**CCTF/06**

**Institute of Metrology for Time and Space**

**FGUP "VNIIFTRI", Russia**

**Time and Frequency activity at the IMVP FGUP "VNIIFTRI"**

Thermal beam magnetic state selector primary Cs standard

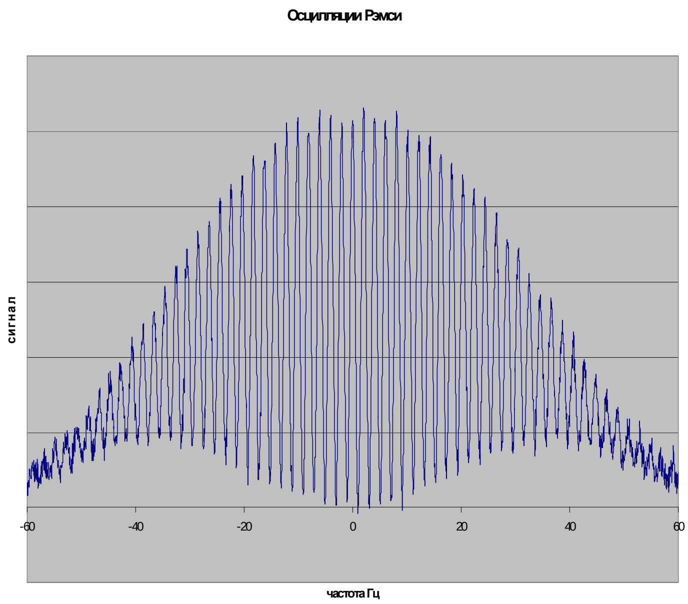
The time unit - the second - is still legally realised in Russian Federation basing on classical thermal beam magnetic state selector primary CS 102 standard. Since last CCTF meeting no considerable changes have happened in it's physical package and electronics. No considerable efforts are applied to improve instrument. More over all resources have been directed to the development new fountain primary Cs standard.

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 relative difference between TAI and CS 102 for the period of 2004 - 2005 is about $(1.4\pm1.9)\times10^{-14}$.

Investigations on fountain primary Cs standard

At present we have almost completed the work with an experimental set-up for studying the processes of atom cooling and movement control. Almost all stages of fountain work were investigated. A microwave frequency synthesizer based specially designed active H-maser was developed. We can control the frequency, the power and the phase of the probing signal, while atomic cloud moves up and down. H-maser has a power about $(3\text{-}5)\times10^{-12}$ W. The same kind second frequency synthesizer is manufactured to study probing signal noise. Because of the lack of space for detection in our experimental setup we detect atoms in the state F=4 only. In order to see the microwave interaction in the process of launching atoms are transferred in the state F=3 and we can see the appearance of atoms in the state F=4 as a result of microwave action. The details of the experimental setup and results are presented in [1].

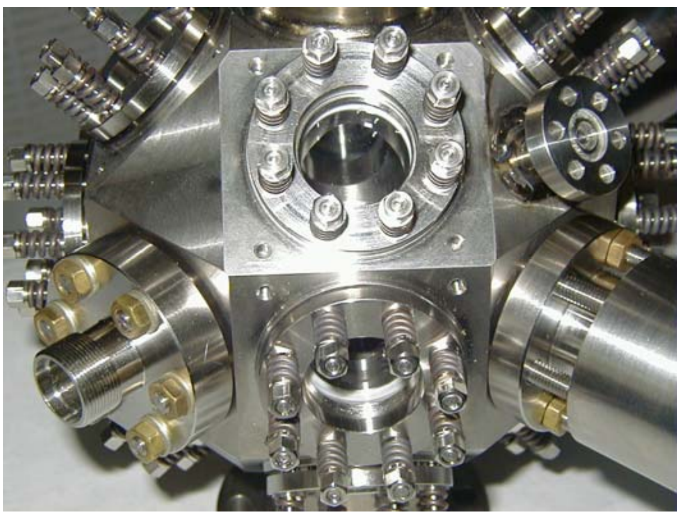
Experimentally and theoretically different kinds of optical pumping were investigated. It was found, that we may increase the number of atoms 2 time in the state F=3, m=0 if we submerge atoms to radiation F3↔F’2 with a transverse polarization while atoms are moving up in the detection region. If we apply F3 ↔ F’3 radiation with vertical polarization we also can double the number of atoms in the state F=3, m=0. At the same time all the other state atoms are removed [2].



Ramsey fringe. The width of the lobe is 1 Hz.

