JOINT-STOCK COMPANY
«RESEARCH-AND-PRODUCTION CORPORATION
«PRECISION SYSTEMS AND INSTRUMENTS»
(JC «RPC «PSI»)

Collation and transfer of time scales with the sub-nanosecond accuracy using laser range and pseudorange measurements

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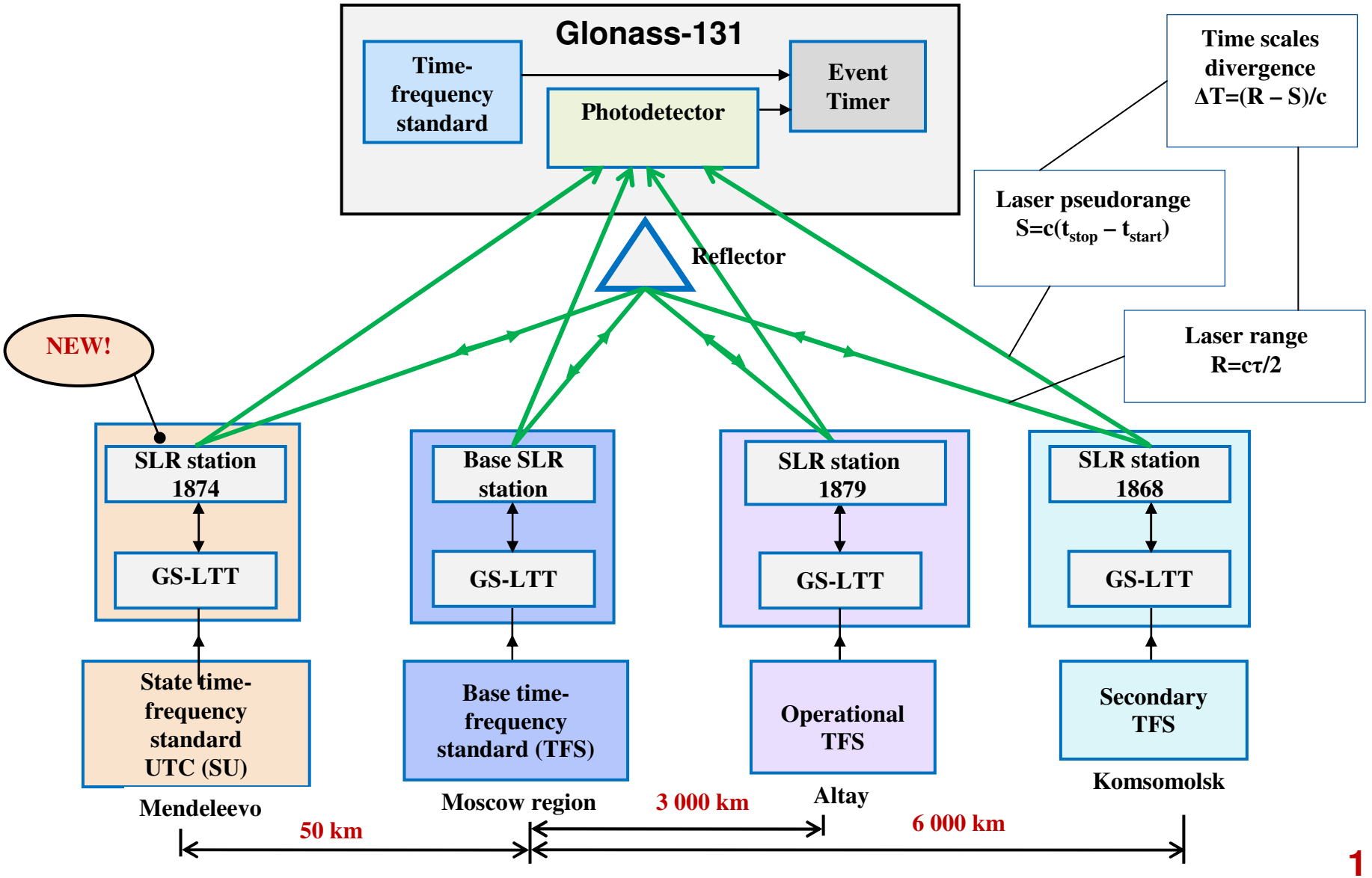
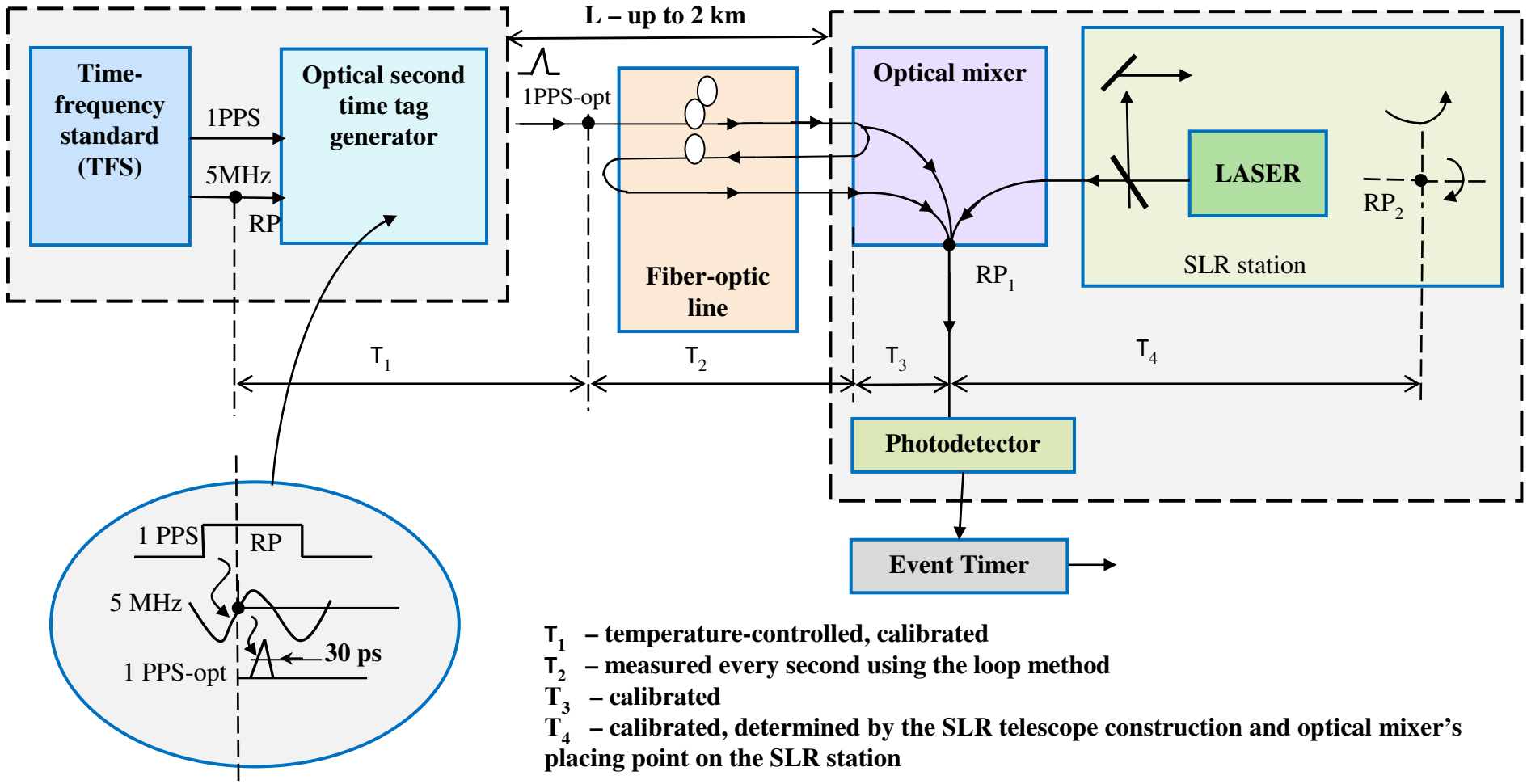
Matera, 2015

