EXPERIMENTAL LASER SYSTEM FOR MONITORING OF GLONASS TIME/FREQUENCY SYNCHRONIZATION
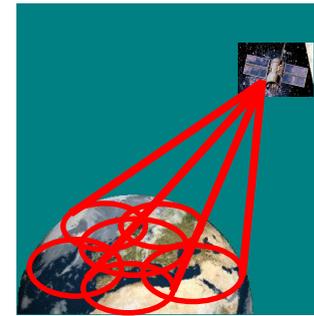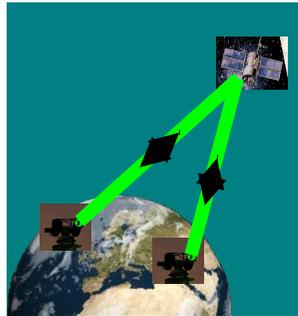
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High accuracy range measurements using satellite SLR stations are used for:

✓ calibration of standard RF monitor stations that, in turn, are used for determination of orbital parameters

✓ refinement of models of disturbing forces affecting navigation satellites

✓ determination of exact coordinates of stations in the geocentric coordinate system

✓ verification of ephemerides transmitted by control stations to navigation satellites

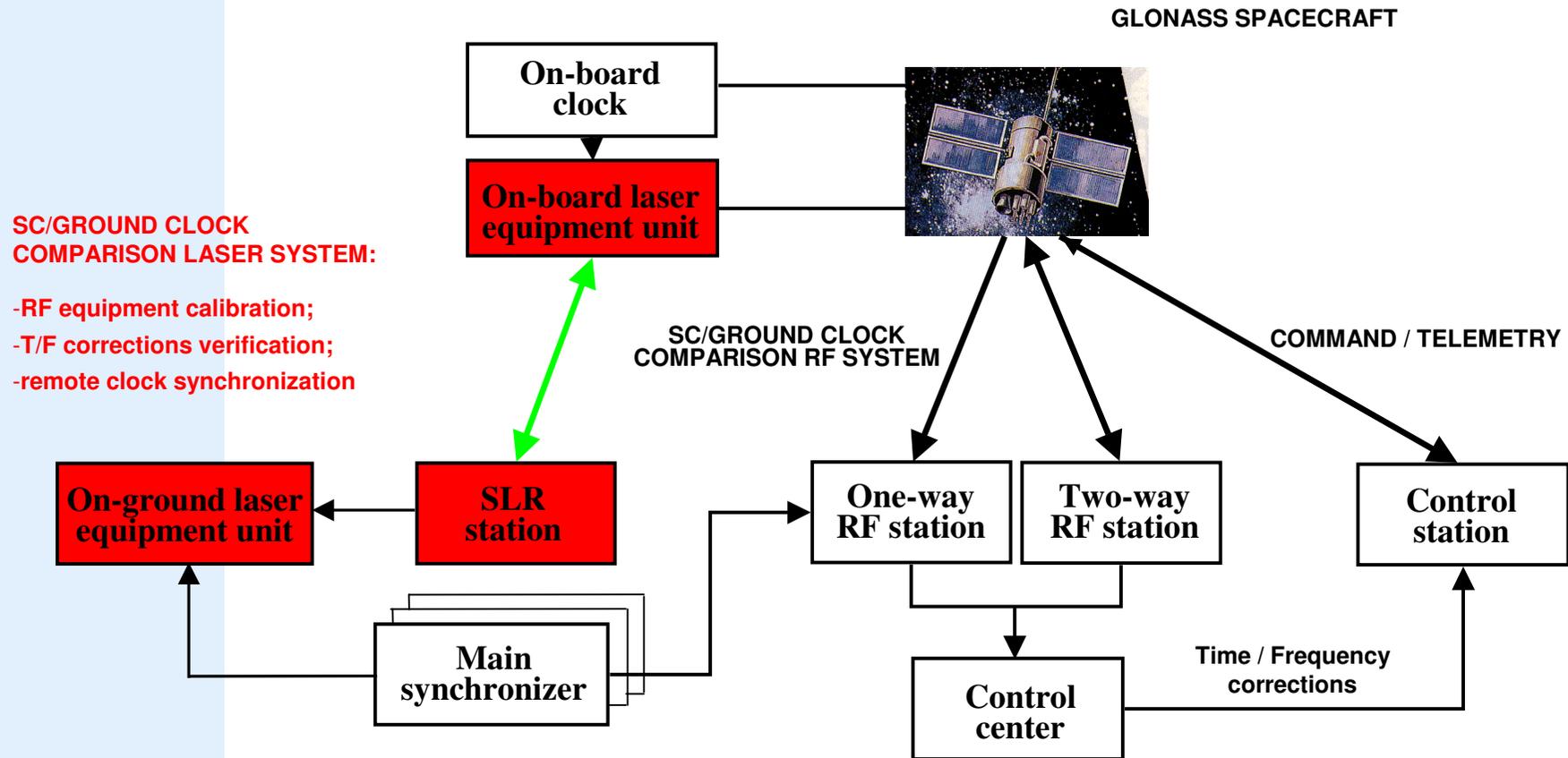**High accuracy of navigation is ensured by:**

