THE NATIONAL TIME AND FREQUENCY SERVICE OF THE RUSSIAN FEDERATION

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Abstract

The paper describes the State Service for Time and Frequency of the Russian Federation. The paper starts with brief historical information. Then the modern legal status and organizational structure of the State Service are described. Because the measurement abilities and accuracy level of the State Service are defined on the basis of standards, the paper contains a traceability chart, the composition, and the performance of the State Standard for Time and Frequency and the network of secondary laboratories spreading from Moscow to Petropavlovsk-Kamchatsky in the Kamchatka peninsula. Taking into account qualified personnel, high performance, and a very advantageous geographical location, today the knowledge and instrumentation of the State Service are involved in many state programs requiring precise time and coordinates support, as well as in traditional activities.

INTRODUCTION

Just after World War II, Russia required a new and much more accurate and reliable coordinate and time reference system for the growing needs of industry, transportation, and the nuclear and space programs. Accepting these new challenges, the State Service for Time and Frequency (SSTF) was established in 1947 in accordance with a decree of the USSR Government signed by Joseph Stalin. At the time of establishment, SSTF combined all available human, scientific, and instrumentation resources of postwar Russia. Since that time, many changes have happened in Time and Frequency activity that strengthen SSTF in both legal and technical respects.

MODERN LEGAL REGULATION AND ORGANIZATIONAL STRUCTURE

According to the Constitution of the Russian Federation, the metric system and timescale calculation are under the jurisdiction of the Russian Federation. To realize these functions, the Law of Russian Federation "On Measurement Consolidation" was adopted in 1993. In its Chapter III "Metrology Services," it is stated that "The State Service for Time, Frequency, and Earth Orientation Parameters Determination (State Service for Time and Frequency) realizes inter-regional and inter-department activity coordination for measurement consolidation assurance in the field of time, standard frequencies, and EOP determination." Figure 1 depicts the organizational structure of the State Service for Time and Frequency. Article 1 of the Statute of the Inter-department commission for time and frequency, adopted by Decree of the Government of Russian Federation No. 125 on 19 February 2001, states that "The Inter-department commission (Commission) for time and frequency is the coordinating body in the area of development and utilization of the state means and systems of reproduction and maintenance of the timescale, standard frequencies, and EOP determination ..."

The Article 3 specifies the main tasks of the commission:

a. the ensuring of coordinated activities of the federal executive authority bodies on development, utilization, and improvement of the technical means and systems of the State Service for Time and Frequency;
b. the determination of the main direction of scientific investigations …

The other governmental paper, the Statute of the State Service for Time, Frequency, and EOP determination, adopted by the Decree of the Government of Russian Federation No. 225 on 23 March 2001, specifies the structure and area of responsibility of the State Service for Time and Frequency. In particular:

"Article 2. The State Service for Time and Frequency realizes the scientific and technical activity for continuous reproduction and maintenance of the national timescale of the Russian Federation and standard frequencies, … ensuring time and frequency measurement and consolidation of EOP determination."

This decree also outlines the role of the Main Metrology Center of the State Service for Time and Frequency as an operational body of the Service:

"Article 5. Scientific, methodical, and operational supervision of the State Service for Time and Frequency is realized by the Main Metrology Center of the State Service for Time and Frequency …"

and perhaps the most significant and far-ranging statement:

"Article 10. **Information from the State Service for Time and Frequency regarding time, frequency, and EOP is obligatory in the Russian Federation.**"

Despite the fact that the names of the Institute of Metrology for Time and Space (IMVP) and the Main Metrology Center of the State Service for Time and Frequency (MMC) are quite different, our institute plays a role of the MMC and as a supervisory body is responsible for the whole everyday practical activity of the State Service establishment. Among the institutions supporting State Time and Frequency Standards are IMVP in the close vicinity of Moscow and a few other secondary time laboratories ranging from Novosibirsk, West Siberia to Petropavlovsk-Kamchatsky, Kamchatka peninsula (Figure 2).

The instrumentation complexes of these institutions constitute the so-called Standard Basis, which plays a key role in the consolidation of time and frequency measurement.