Diagram of Laser Time Transfer (LTT) through Glonass-131



LTT ground segment functional diagram and systematic error sources



T_1 – temperature-controlled, calibrated
T_2 – measured every second using the loop method
T_3 – calibrated
T_4 – calibrated, determined by the SLR telescope construction and optical mixer's placing point on the SLR station

Purpose of the ground segment – high-precision recording of laser impulse start time moments in the external time standard's time scale with the error of about 10^{-11} sec

LTT ground segment error budget

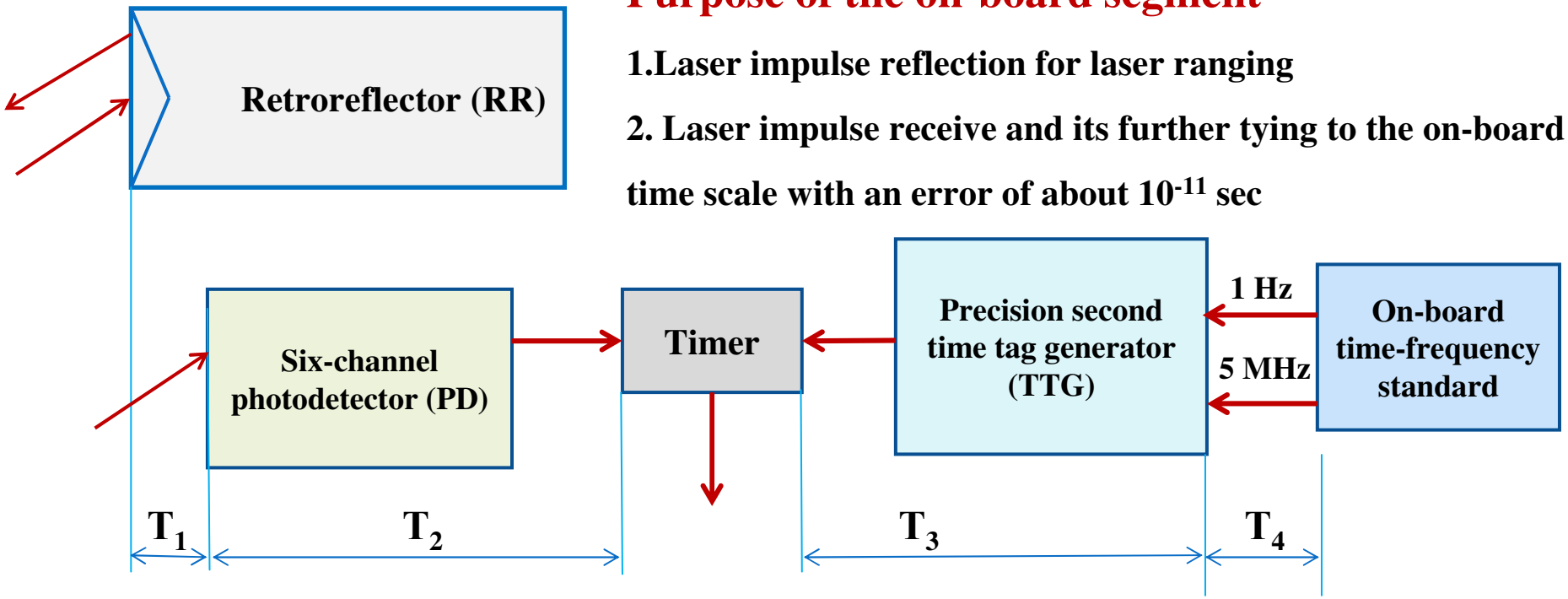
Error source	Random component, ps	Time delay calibration error, ps
Optical second time tag generator	25	10
Fiber-optic communication line	35	10
Optical mixer	-	15
SLR calibration correction	-	15
Event timer	35	-
TOTAL	56	33

LTT on-board segment structure and systematic error sources

Purpose of the on-board segment

1.Laser impulse reflection for laser ranging

2. Laser impulse receive and its further tying to the on-board time scale with an error of about 10^{-11} sec



T_1 – total geometrical delay which depends on the interposition of PD and RR ($T_1^{(1)}$), ground station sight line direction and PD channel number ($T_1^{(2)}$);
T_2 – PD delay (depending on the signal amplitude and PD temperature);
T_3 – TTG delay (depending on the temperature);
T_4 – cable delay.

