The New Project and Plan of Ground-Space Laser Time transfer in China

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Outline

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2. Review of Beidou LTT system
3. LTT on CSS
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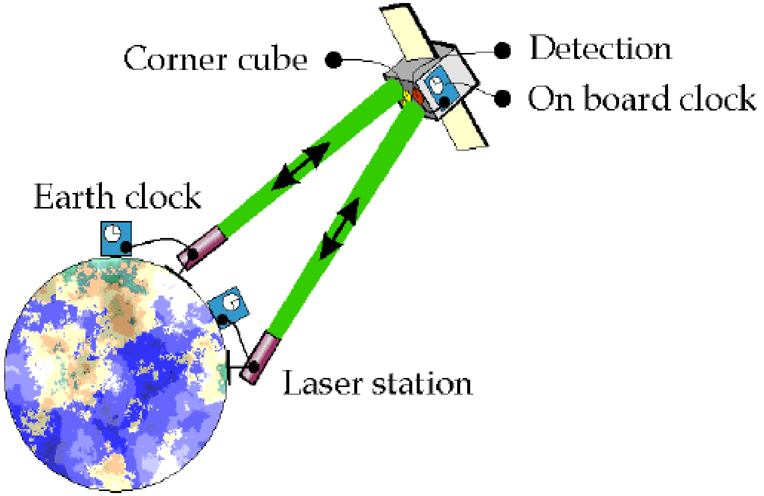
1. Introduction

Time Transfer



- Evaluating performance of space clocks through comparison to the ground high stable clocks by means of laser measurements.
- Synchronizing different clocks at different places, such as satellite navigation system, establishment of global time system.
- Testing of the Relativity theory with high precision.

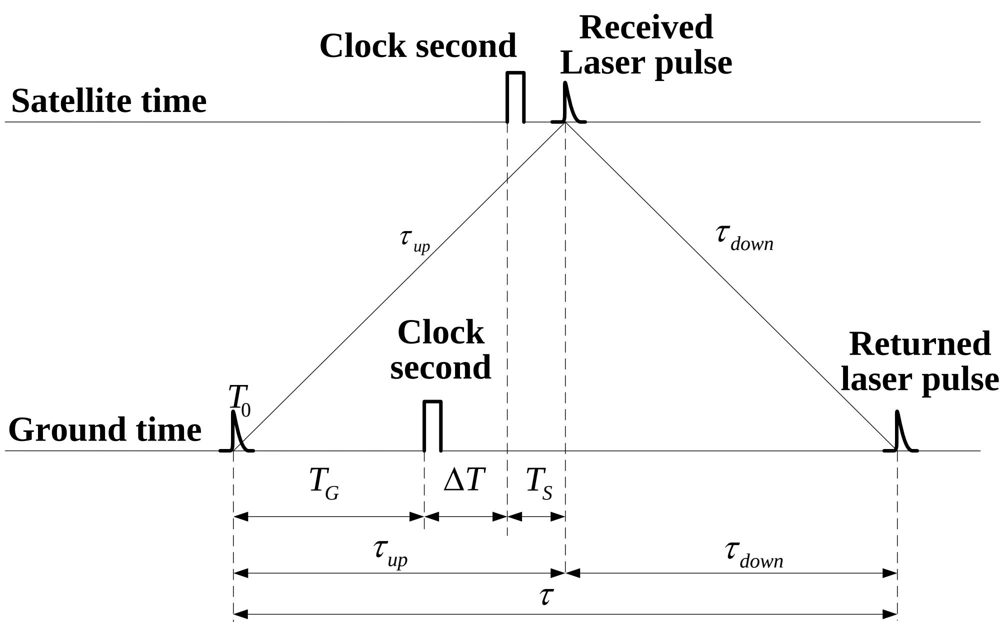
1. Introduction

- Laser time transfer is known as a high accuracy method to compare ground and space clocks with accuracy outperforming the radiofrequency techniques by more than one order of magnitude.