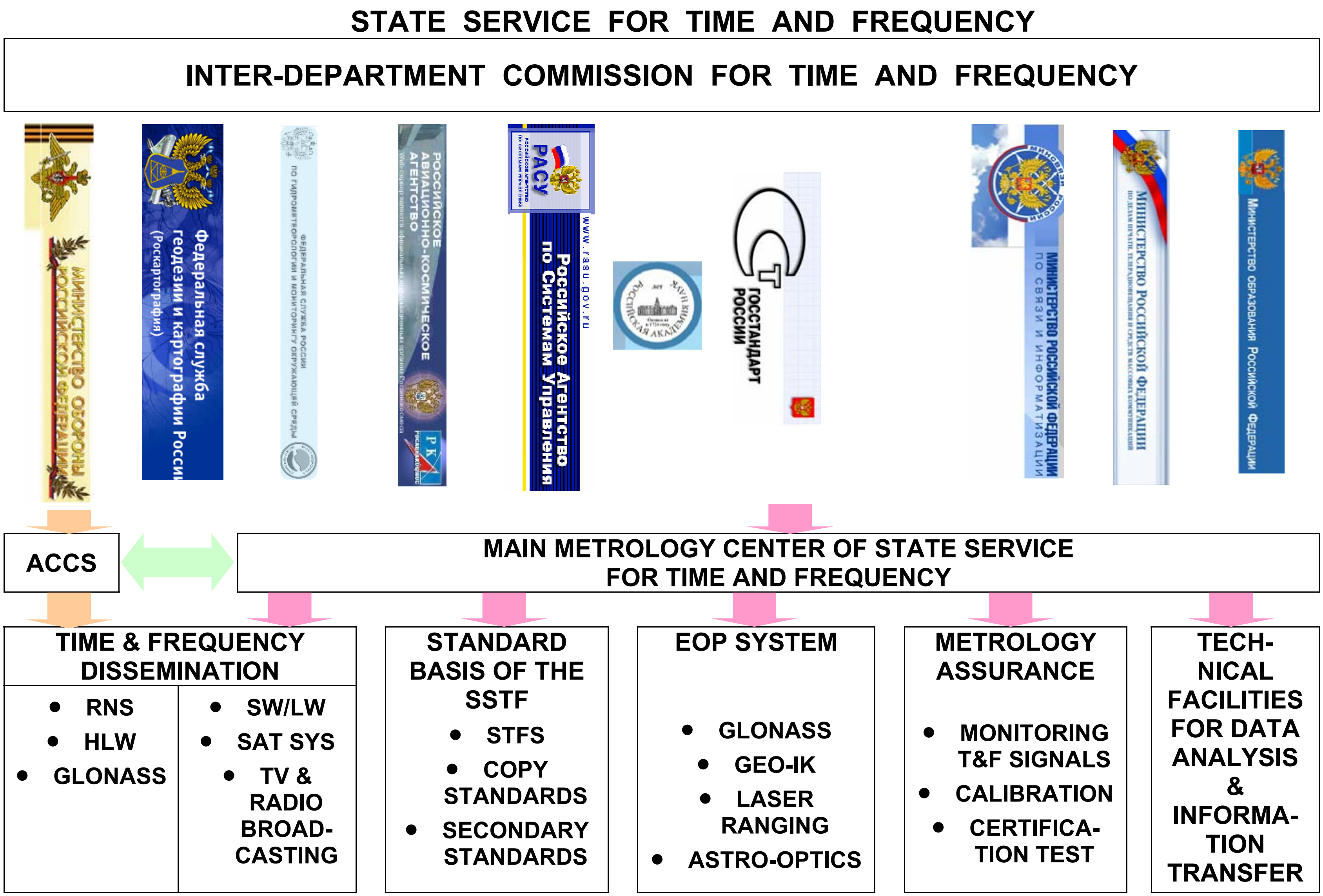
STATE SERVICE FOR TIME AND FREQUENCY
INTER-DEPARTMENT COMMISSION FOR TIME AND FREQUENCY
Федеральная служба геодезии и картографии России
Российское Агентство по Системам Управления
ГОССТАНДАРТ РОССИИ
ACCS
MAIN METROLOGY CENTER OF STATE SERVICE FOR TIME AND FREQUENCY
TIME & FREQUENCY DISSEMINATION
RNS
HLW
GLONASS
SW/LW
SAT SYS
TV & RADIO BROAD-CASTING
STANDARD BASIS OF THE SSTF
STFS
COPY STANDARDS
SECONDARY STANDARDS
EOP SYSTEM
GLONASS
GEO-IK
LASER RANGING
ASTRO-OPTICS
METROLOGY ASSURANCE
MONITORING T&F SIGNALS
CALIBRATION
CERTIFICA-TION TEST
TECH-NICAL FACILITIES FOR DATA ANALYSIS & INFORMA-TION TRANSFER