➢ high precision of ephemerides transmitted to navigation satellites

➢ high accuracy of synching of navigation satellites' on-board time scales with GLONASS system time scale

GLONASS synchronization system with laser equipment

GLONASS SPACECRAFT

On-board clock

On-board laser equipment unit

SC/GROUND CLOCK COMPARISON LASER SYSTEM:

-RF equipment calibration;

-T/F corrections verification;

-remote clock synchronization

SC/GROUND CLOCK COMPARISON RF SYSTEM

COMMAND / TELEMETRY

On-ground laser equipment unit

SLR station

One-way RF station

Two-way RF station

Control station

Main synchronizer

Control center

Time / Frequency corrections

Laser system operation principle and parameters

On-board laser equipment unit

RRA

Telemetry RF link

SLR station

Main time scale

Control center

SLR station

On-ground laser equipment unit
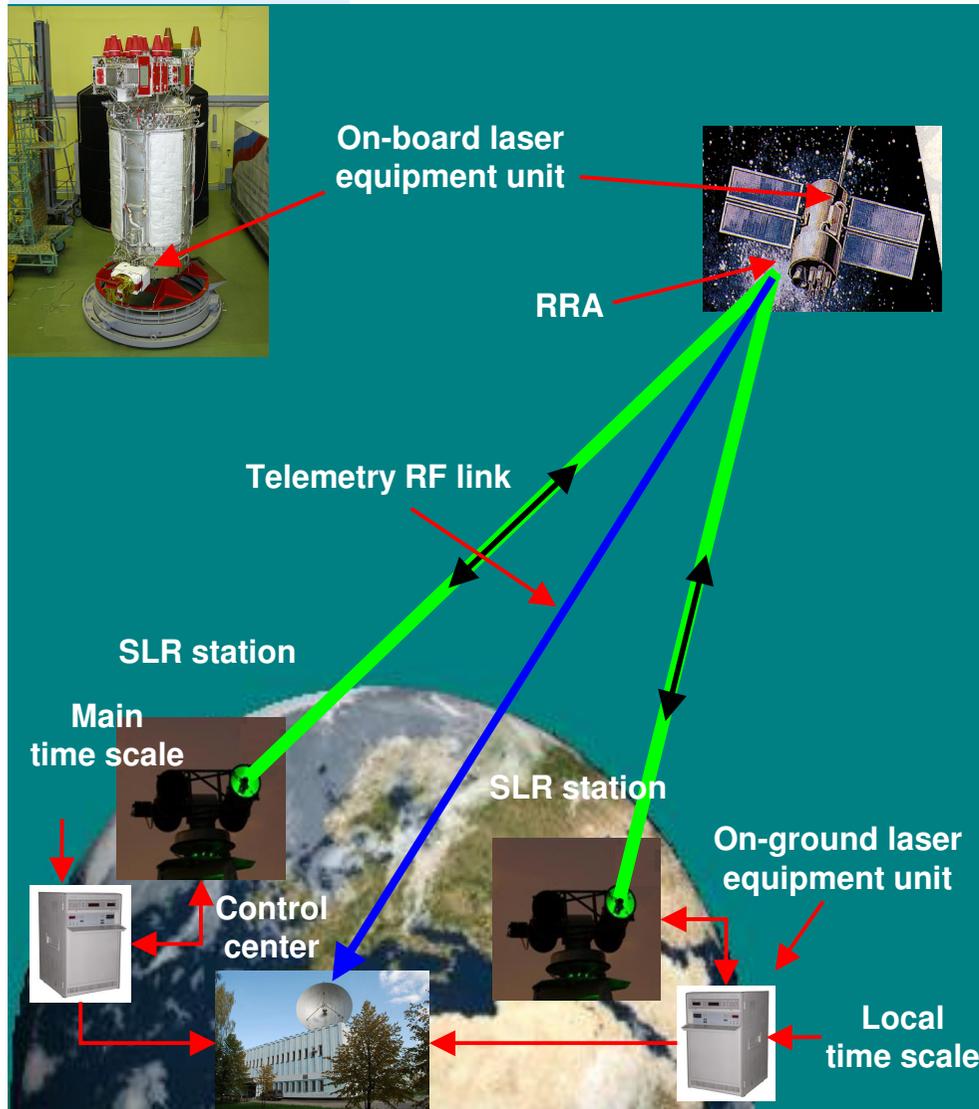
Local time scale