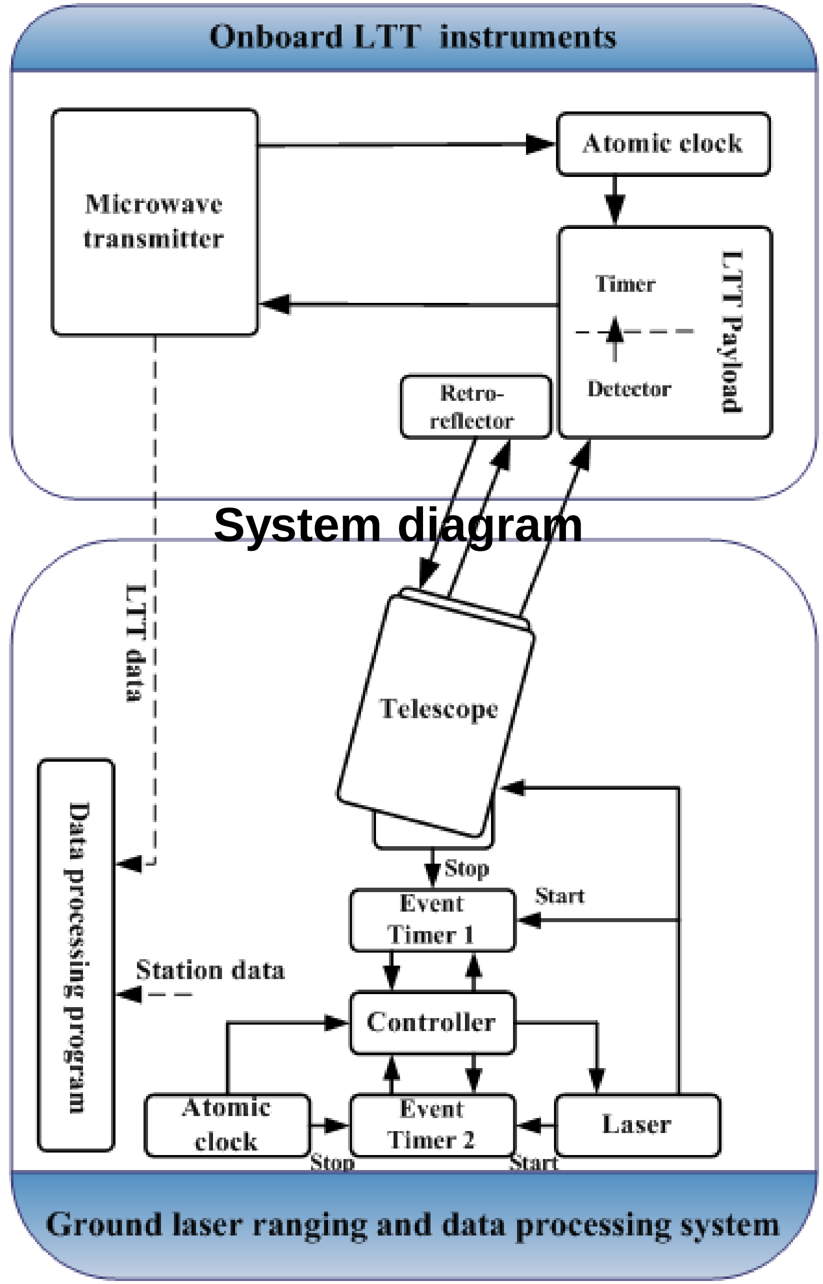
- Time transfer by laser (round trip) projects have been carried and the plan is underway：
    - LASSO (Laser Synchronization from Stationary Orbit) (1989 and 1992),
    - Beidou LTT (Laser Time Transfer) (2007~ 2012) ,
    - T2L2(Time Transfer by Laser Link) (2008~) ，
    - ELT (Europe Laser Timing) (~2018),
    - LTT on China’s Space Station-Tiangong (~2022)。

2. Review of Beidou LTT system

Principle of laser time transfer



$$\Delta_{AS} = \frac{t_E + t_R}{2} - t_B + \frac{C_{Sag}}{2} + C_{Rel} + C_{Atm} + C_{ICal} + C_{ECal}$$



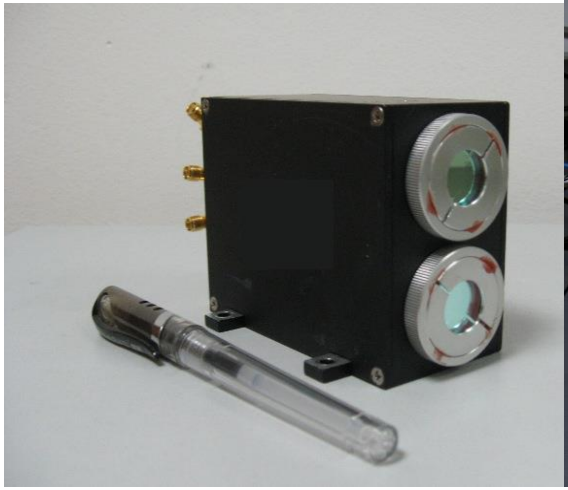
System diagram

4 sets of Beidou LTT (2007-2012)
MEO1, IGSO1, IGSO3, MEO3
300ps single shot precision,
20ps@500s timing stability