Figure 1

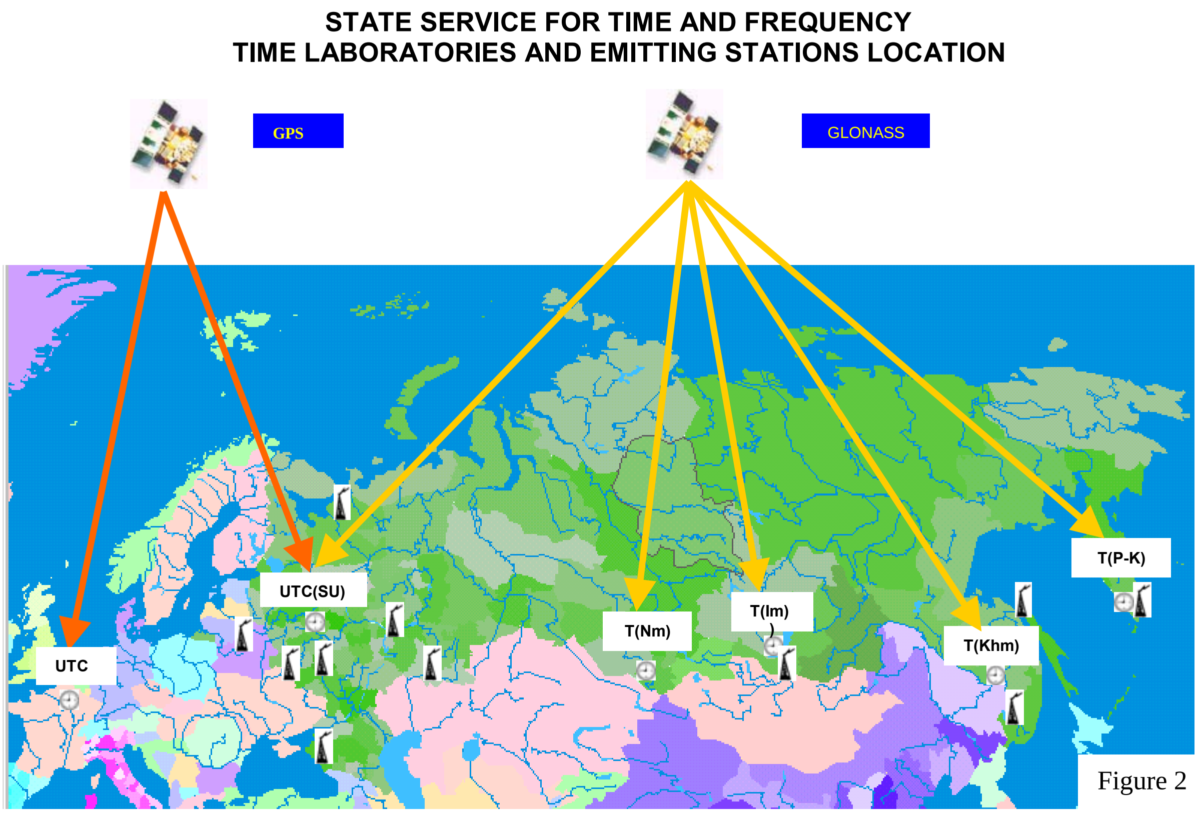
STATE SERVICE FOR TIME AND FREQUENCY
TIME LABORATORIES AND EMITTING STATIONS LOCATION
GPS
GLONASS
UTC
UTC(SU)
T(Nm)
T(Im)
T(Khm)
T(P-K)

