns.



Basing on these assumption we simulated REF – UTC data and then generated UTC(SU) basing on time differences between these time scales. Steering frequency corrections have been applied every month in conformity to BIPM Time Section publication to produce UTC(SU).

As a result we got two estimations of RMS difference UTC – UTC(SU). The first for current link with u_A uncertainty 1 ns gives RMS ~ 4.1 ns (blue) and the second for link uncertainty 0.3 ns gives RMS ~ 3.3 ns (yellow).

The budget of the latter result consists of about 2 ns time error gained by TA(SU) during 1 month, time link contribution and UTC time errors. Perhaps further improvement may be achieved after establishing rapid UTC as legal mean.

Time transfer

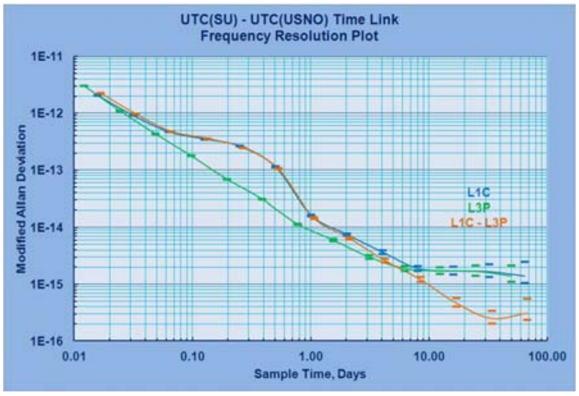
Till now operational time transfer link is based on GNSS signals. Our equipment consists of set GNSS receivers of TTS3 and TTS4 type. Perhaps the most interesting result of last year was estimation of u_A uncertainty for long range time link between our laboratory SU and USNO.

This estimation have been done basing on readings SU TTS3#26 receiver (GPS C/A and P3) and USNO AOS SRC TTS-2 #014 (GPS C/A) and ASHTECH Z-XII3T #RT920012203 (GPS P3). Then we calculate second difference

{[UTC(SU)-GPSST]-UTC(USNO)-GPSST]}$_{C/A}$

- {[UTC(SU)-GPSST]-UTC(USNO)-GPSST]}$_{P3}$

In this way we've eliminated influence of UTC(SU) – UTC(USNO) variation for big sample time. The obvious manifestation of this limitation is coincidence of C/A and P3 link resolution (green and blue curve) for sample time more than 10 days. The rest difference contains only noises in both time links.

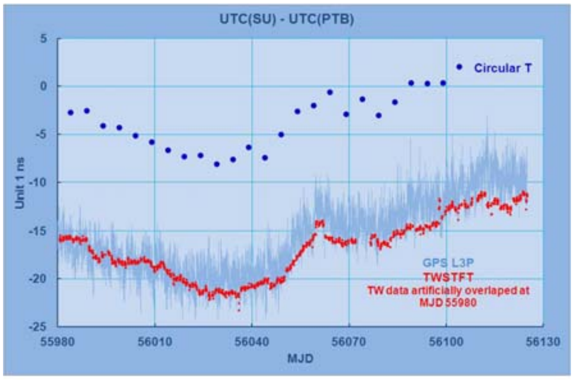


C/A – P3 difference demonstrate u_A frequency comparison uncertainty considerably less than 1×10^{-15}. Such a resolution level open the door for frequency comparisons CS 103 and CS 105 fountain standards with remote ones.

The other very important result is TWSTFT activity. At present we have in our disposal two stations: one stationary and one transportable. Both stations experi-

mentally operate since beginning 2012.

Experimental sessions with PTB and Far East, and South East laboratories continues more than half a year via AM2 satellite. Due to AM2 limitations only about ten sessions per day is now available. A sample of time scale comparison between VNIIFTRI and PTB using operational GNSS and experimental TWSTFT is presented below. At the moment TWSTFT data from VNIIFTRI is referred to not to UTC(SU) but to UTC(SU) Master Clock. According to specification RMS difference UTC(SU)-UTC(SU) MC does not exceed 1-2 ns.



Till now this link is not calibrated and can't be used to contribute to TAI to full extend. This is the most urgent need especially keeping in mind much more better u_A uncertainty for TWSTFT link compare to GNSS one. Nevertheless even now with existing status this link may be used for primary CS standard frequency comparison.

One more important result is experimental TWSTFT transportable station calibration trip to St. Petersburg. Within this trip three types of instruments have been involved: portable hydrogen clock, GNSS receivers and TWSTFT transportable stations. Detailed presentation will be delivered at TWSTFT WG meeting.

Changes in secondary time keeping laboratories

At present three of four state secondary time laboratories under supervision of Federal Agency on Technical Regulating and Metrology (former Gosstandard) have become branches of

VNIIFTRI. They are time laboratories in Irkutsk, Khabarovsk and Petropavlovsk at Kamchatka peninsula. SNIIM - Institute in Novosibirsk is still self-governed.

All four laboratories during last three years have been considerably updated including main time keeping instruments (4 modern H-masers type of CH1-75A, the same as in VNI-IFTRI), time and frequency clock intercomparison system (time resolution 20 ps single shot and frequency resolution $\leq 1\times10^{-16}$ for averaging time 1 day), modern GNSS time transfer system based on TTS3 and TTS4. TWSTFT stationary station have been bought for Khabarovsk time laboratory but not installed till now. Time keeping and measuring instrumentations in all locations are installed in temperature and humidity controlled chambers and are under metrology investigations.

GLONASS future

New federal program GLONASS have been adopted for the period of 2012-2020. Within this program will be:

- regularly replenished satellite constellations;
- arranged geostationary satellite segment;
- introduced new frequency bands, CDMA along with existing FDMA;
- improved accuracy of navigation solution in Russian geocentric geodetic system including time solution;
- improved coordination of the GLO system time to UTC(SU) and UTC(SU) itself to UTC;
- improved accuracy of Russian geodetic system and its conformity to ITRF;
- improved the Earth orientation parameters and ephemeris in the Solar system;

Concerning Resolution 1 24 CGPM

VNIIFTRI time division support in whole Resolution 1 of 24 CGPM. Forty five years of nonstop progress since adoption by 13 CGPM in 1967 of the new definition of the SI time unit – the second, and about thirty years since adoption by 17 CGPM in 1983 of the new definition of the SI length unit – the meter, successfully demonstrate beneficial of SI base units defined in terms of the invariants of nature − the fundamental physical constants or properties of atoms. VNIIFTRI consider this Resolution will enhance influence of the SI time unit – the second to other SI base units and will promote further advances in time and frequency metrology and associated areas.