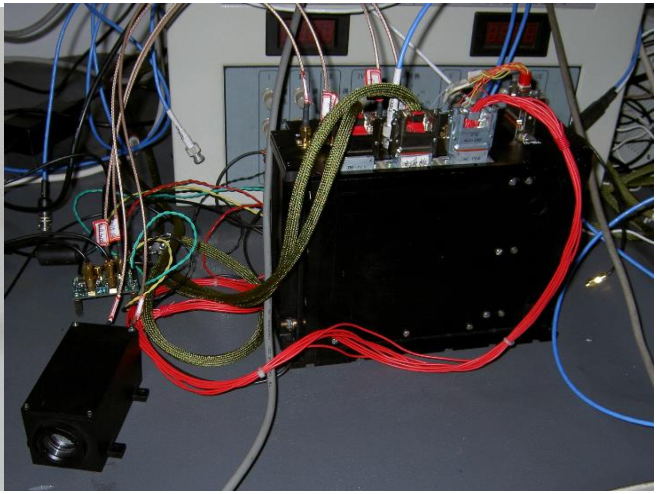
2. Review of Beidou LTT system

Onboard instruments

LRA



Updated detector



Detector and timer

Onboard instruments:

- LTT payload（detector+timer）
- LRA
- onboard clock
- control system

Ground instruments:

- SLR system
- Laser fire time control system
- Control and data process

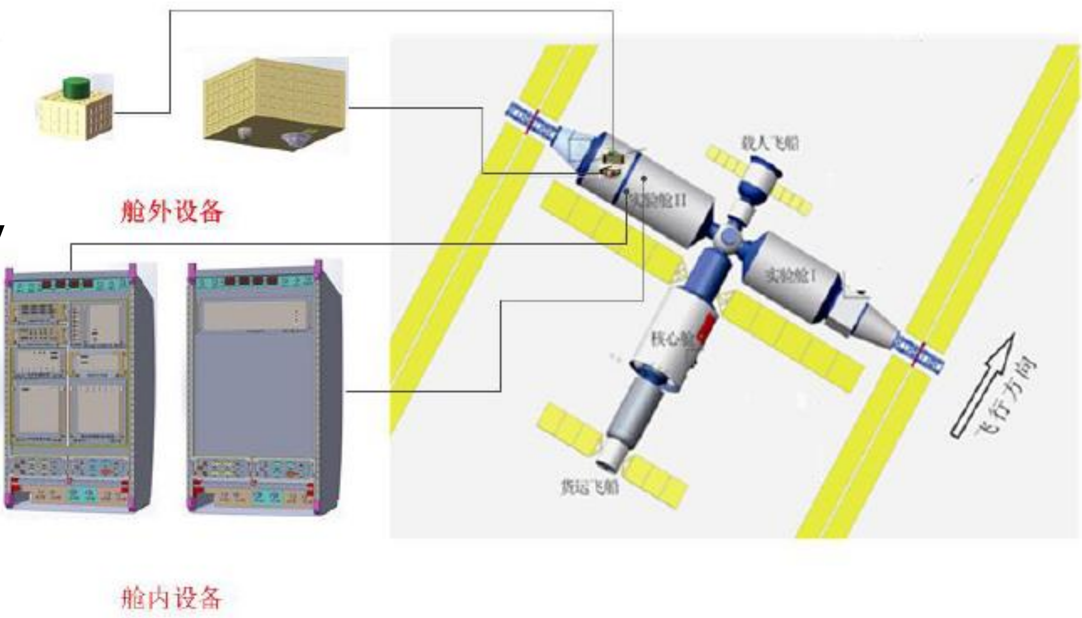
Made by SHAO

Ground instruments SLR telescope

3. LTT onobard China's Space Station

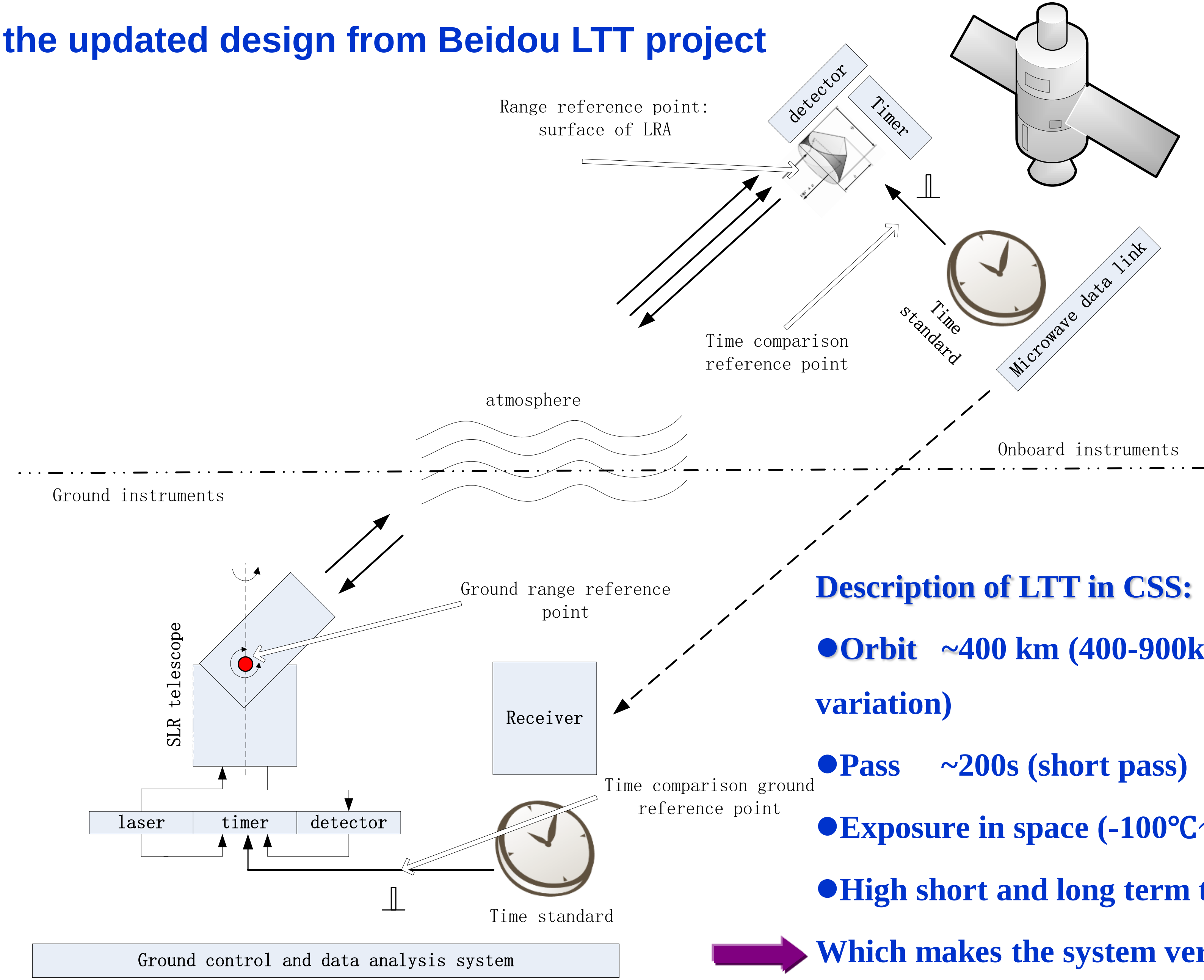
- **China will established China's Space Station（CSS） around 2020-2022**
- **A High-precision time frequency experiment rack will be installed, which include a hydrogen atomic clock, a cooled atom microwave clock, a cooled atom optical clock and other equipment, as well as companion ground components.**
- **RF / Laser time transfer methods**
- **Time comparison stability**

  <1ps@300s, <1ps@1day



LTT for CSS

the updated design from Beidou LTT project



Description of LTT in CSS:

- **Orbit ~400 km (400-900km distance variation)**
- **Pass ~200s (short pass)**
- **Exposure in space (-100℃～100 ℃)**
- **High short and long term timing stability**