Figure 2

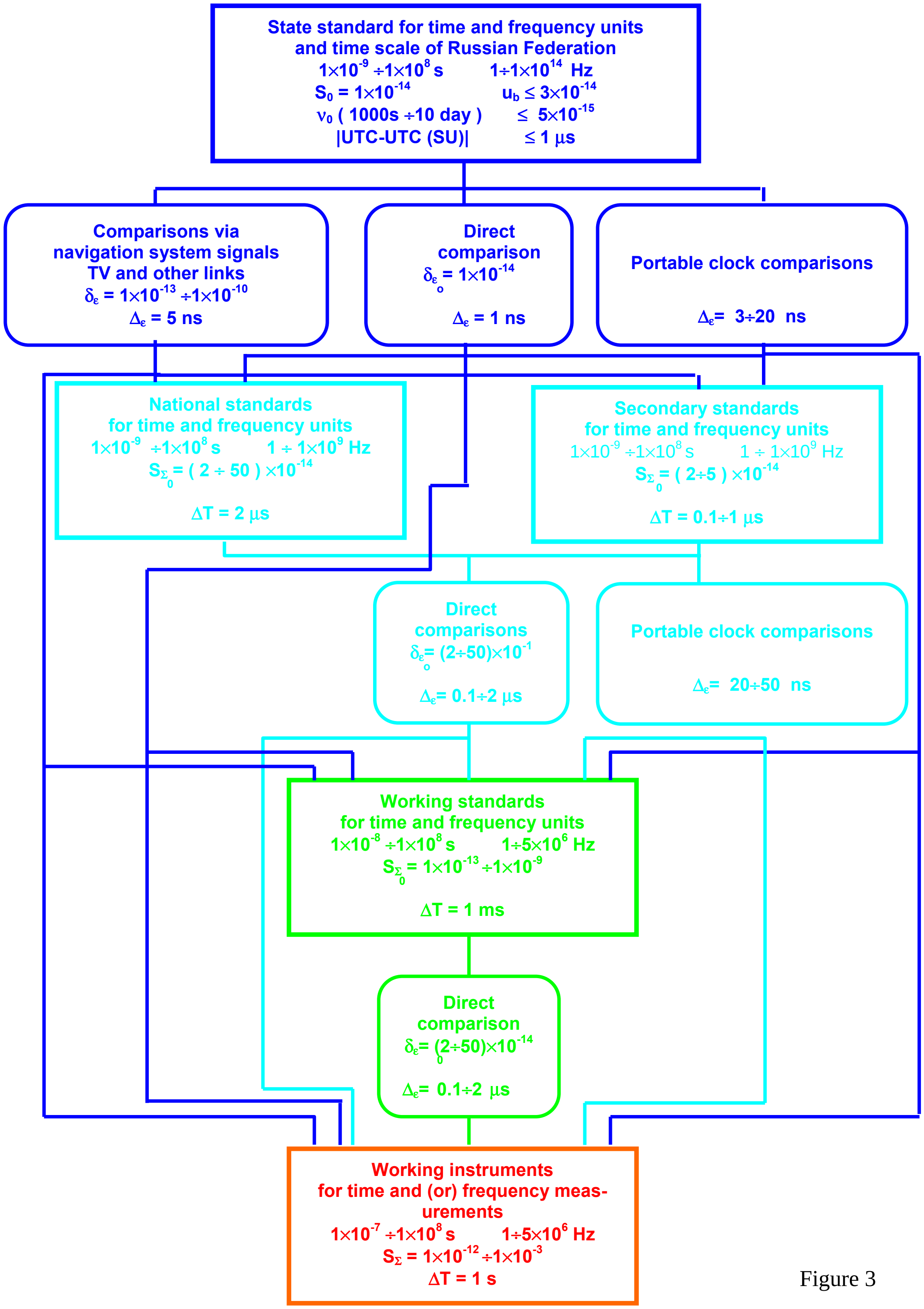
State standard for time and frequency units
and time scale of Russian Federation
$1\times10^{-9} \div 1\times10^{8}$ s $1 \div 1\times10^{14}$ Hz
$S_0 = 1\times10^{-14}$ $u_b \leq 3\times10^{-14}$
ν_0 (1000s ÷10 day) $\leq 5\times10^{-15}$
|UTC-UTC (SU)| ≤ 1 µs
Comparisons via
navigation system signals
TV and other links
$\delta_\varepsilon = 1\times10^{-13} \div 1\times10^{-10}$
$\Delta_\varepsilon = 5$ ns
Direct
comparison
$\delta_{\varepsilon_o} = 1\times10^{-14}$
$\Delta_\varepsilon = 1$ ns
Portable clock comparisons
$\Delta_\varepsilon = 3 \div 20$ ns
National standards
for time and frequency units
$1\times10^{-9} \div 1\times10^{8}$ s $1 \div 1\times10^{9}$ Hz
$S_{\Sigma_0} = (2 \div 50) \times10^{-14}$
$\Delta T = 2$ µs
Secondary standards
for time and frequency units
$1\times10^{-9} \div 1\times10^{8}$ s $1 \div 1\times10^{9}$ Hz
$S_{\Sigma_0} = (2 \div 5) \times10^{-14}$
$\Delta T = 0.1 \div 1$ µs
Direct
comparisons
$\delta_{\varepsilon_o} = (2 \div 50)\times10^{-1}$
$\Delta_\varepsilon = 0.1 \div 2$ µs
Portable clock comparisons
$\Delta_\varepsilon = 20 \div 50$ ns
Working standards
for time and frequency units
$1\times10^{-8} \div 1\times10^{8}$ s $1 \div 5\times10^{6}$ Hz
$S_{\Sigma_0} = 1\times10^{-13} \div 1\times10^{-9}$
$\Delta T = 1$ ms
Direct
comparison
$\delta_{\varepsilon_0} = (2 \div 50)\times10^{-14}$
$\Delta_\varepsilon = 0.1 \div 2$ µs
Working instruments
for time and (or) frequency meas-
urements
$1\times10^{-7} \div 1\times10^{8}$ s $1 \div 5\times10^{6}$ Hz
$S_\Sigma = 1\times10^{-12} \div 1\times10^{-3}$
$\Delta T = 1$ s

