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METHODS FOR COORDINATE AND TIME DATA COLLECTION IN THE LASER STATION «TOCHKA»

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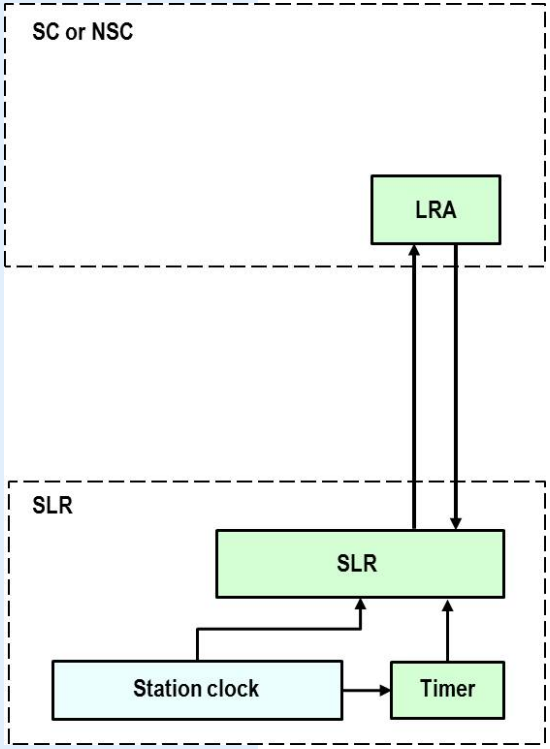
Agenda

1. Satellite laser ranging development trends;
2. Requirements for SLR-stations used for completion of ephemeris and time measurement tasks in GNSS;
3. Methods for coordinate and time data collection and calibration in the laser station «Tochka»;
4. Results of laser time transfer technology try-out using SC «Glonass»;
5. Plans on production and further global distribution of the laser stations «Tochka»;
6. Conclusions.

SLR technology development trends

Stations of the 1st type



SLR development trends allow us to pick out two basic types of SLR-stations designed for:

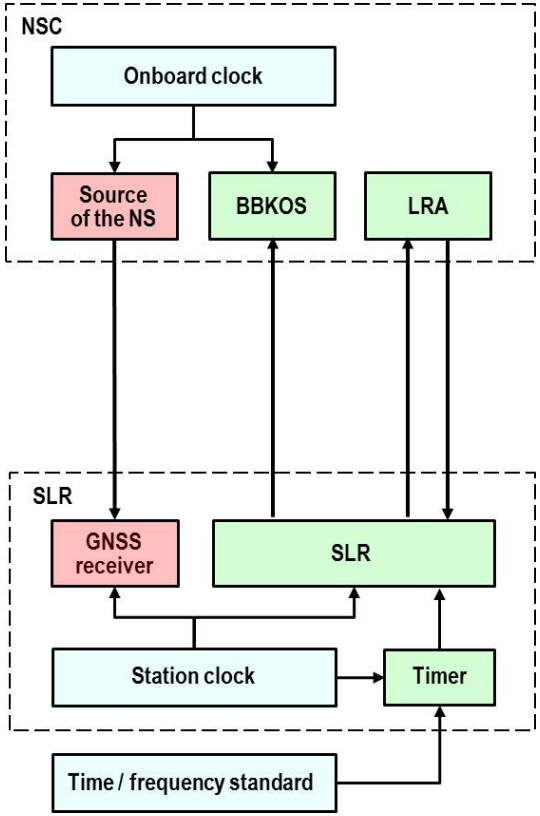
- completion of fundamental and applied tasks of space geodesy and geodynamics (GGOS);

- increase of accuracy of ephemeris-time support for GNSS.

Stations of the 1st type measure the range to SC and NSC with millimeter accuracy.

Stations of the 2nd type simultaneously collect both laser ranging, laser and radio pseudoranging data in GNSS.

Stations of the 2nd type



Coordinated laser and radio measurements enable stations of the 2nd type to complete 3 basic tasks in GNSS:

- GNSS spacecraft orbit determination and monitoring by laser ranging;
- determination and monitoring of divergence between on-board and ground time scales using laser and radio pseudoranging under any weather conditions;
- calibration of hardware delays in primary code and phase navigation measurements and their combinations.