LTT on-board segment error budget

Error source	Single-time RMS σT_i, ps	Systematic error T_i, ps
PD and RR spatial distribution on a satellite ($T_1^{(1)}$)	-	≤ 20
Ground station sight line directions change ($T_1^{(2)}$)	-	≤ 5
PD delay (T_2)	≤ 70	≤ 110
TTG delay (T_3) and time count increment	≤ 54	≤ 50
Radio frequency cable delay	-	≤ 10
TOTAL	≤ 90	≤ 123

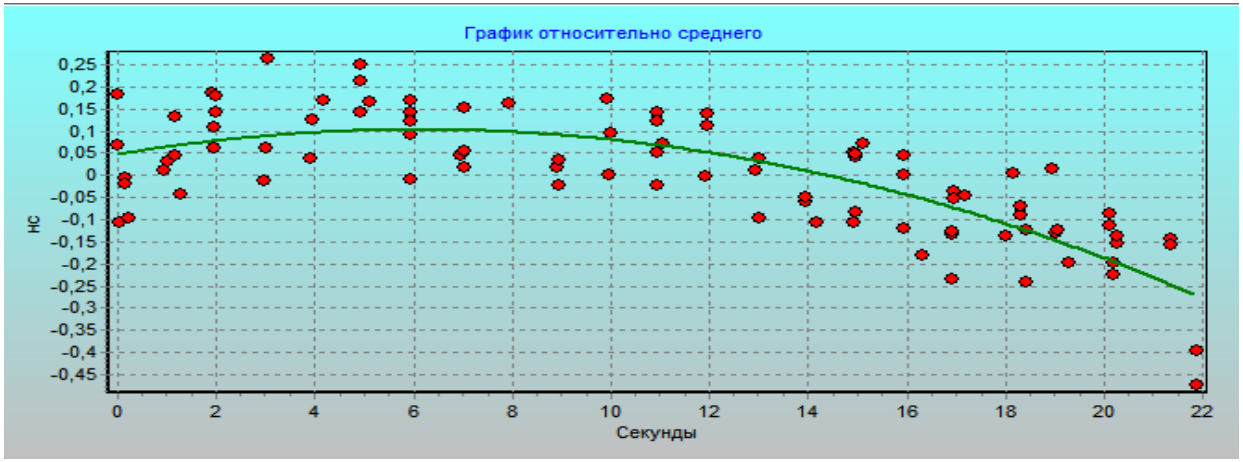
Error budget of determination of divergence between the Glonass-131 on-board and ground time scales

Error source	One-time measurement random component, ps	Delay calibration error, ps
On-board segment	90	123
Ground segment	56	33
SLR	240	50
TOTAL	262	137
Upon averaging on the interval of 30 seconds	26	137

Example of random error estimation for determination of divergence between the Glonass-131 and base TFS time scales