Figure 3

MODERN TECHNICAL STATUS

The top level of time and frequency measurements according to the State Traceability Chart for Time and Frequency Measurements (Figure 3) is guaranteed to the State Time and Frequency Standard, which is maintained at the Institute of Metrology for Time and Space.

Its principal parts are:


Figure 4

a. the laboratory primary cesium standard (Figure 4). This cesium standard is based on old principles of thermal atomic beam and magnetic state selection. The width of the central Ramsey fringe is about 100 Hz and the uncertainty u_b (accuracy) of the instrument is 3×10^{-14}. The existence of the primary cesium standard enables the State Standard to reproduce a unit of time in full accordance with the SI definition. Despite an inferior accuracy level, frequency differences relative to TAI for the last 3 years do not exceed 1×10^{-14}.

b. an ensemble of continuously operating H-masers, amounting to 10 instruments (Figure 5), which is the source for timescale generation. All the instruments employ a cavity autotuning system. The flicker floor level of the best timekeeping instruments is about $2\text{-}3\times10^{-15}$ and is reached at a sampling time of 1 day. Each H-maser exhibits a detectable frequency drift. Its values are quite different, typically about ~$2\text{-}3\times10^{-16}$/day, depending on the particular instrument, but the sign of drift is usually the same. Because the drift is more or less stable and predictable, there is no problem taking it into account for timescale calculations.


Figure 5

The performance of the national timescale UTC (SU) is depicted in Figures 6 and 7 relative to UTC, based on official BIPM publications. During the last 2 years, |UTC - UTC (SU)| does not exceed about a few tens of nanoseconds. The obvious spikes at about MJD 52740 are due to GPS receiver failure. On the other hand, during the last 2 years there is an obvious residual frequency drift of ~3×10^{-17}/day. We would like to stress that during last few years there were no steering corrections introduced to UTC (SU).

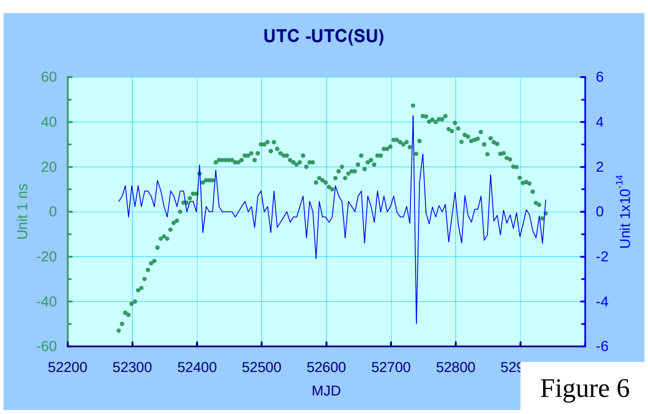

Figure 6

Figure 7 depicts UTC (SU) frequency stability relative to UTC. The behavior of the stability plot is quite predictable and expected, keeping in mind the time link resolution and individual H-maser stability estimations mentioned above.