Requirements for SLR-stations used for ephemeris-time measurements in GNSS

Average station performance on GNSS per year
(from Global Performance Report Cards)

Station	Total number of NP on GNSS	Number of NP on GNSS per 24h
Yarragadee	25 469	69.8
Changchun	20 664	56.6
Greenbelt	5 744	15.8
Mount Stromlo	9 081	24.9
Graz	14 266	39.1
Matera	8 006	21.9
Herstmonseux	9 198	25.2
Wettzell	10 236	28.1
Altay	6 993	19.2
Brasilia	6 628	18.1
Arkhyz	4 622	12.7
Komsomolsk	6 232	17.1

One of the key requirements SLR-stations used for ephemeris-time measurements in GNSS should meet is a high performance rate.

If one presumes that, when the sky is clear, each station working on GNSS must produce one normal point every 15 minutes per each navigation spacecraft in the service area of a station, then the performance rate under clear sky conditions must reach 576 NP per 24h.

Considering weather conditions (open sky probability is 0.4), this complies with an average daily performance rate of about 200 NP per 24h. In fact, meeting this requirement means that in order to provide full-fledged performance on GNSS, a station cannot be involved into completion of any other tasks.

The main reserve to increase performance rates of laser stations is decrease of the time spent on collecting NP data at the expense of the station performance frequency increase or installation of double-spot circular retroreflectors featuring a minor signature on the GNSS satellites.

Other mandatory requirements for stations used for ephemeris-time measurements in GNSS are the following:

- equivalent station performance under night and day conditions;
- providing photodetector operation in a single-electron reception mode;
- precise laser beam pointing system calibration;
- precise laser ranging channel calibration;
- precise laser pseudoranging channel calibration;
- station performance automation.

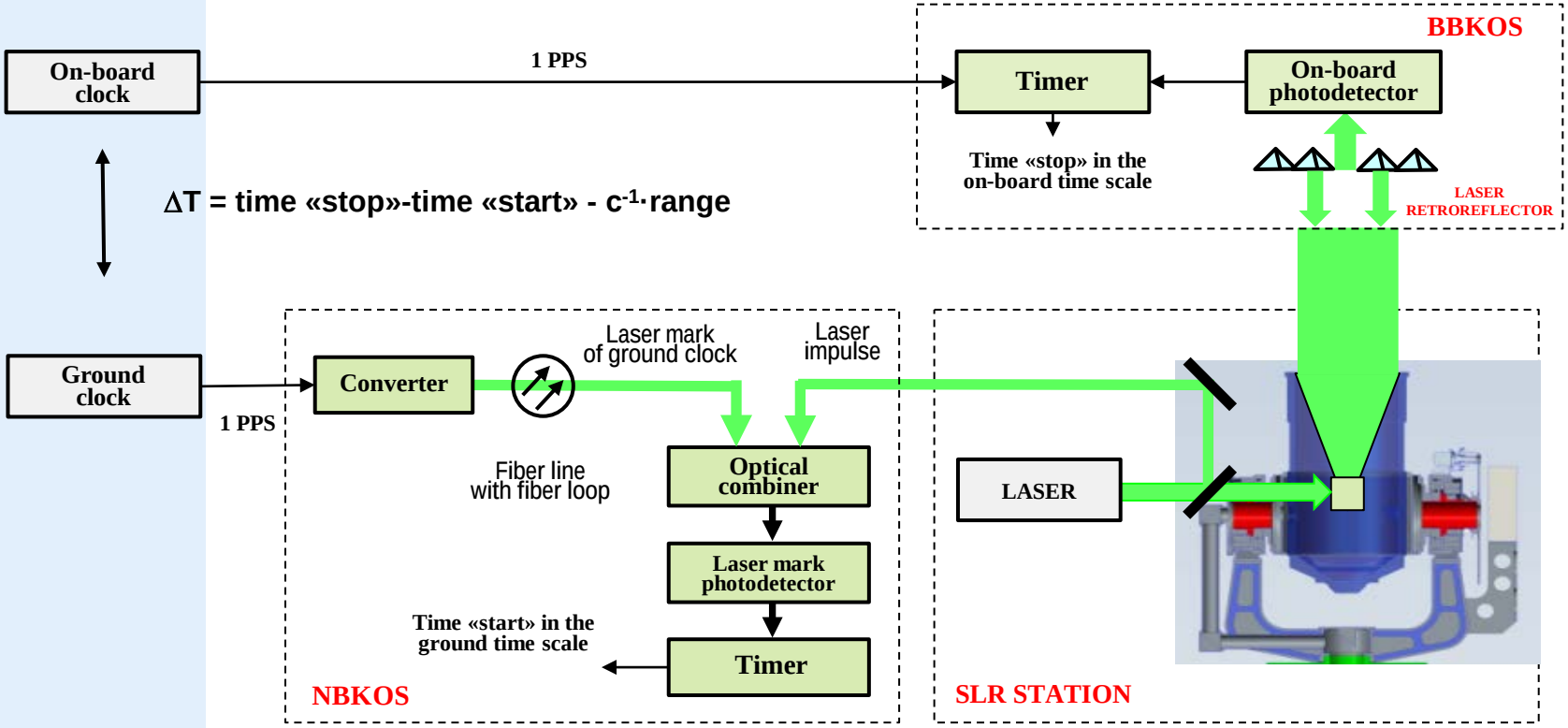
All these requirements are met by the radio-laser station «Tochka»