Operation principle:

- TOF measurement by SLR station
- measurement of the laser pulse start-time in on-ground time scale
- measurement of the laser pulse arrival time in on-board time scale
- delivery of the measurement data to control center
- mutual processing of the measurement data

Target parameters:

- time scale difference systematic error, …………………....< 100 ps;
- time scale difference random error…………………...…...< 100 ps.

SLR stations involved in the experiment

Moscow region

Komsomolsk-on-Amur

Main synchronizer

Altai Optical and Laser center

Ground clocks

On-board equipment parameters and calibration methods

On-board laser equipment unit

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                    ┌──────────────┐
              ┌────▶│  Processor   │──────┐
              │     └──────────────┘      │
┌──────────────────┐   ┌──────────────┐   │
│  On-board timer  │◀──│ Photoreceiver│   │
└──────────────────┘   └──────────────┘   ▼
        ▲                    ▲       Telemetry RF link
        │                    │
┌──────────────────┐
│  On-board clock  │
└──────────────────┘
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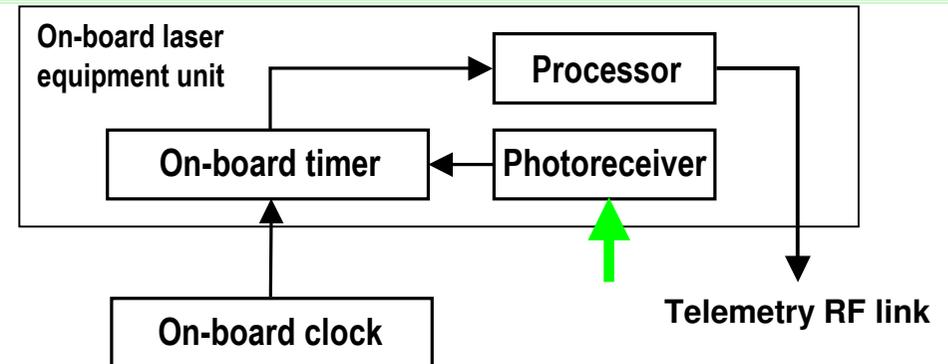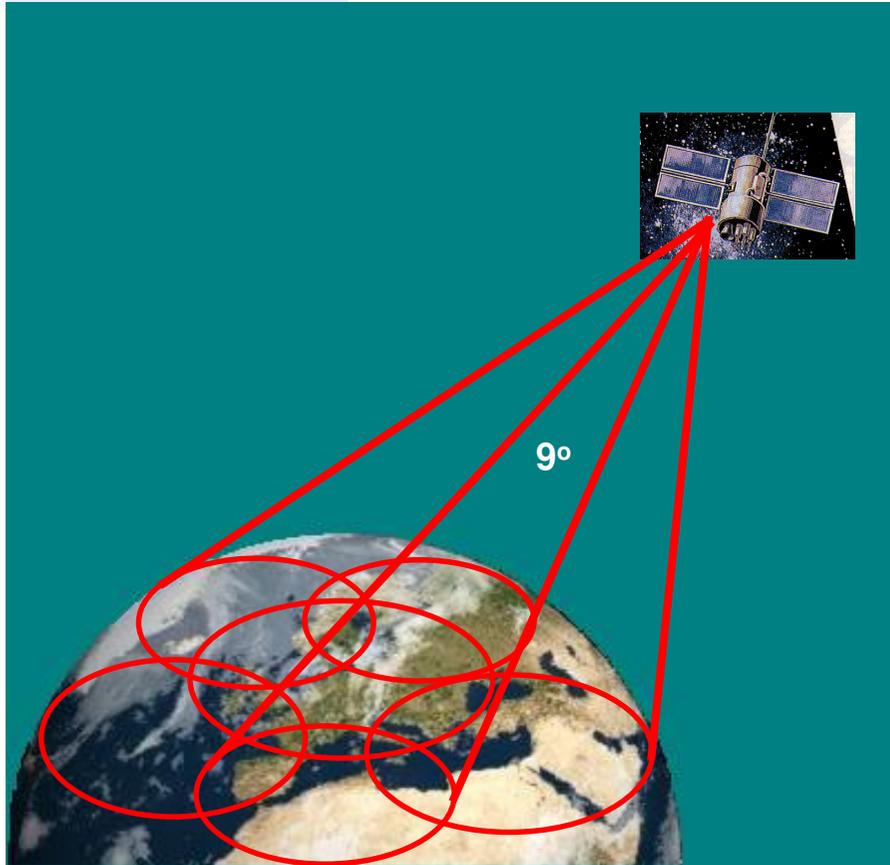
On-board equipment parameters:

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photodetector type……………………………........APD
receiver channel number…………………………..7
input pupil diameter……………………………….8mm
single channel FOV……………………………….9º
wavelength ……………………………….......532 nm
optical filter width………………………………….3 nm
input irradiation limits…………….…………………0.02 ÷ 2 fJ/mm²
single shot error……………………..……………< 300 ps
data volume……………..……………………….....2·10⁶
unit mass……………………………………………6.5 kg
unit power consumption (incl. TS system)…< 35 W
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Calibration methods:

- temperature - dependent on-board equipment time-delay active calibration
- receiver output pulse amplitude measurement (time walk effect mitigation)
- SC attitude determination (correction for laser beam incident angle)

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On-ground equipment parameters and calibration methods

Optical mark pulse

Laser pulse

OE converter

On-ground clock

Fiber loop

Calibration photoreceiver

SLR laser

On-ground timer

Computer

SLR data
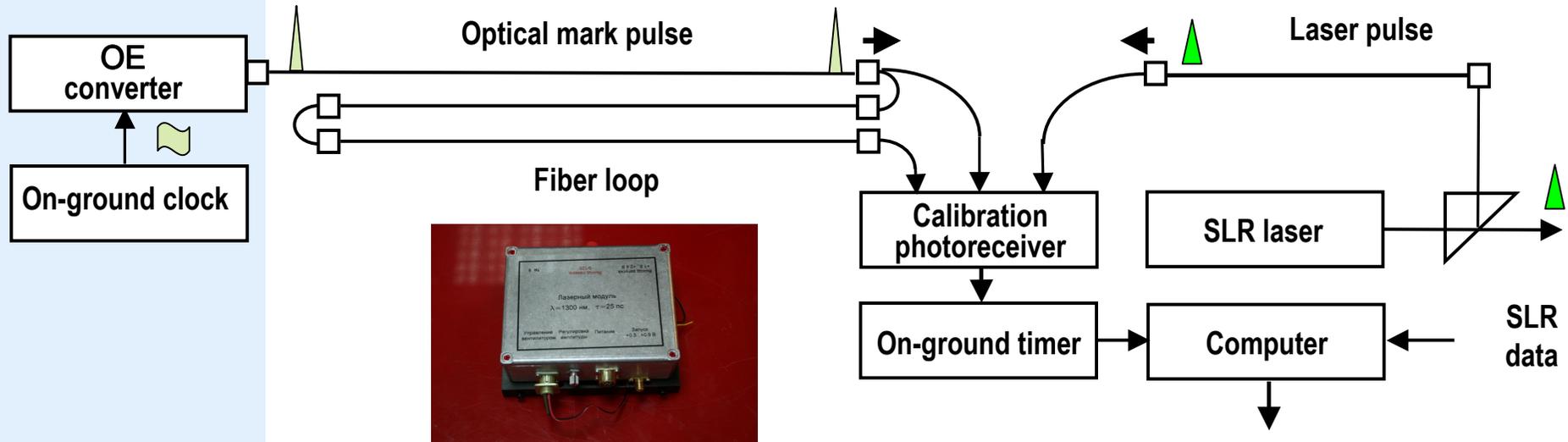
On-ground equipment unit parameters:

- optical mark pulse duration…………………………………………………………..........35 ps;
- calibration photoreceiver response time…………………………….................70 ps;
- timer random error…………………………………………………………………40 ps;
- single shot measurement error……………………………………….......…220 ps;
- SLR repetition rate………………………………………………….................300 Hz;

Calibration methods:

- fiber loop application for monitoring of temperature-dependent optical mark pulse delay;

- multiple measurement of SLR system correction value during SLR observation session;

Error budget analysis

For on-board module:

Random error of a single measurement of pulses arrival times is determined by:
✓ laser pulse length
✓ noise of photo receiver, timer and on-board synchronizer
   With 200 ps resolution of the on-board photo receiver and probe pulse length less than 300 ps, error of a single measurement of
…laser pulse arrival time is evaluated as not exceeding 300 ps.