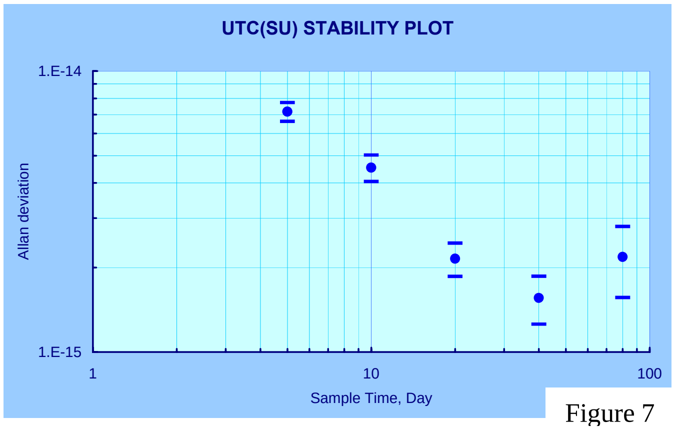

Figure 7

c. The time and frequency intercomparison system: The single-shot time resolution somewhat better 100 ps and the frequency resolution is time-dependent and quite enough to get H-maser stability estimations for sampling times from 1 s to a few days.
d. There are a few instruments for comparison with remote clocks. First of all, one has to mention the well-known TTR6 time transfer system in CV mode. According to our estimations based on UTC – UTC (SU) data from BIPM's Circular T, phase (time) noise for sampling times from 5 days to 100 days looks like 1 – 2 ns flicker noise. It means that we may get more or less valid stability estimation for sampling times more than 20 days. In the near future, we expect to introduce a multichannel GPS/GLONASS receiver that may somewhat improve the time link resolution.

   The other, but regionally limited, instrument is a TV common-view link. Within the viewing area of the TV tower, the time link resolution is comparable to that of GPS and is also not now sufficient to compare H-masers on a 1-day basis.

   One more method of remote clock comparison, based on portable clocks, is much more expensive and gets a time resolution of about 1 ns for a transportation period of less than half a day.

As a concluding remark to the description of the State Time and Frequency Service, we would like to mention that all its essential components are placed in thermostabilized rooms and that power is supplied from reserved sources located in premises outside the main territory of VNIIFTRI.

According to the State Traceability Chart for Time and Frequency Measurements, the precision level of the State Time and Frequency Standard is transferred to a set of secondary means. Let's look at some of them from the State Service for Time and Frequency (Figures 1 and 2).

Due to the enormous Russian territory and lack of sufficiently accurate and reliable time links at the end of the sixties, few secondary time laboratories were located in Gosstandard's establishments in the eastern part of country from the West Siberia – Novosibirsk through East Siberia – Irkutsk to the Far East – Khabarovsk and Kamchatka peninsula – Petropavlovsk-Kamchatsky. All these laboratories are under the jurisdiction of Gosstandard and have been supervised in the recent past by IMVP "VNIIFTRI" as the Main Metrology Center. Today, due to changes in structure of Gosstandard, three of them, excluding Novosibirsk, became branches of "VNIIFTRI," and all of them are still bodies under IMVP supervision.

The time equipment of these laboratories looks quite similar. It consists of an ensemble of four to six H-masers, time intercomparison instruments, and time transfer equipment, based on GPS/GLONASS CV technology. According to the State Traceability Chart (Figure 3), these secondary standards ensure the time unit consolidation at the level of $2\text{-}5\times10^{-14}$ and a timescale difference ≤ 100 ns relative to UTC (SU). The overall view of the timekeeping equipment and typical performance for last year are presented in

Figure 8. The mean value of |UTC – TC (SS)| < 20 ns and the root-mean-square deviation does not exceed 30 ns for any laboratory. The timescale stability is about or better than 1×10^{-14}.

Apart from timekeeping tasks, each secondary time laboratory, as well as the primary one in Mendeleevo, carries out the round-the-clock function of the state monitoring station for time and standard frequency signals. And it does not matter what the origin of signals is – domestic or foreign, land or space satellite systems. The monitoring data are transferred to the Main Metrology Center in IMVP and then processed and distributed on regular basis among users as official publications of the State Service for Time and Frequency.

Besides, some laboratories, for example those in Mendeleevo and Irkutsk, continuously operate RBU, RTZ, and RWM radio stations that emit time signals in the UTC system in the range of long and short waves respectively.

A few words about determination of the Earth orientation parameters: The EOP Division has operated at IMVP since the very beginning. A few tens of years ago, the main data source was astro-optical observations produced by all available observatories in Russia, from the large academic ones, such as Pulkovo or Nikolaev, to observatories in universities. Today, the main data sources are GPS/GLONASS carrier-phase receivers. Each establishment shown on the map in Figure 3 is equipped with dual-frequency multichannel GPS/GLONASS carrier-phase receivers from Javad Positioning Systems. All receivers are fed from local H-masers. Aside from that, many other establishments at universities, the Russian Academy of Science, and other departments adjoint to the State Service for Time and Frequency contribute to the database. Then all collected data are processed and EOPs are derived at IMVP, and the official EOP data are distributed among users on a regular basis.