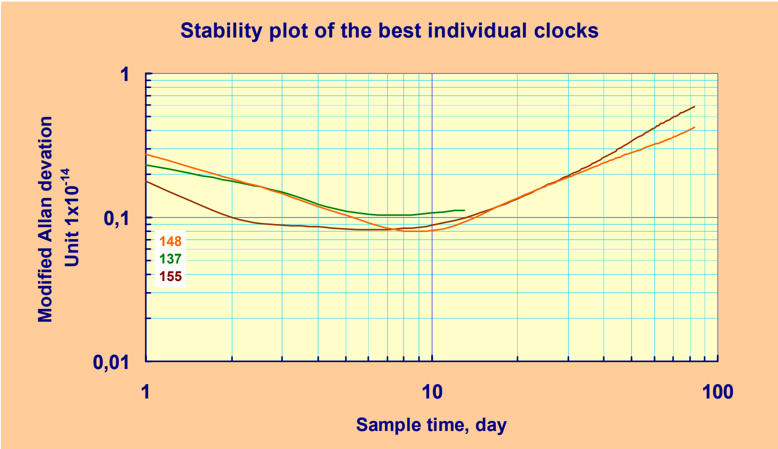
On the attached figure the Ramsey fringe with one detector scheme is presented. We estimated the potential accuracy of an experimental setup as $8\times10^{-15}$.

This year the project of building the primary frequency standard of the fountain type was approved. It is planned that it start an operation to the end of the next year. Almost all the components of a vacuum system is manufactured now. On the next picture the molasses section is presented.

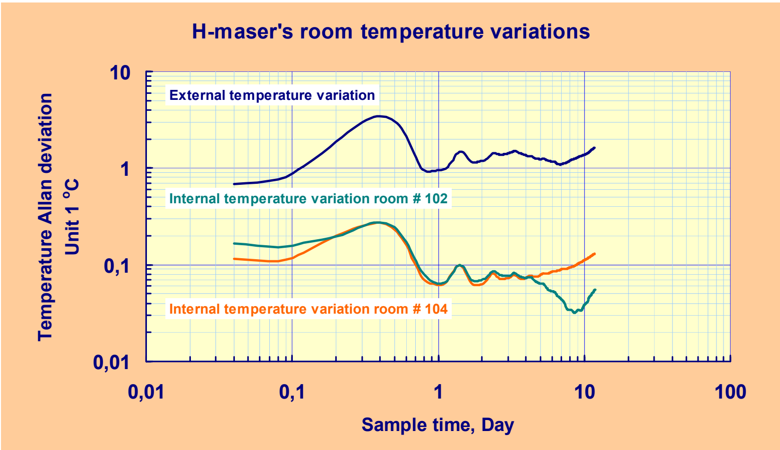

Molases section. There are three mutually perpendicular planes with four beams in every plane.

UTC(SU) time scale generation and keeping

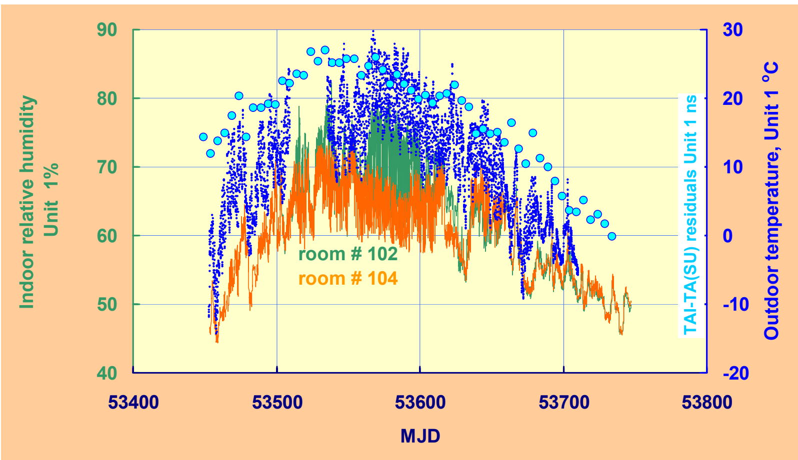
As previously the mainframe of time keeping instrumentation consists of 10 H-maser ensemble. Since last CCTF no considerable changes have happened in instruments - usual maintenance and repairing only. The embedded picture presents individual H-maser stability for the selected best instruments.




Some climate control updates were produced in H-maser's rooms. As a result temperature stability was somewhat improved. Despite the temperature control factor exceeds 20 dB for one day sample time this is not enough to demonstrate to full extend H-maser's stability performances. Looking at H-maser's individual stability plot one may conclude that temperature variations within especially one half day (day/night) considerably disturb clock's behaviour. Clocks reach there flicker floor level for sample time about ten days and this floor approximately corresponds to the value estimated basing on specified clock frequency temperature sensitivity ~$1\times10^{-14}$/K.