   Systematic error of pulse arrival times is determined by:
✓accuracy of calibration of time delays in cable connection with on-board synchronizer, in the timer and in the photo receiver
✓ laser beam reflection geometry i.e. accuracy of determination of pulse arrival time difference at the reflection center of the
…retroreflector system and at the optical center of the on-board module
✓To eliminate variable latencies related to dependence of measured pulse arrival times on pulse amplitudes, the active amplitude
calibration of photo receiver channels by means of built-in laser diode is provided.

For on-ground module:
Random error of a single measurement of reply pulses arrival times taking into account errors of linking measurements to the
ground clock time scale is determined by:
✓ laser pulse length
✓ SLR reply pulse photo receiver resolution
✓ random errors of SLR and GSLR timers
✓ jitter of ground clock optical marks
   With 30 ps resolution of SLR photo receiver and probe pulse length of less than 300 ps the error of a single GSLR
…measurement is estimated to be not greater than 220 ps.

Systematic error of ground measurements is defined by:
✓ accuracies of calibration of latencies in fiber connections between measurement photo receiver, ground clock and
…transmitting laser of the SLR
✓ accuracy of system correction of the SLR
   To determine latency of optical time marks in the fiber communication line an additional double length fiber loop is used. To
…increase accuracy of determination of SLR system correction, calibration measurements are performed directly during laser
…ranging session with further averaging of multiple measurements of the system correction.

SC/ground measurement mutual processing algorithm

1. Calibration corrections for on-board measurements (reducing them to the reflection center of RRA) and for ground-based ones (reducing them to the cross point of the rotation axes of SLR optical telescope) are introduced

2. On-board measurements corresponding to each start-time moment of probe pulses are selected using a priori data

3. One-way time of flight of laser pulses and is determined using least squares method separately for on-board and ground measurements

4. On-board and on-ground clock time difference is calculated: $X = \tau_b - \tau_g$
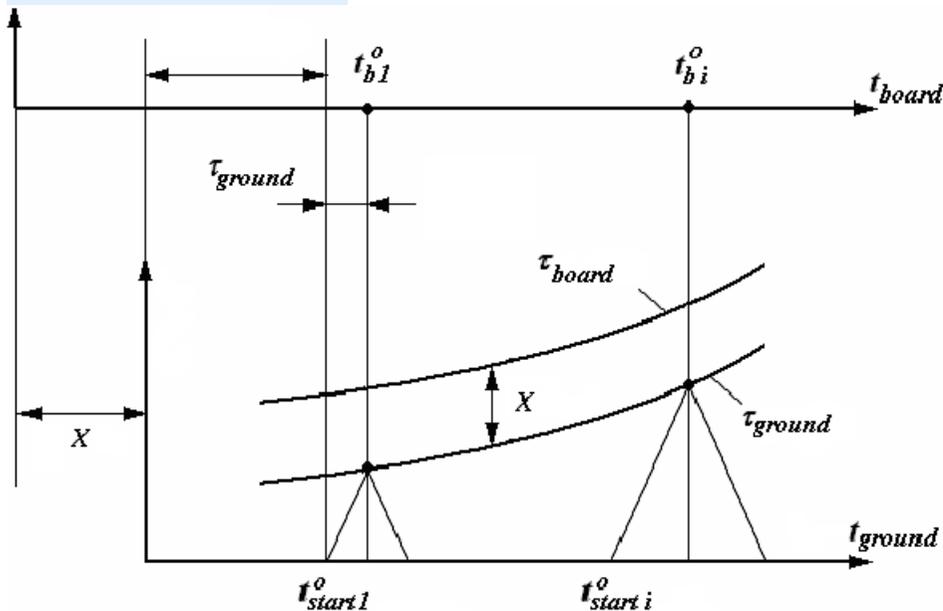
Expected uncertainties after 1000 sec measurement time:

- single-shot time measurements:

$$\sigma_x = \sqrt{\sum \sigma_i^2} = 200...300\ ps$$

- time scale synchronization:

$$\sigma_m = \sigma_x / \sqrt{N} = 5...8\ ps$$

- frequency stability evaluation:

$$\sigma_y = \frac{\sqrt{3} \cdot \sigma_x}{T \cdot \sqrt{N}} = 8 \cdot 10^{-15} ... 1.2 \cdot 10^{-14}$$

Conclusion:

Expected parameters of the laser system for control of GLONASS synchronization will allow to increase accuracy of determination of differences between time scales by an order of magnitude comparing to standard RF means.

THANK YOU ☺