SECONDARY TIME LABORATORIES EQUIPMENT AND MAIN PERFORMANCE

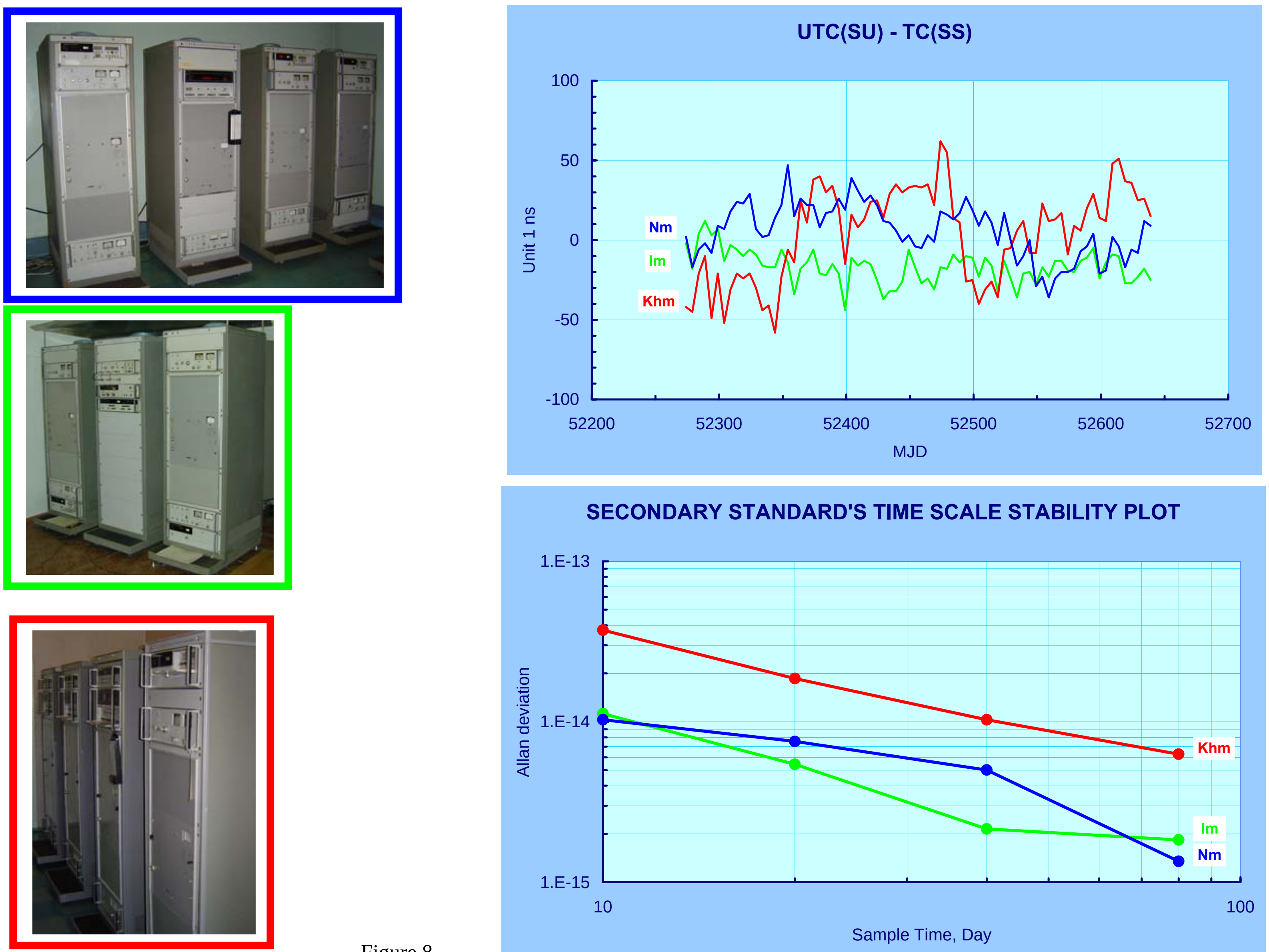

Figure 8

PROSPECTS

In the near future, dramatic changes are expected in the accuracy level of atomic timing in the State Service for Time and Frequency. Today, we have a prototype of new primary cesium standard based on fountain principles and deep laser cooling (Figure 9). The most essential and sophisticated parts of the instrument have been successfully tested. Cesium cloud temperatures of about few μK have been achieved. Recently, the width of the central Ramsey fringe was measured to be about 1 Hz.