Methods for coordinate and time data collection in the laser station «Tochka»

Laser pulse start time in the external frequency-time standard's time scale is measured by an extra ground module NBKOS installed at the SLR-station.

Laser pulse arrival time in the on-board frequency-time standard's time scale is measured by an on-board optoelectronic module BBKOS installed on the GLONASS satellites.

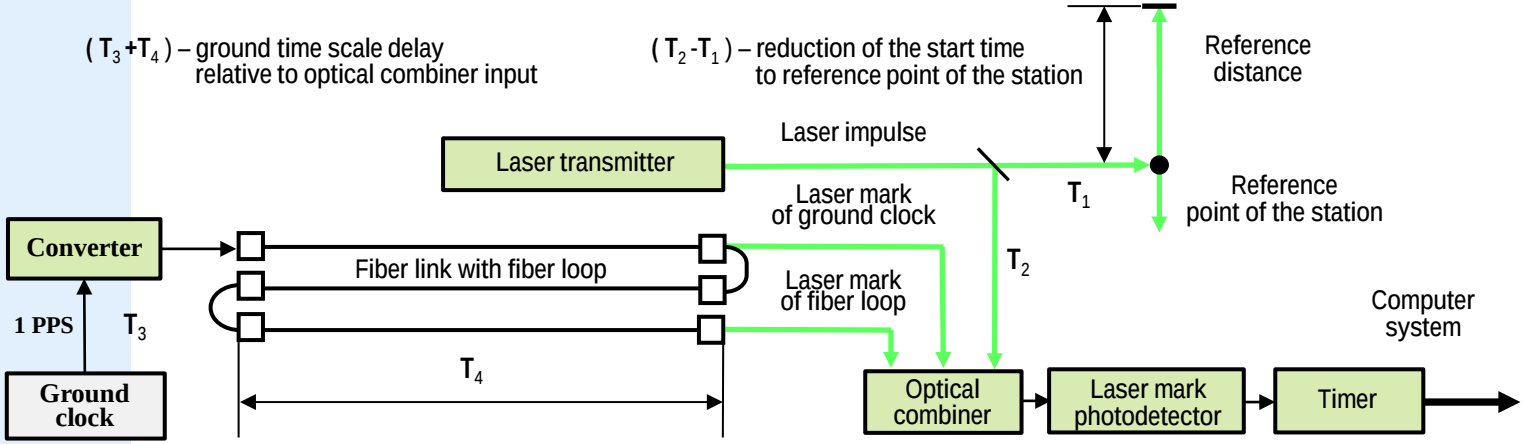
Divergence between the on-board and ground time scales is determined as a difference between the pulse arrival and start times with the deduction of the range (measured by the station) divided by the speed of light.



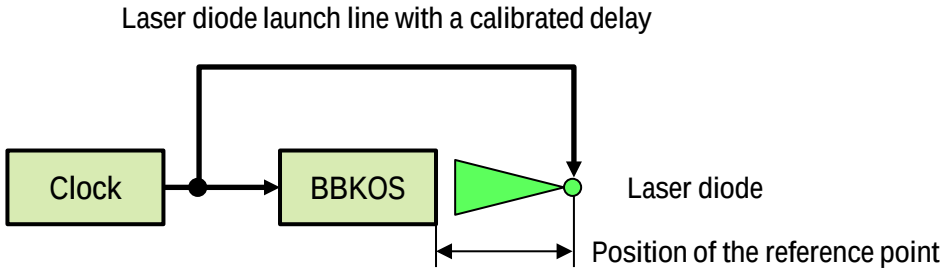
Methods for coordinate and time data calibration in the laser station «Tochka»

Ranging channel calibration is performed continuously through standard calibration distance measurements simultaneously with ranging to navigation spacecraft.