The other important issue is humidity influence on clock behaviour. Till now we have no direct evidences of the phenomena. Along with these some indirect results may be interpreted as humidity influence.




Presented picture delivers TAI-TA(SU) residuals (blue circles) after removing constant TA(SU) frequency drift about 0.0036ns/day$^2$ and corresponding external temperature (blue solid line) and internal humidity (green and red solid lines) variations in H-maser's rooms.

One may suppose that obvious variations in time scale residuals may originate from phase instability in antenna's amplifiers and cables of time transfer instruments. But it is difficult to suppose that they may have such a value despite about 50 $^{o}$C seasonal variation in temperature. The total values of delays in antenna's preamplifier and in a piece of outdoor antenna cable do not exceed 30 ns, so expected relative variations is about 100%. More over, we did not detect such a delay difference variations between our operational time transfer receiver and other code and carrier phase geodesy instruments in disposal.

The other possible source of phase variations is humidity. The correlation between detected phase variations and relative humidity has quite the same value as between phase variations and temperature. More over, keeping in mind that at constant temperature relative humidity level is exactly proportional to the absolute amount of water vapour in air, one may interpret obvious correlation as a cause and effect. It worth to remind that more than decade before there was detected seasonal frequency variations in time scales based on ensembles of HP 5061 clocks [3]. At that time it was somewhat astonishing, because of all these clocks were located in well thermostabilized chambers. Possible explanation of the phenomena may be humidity influence.

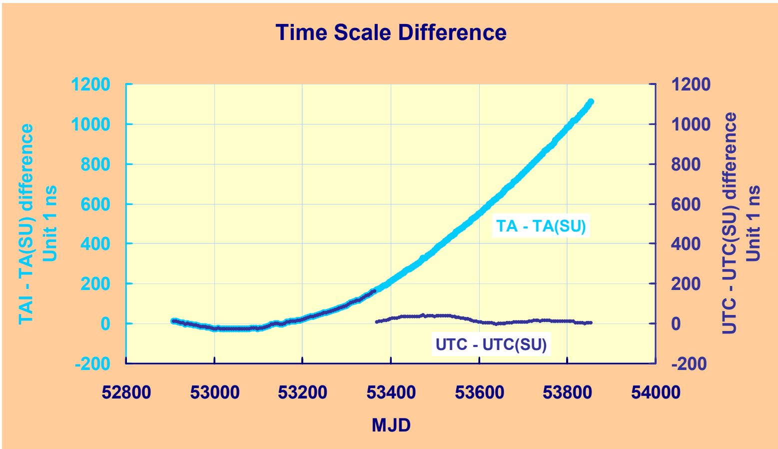
At the moment possible humidity influence is not main source of instability for our H-maser ensemble, but in future systems taking aim to achieve much more better long term stability level, environmental conditions: temperature and humidity stability and reliability of continuous operations of such a systems may play a key role. First of all due to the fact of their influence on the whole ensemble - one can't detect this influence basing on clock's intercomparison data.

The most considerable changes since last CCTF meeting have happened in time keeping process. On 2004, December 30 the realisation of UTC(SU) - the national time scale of Russian Federation - was changed. We continue to maintain autonomous atomic time scale TA(SU) without any changes in algorithm and have started new realisation of the UTC(SU) - steering to UTC. The main goal of steering time scale is to generate UTC(SU) as close as possible to the UTC, following to the recommendation S5 (1993) [4], and do not spoil considerably medium term frequency stability due to steering disturbances.

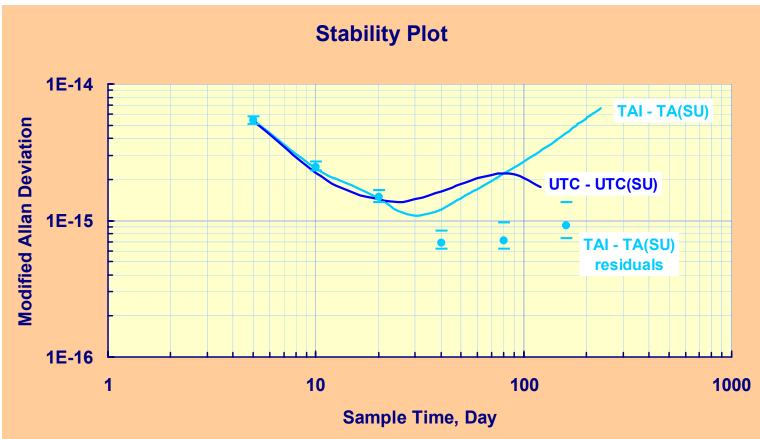
The main ideas of applied steering algorithm were quite the same as it was reported in [5] and were based on PhaseLockLoop (PLL) principles. The gained time difference was estimated and then a proper permanent for the whole month steering frequency bias was introduced to eliminate it. Steering correction to be introduced in month i+1 have been calculated in month i basing on UTC-UTC(SU) readings for the months i-2 and i-1. A linear fitting prediction model was used for time scale difference. To prevent possible abrupt frequency changes due to time link noises and keeping in mind high internal frequency stability of the atomic time scale TA(SU) based on the ensemble of

H-masers a steering limit was introduced. The value of steering limit was in conformity to frequency stability and residual frequency drift of TA(SU) relative to TAI.