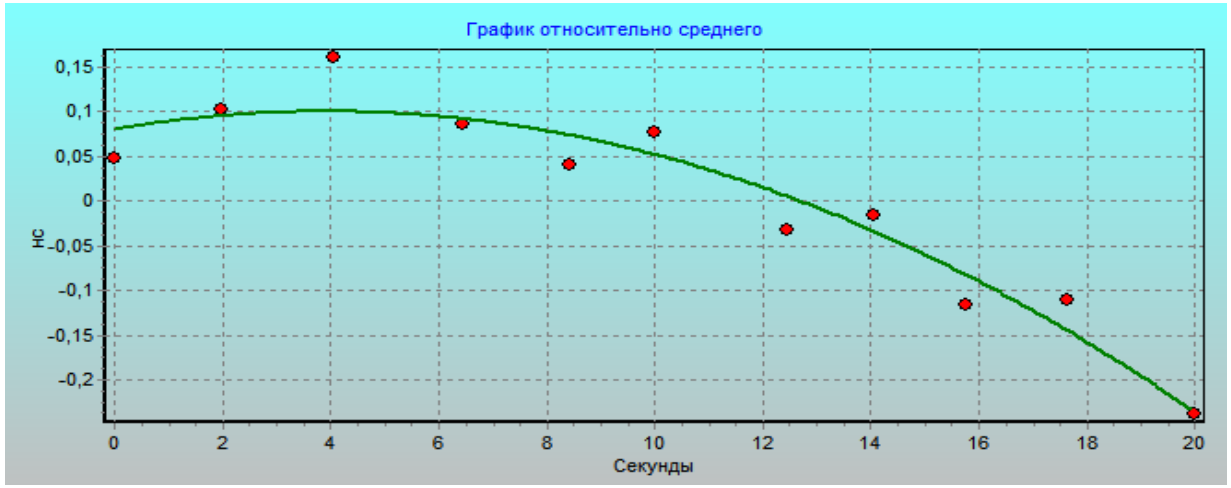
(«raw data») RMS 82 ps

Date: 06.10.2013 Start time: 20.15.41.305 End time: 20.16.03.955



Upon averaging on the interval of 2 sec RMS 36 ps

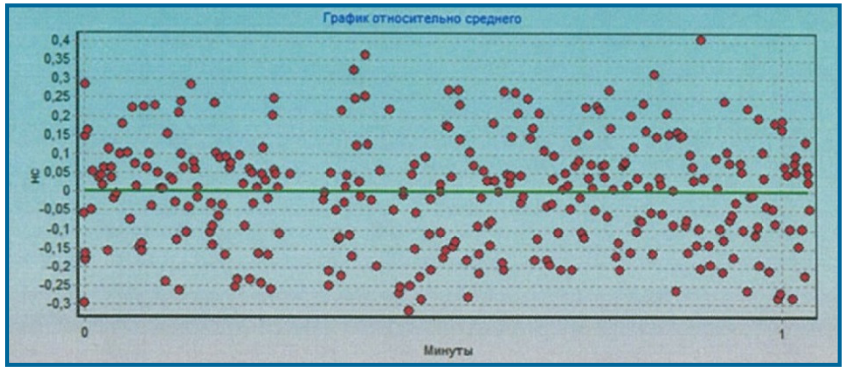
Date: 06.10.2013 Start date: 20.15.43.73 End date: 20.16.03.66



Laser impulse arrival time recording error

2σ= (0,17 – 0,28) ns

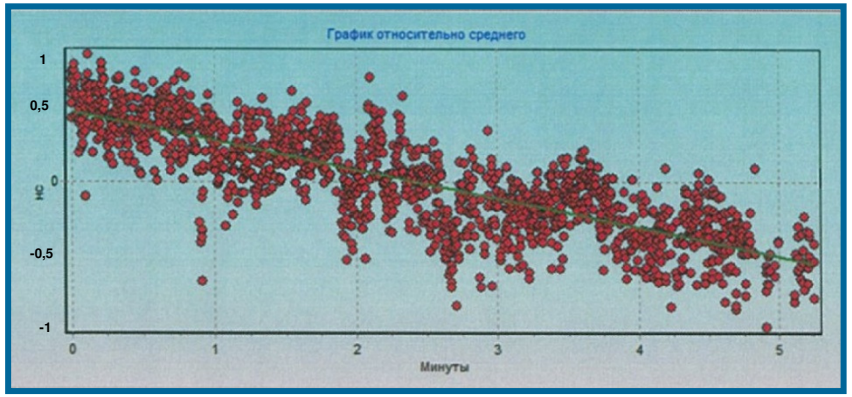
Example of quasi-simultaneous measurement of divergence between the Glonass-131 and three ground time scales



Altay – Glonass-131

24.08.15, start time 20:50, end time 20:52

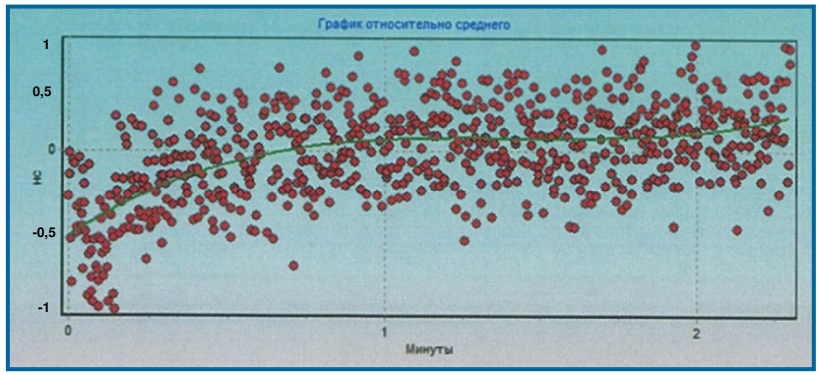
$RMS_1 \leq 147$ ps (one-time measurement)



Moscow – Glonass-131

24.08.15, start time 21:01, end time 21:09

$RMS_1 \leq 187$ ps



Komsomolsk – Glonass-131

24.08.15, start time 21:09, end time 21:11

$RMS_1 \leq 153$ ps

Main directions of LTT availability increase

Limiting factors	Solutions
Overcast, ballistic restrictions on time collation synchronism	▪ Making laser stations function in a 24/7 mode of operation. ▪ Increasing the number of the Glonass satellites equipped with LTT hardware ▪ Adding radio (all-weather) measuring channels which are calibrated by laser means and replace them under bad weather conditions to the laser ones

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