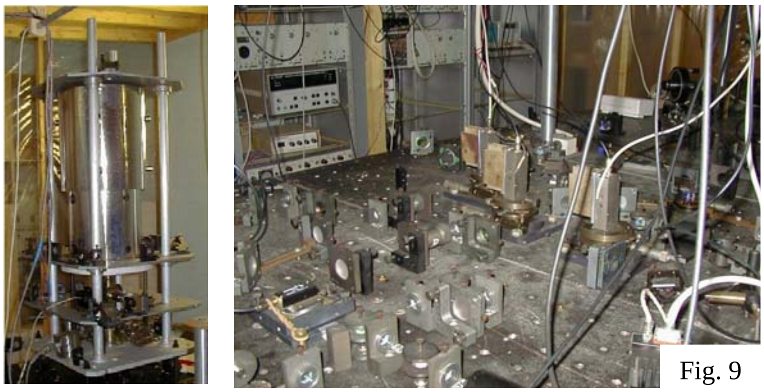

Fig. 9

We also expect a considerable increase in reliability of H-masers and improvement in their stability. So as a result, we expect to get the atomic timescale stability level depicted in Figure 10. Along with that, we have to improve time transfer link time resolution to about 100 ps at a 1-day sampling time. These improvements will enable us to contribute more considerably to BIPM’s time database.

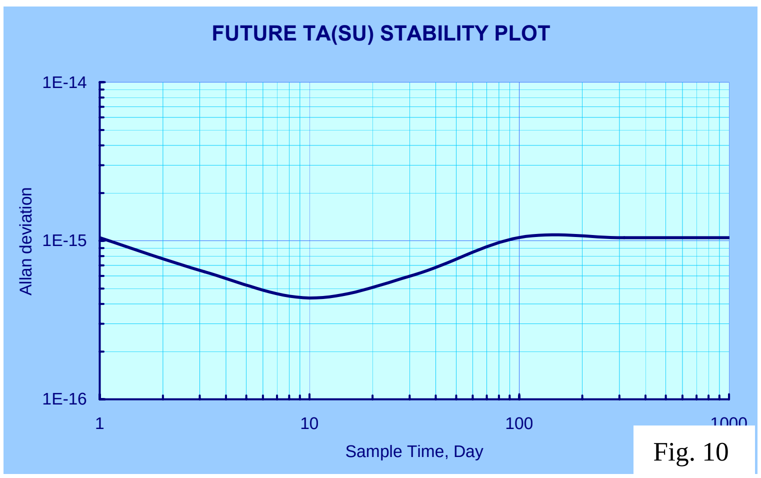

Fig. 10

Basing on expected improvements, we will be able to generate a much more stable and accurate TA (SU) and UTC (SU). These scales may be applied not only to pure timing, but also to any project requiring precise time and coordinates support.

For example, today we are a Partner of Agreement with the Russian Aviation and Space Agency regarding time/reference coordinate support and metrology assurance of GLONASS. Besides that, the above-mentioned time laboratories are included into the list of reference stations for GLONASS/GPS differential navigation. From the very beginning of GLONASS, the laboratories of the State Service for Time and Frequency have been strongly involved in the monitoring of GLONASS. Today, they have been invited by the GLONASS administration to be part of the Control Segment of the system, and will be equipped with proper instrumentation and will supply GLONASS with necessary data for time/ephemeris support.

Questions and Answers

WLODEK LEWANDOWSKI (Bureau International des Poids et Measures): Do you have any plans for two-way time transfer to implement this new method?

KOSHELYAEVSKY: We are strongly interested in it, but up to now we have not enough reserve to install it. It is a pity, but nothing can be done.

LEWANDOWSKI: You are, you know, between Europe and Asia and you are the missing laboratories in this development.

KOSHELYAEVSKY: We are ready to cooperate with any laboratory that is ready to maintain such an instrument. But we have not enough reserves to buy it.

LEWANDOWSKI: So, no plans for the near future?

KOSHELYAEVSKY: Maybe, but not in this calendar year.