Such approach has been applied starting 30 December 2004 till now with steering limit $\leq 3\times10^{-15}$ (259 ps/day) and result is depicted on attached figure. At the start moment 2004, December 30, time difference between UTC and UTC(SU) was about 160 ns and relative frequency difference about $1.6\times10^{-14}$. To remove the initial time and frequency differences we introduced time step of 160 ns to the UTC(SU) but could not introduce necessary frequency step into UTC(SU) but $1.0\times10^{-14}$ only, so it takes us about half a year to equalise frequency difference. Along with it during this period additional time difference about 40 ns has been gained and we needed once more a few months to reach UTC-UTC(SU) difference in close vicinity.




The next figure depicts achieved frequency stability level of TA(SU) and it's residuals relative to TAI and UTC(SU) relative to UTC.




Steering algorithm applied to the UTC(SU) removed obvious frequency drift in TA(SU) and considerably improved tracking ability of the UTC(SU) relative to UTC. The achieved tracking ability characterised by mean time deviation $|UTC - UTC(SU)| = 18 \pm 13$ ($1\sigma$) ns. For the first time in the history of Russian atomic time we developed steering co-ordinated time scale UTC(SU) in close vicinity to UTC. The achieved level is not indicative because more than half of first year we were forced to compensate initial frequency difference. The investigation on steering time scales will be continued and steering ability will be improved.

The closest goals

Contrary to the situation of at least previous decade today we have much more optimistic perspectives regarding future of State Time and Frequency Standard and secondary time laboratories. Just before this meeting Government of Russian Federation have introduced changes into federal task program "Global Navigation System". These changes include a specific issues regarding measures on updating State Time and Frequency Standard means including secondary laboratories, time links, generation composite high stable national time scale, based on all available clocks, carrying out investigations on developing time standards based on new physical principles. This program covers period of 2007-2011 and consists of two main stages.

It is scheduled to develop two Cs fountain instruments, one with accuracy level $\leq 1.0\times10^{-15}$ in 2009, and next $\leq 5.0\times10^{-16}$ in 2011. Apart from it new ensembles of H-masers with individual instability few parts$\times10^{-16}$ will be installed in Mendeleevo and secondary laboratories. The total number of H-masers will be more than 20. We have to update considerably clock's intercomparison system, signal distributing and feeder systems. Updated time transfer links based on GLONASS, GPS and GALILEO common-view as well as TWSTFT will connect us not only with domestic laboratories but with international time community also.

For the three years immediately ahead we expect to reach time scale stability $\sigma_y(\tau)\leq 3.0\times10^{-16}$ for $1\leq\tau\leq30$ days and RMS difference |UTC - UTC(SU)| ≤ 15 ns.

Next two years program will yield in 2011 further improvements: time scale stability $\sigma_y(\tau)\leq 1\text{-}2\times10^{-16}$ and |UTC - UTC(SU)| RMS difference ≤ 10 ns.

Along with it is expected that GLONASS operational performances will be considerably improved: the uncertainty of navigation solution does not exceed 3 meters and UTC(SU) time transmission uncertainty by GLONASS will be less 6 ns in 2011.

References


1 Ю.С. Домнин, Г.А. Елкин, А.В. Новоселов, В.Н. Барышев, Л.Н. Копылов,Ю.М. Малышев, В.Г. Пальчиков, "Применение холодных атомов цезия в квантовых стандартах частоты", *Квант. электроника*, 2004, **34** (12), 1084-1095.

2 Yu.S. Domnin at al. In the press.

3 N.Koshelyaevsky, S.Pushkin, Revealing of the Seasonal Variation in the Atomic Time Scales Basing on the Ensemble of H-Masers, Working Group on TAI, GT-TAI/95-10, Sevres,

France, 1995.

4 Need to improve world-wide time co-ordination to UTC, Recommendation S5 (1993), Report of the Comite Consultatif pour la definition de la second (12th meeting-1993) to the Comite International des Poids et Mesures.

5 N. Koshelyaevsky, E. Zagirova, UTC(SU) Steering Time Scale Strategy. Data Stimulation and First Results, Proceeding of the 19th European Frequency and Time Forum, 21 - 24 March 2005, Besancon, France.