Ground module calibration is also performed continuously through measurement of laser time tag delays inside the fiber-optic line in relation to the laser loop tag.



On-board module is regularly calibrated using the laser diode launched by 1PPS pulses of the on-board frequency-time standard, considering a launch line delay.



Coordinate and time data calibration accuracy in the laser station «Tochka»

Coordinate and time measurement accuracy evaluations, including time transfer ones, were obtained over the period of 2014-2015. Accuracy evaluations were obtained as a result of both ground tests of equipment and a number of experiments aimed at measuring the divergence between the on-board and ground time scales among selected laser stations equipped with ground modules and an SC «Glonass-747» equipped with the on-board photodetecting unit.

The table below gives evaluations of errors reduced to the pulse duration of the 50 ps laser used in «Tochka».

System component	Random error of a single measurement, no greater than	Residual systematic error of measurements, no greater than
Ground module	20 ps	30 ps
On-board module	80 ps	60 ps
Laser rangefinder	50 ps	10 ps
Total	96 ps	65 ps
Total on the averaging interval of 30 s	10 ps	65 ps

Results of experiments on laser transfer of the State primary frequency-time standard's time scale

In 2015, the laser station «Mendeleevo» based at «VNIIFTRI» was equipped the ground module for laser pulse send registration in the State frequency-time standard's and UTC(SU) time scales. Over the period from 23.03.2016 to 23.04.2016, we have conducted the first space experiments on transfer of the UTC(SU) time scale to the GLONASS system time scale standard.

Date	$\Delta T_{UTC\ (SU)\ -\ CS\ /\ laser}$	$\Delta T_{UTC\ (SU)\ -\ CS\ /\ radio}$	$\Delta\Delta T_{UTC\ (SU)\ -\ CS}$
23.03.2016	26669.2 ns	26680.2 ns	+11.0 ns
21.04.2016	26659.9 ns	26675.2 ns	+15.3 ns
23.04.2016	26658.6 ns	26668.5 ns	+9.9 ns
Mean deviation			+12.1 ns

The GLONASS system time scale shift difference in relation to UTC(SU) obtained using the data collected from laser and radio aids is considered as a calibration correction for measurements of radio aidss for determination of GLONASS system time scale divergence in relation to UTC(SU).

Results of ground try-out and conducted experiments allow us to confirm that the time measurement technology has successfully passed evaluation tests and at the present time is at the stage of integration to the GLONASS system.

Plans on production and further global distribution of the laser stations «Tochka»

The first 3 laser stations of the «Tochka» type are planned to be built and placed at the Russian sites in Mendeleevo (Moscow Oblast), in Irkutsk and Petropavlovsk-Kamchatskiy in 2017

We are currently planning to create 4 more stations of the «Tochka» type and install them within the foreign territories until 2020. At the present time, we are reviewing Mexico, Indonesia (Java island), French Polynesia (Tahiti) and Argentina. Besides of that, we consider an opportunity to place these stations in Israel and New Zealand.

Conclusions

1. **Experimental try-out of the laser time measurement technology in GLONASS and time transfer using on-board equipment of the GLONASS navigation SC proves that it is possible to use this technology for time transfer over long distances with an absolute error of no greater than 0.1 ns;**
2. **Considering severe requirements for laser measurement data volumes necessary to increase the accuracy of completion of GNSS ephemeris-time tasks, the key strategy for GNSS satellite tracking for every station is to take measurements on all GNSS satellites passing through the service area of a station;**
3. **The laser station «Tochka» meets all the requirements for stations designed for ephemeris-time measurements in GNSS;**
4. **In order to provide solution for fundamental and applied tasks of space geodesy and geodynamics simultaneously with continuous data collection for GNSS coordinate-time support accuracy increase tasks, it is reasonable to equip laser tracking sites with two SLR-stations (1st and 2nd types) which is crucial in connection with GGOS project development.**

Thank you for your attention ! ☺