Which makes the system very challenge

Specifications of LTT for CSS

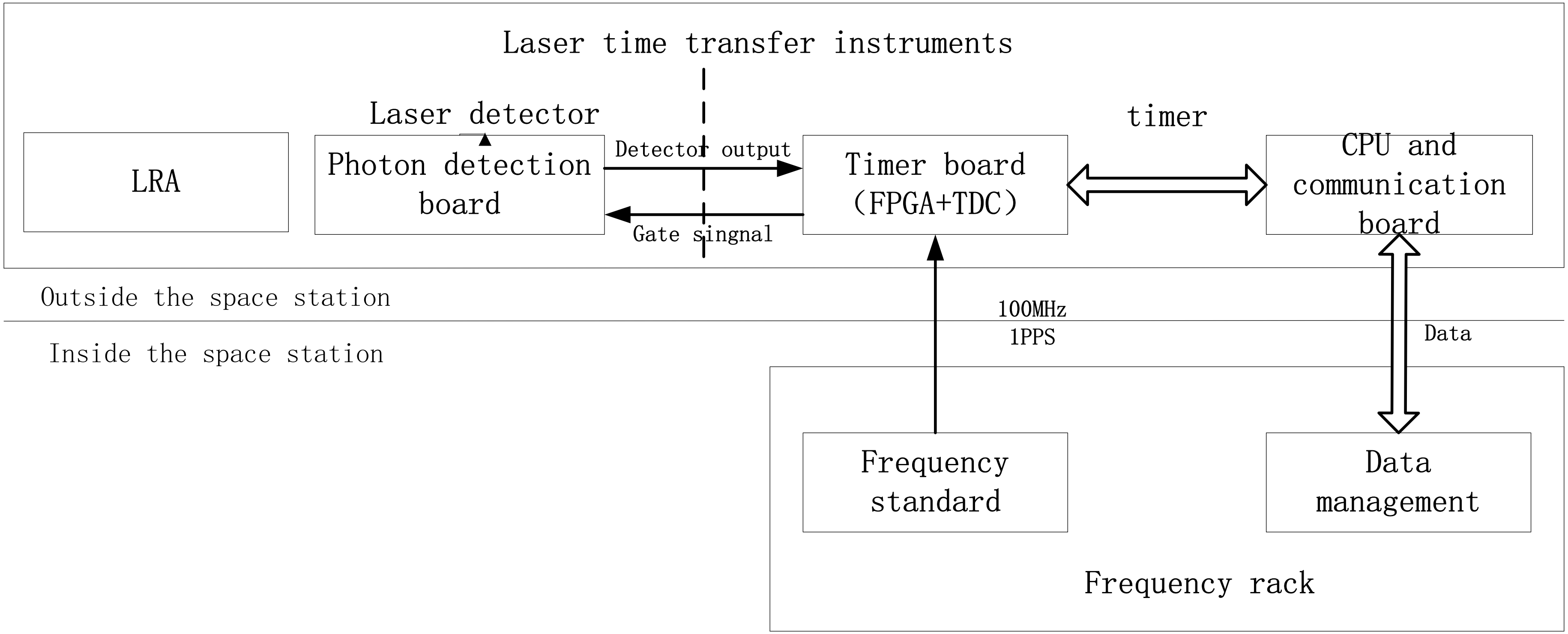
	Beidou LTT
System specification:	
1.Time measuring precision (single shot, RMS) 60ps	**300ps**
2.Time measuring stability : 1ps@300s 1ps@1day	**20ps@500s**
3.Repetitions rate 1kHz	**1Hz/20Hz**
4.Observation: elevation >20° (400km)	**>20° (20000km)**
Onboard detector:	
1.Single photon	**Single photon**
2.Detection precision (single shot, RMS) <30ps	**150ps**
3.Gate mode	**Gate**
4.FOV 128°	**30 °**
Onboard timer:	
1.Single-shot RMS resolution: <10ps	**100ps**
2.Average measurement rate: >1kHz	**20Hz**

LRA

Size: Ø150mm×61mm Dihedral offset: 14″±2″

Compact octahedral array, less spread effect

Diagram of onboard LTT



Frequency standard: 100MHz & 1pps
Data interface: Fiber link/ 1553B
Data link: micro-wave

Design of onboard LTT

A brief consideration:

1> Very big FOV

2> Big noise

{ a special optic design

narrow bandwidth filter

3> Very huge temperature change

voltage compensation and temperature control

4> High timing stability

high performance detector and timer

photon variance ---- time walk

temperature control ---- detection delay

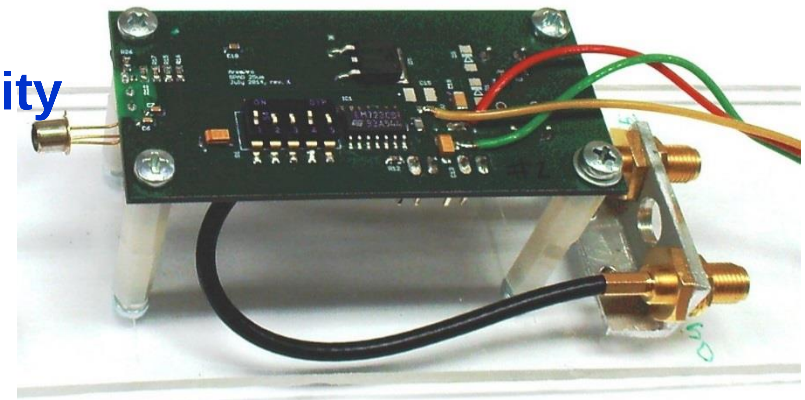
high detection rate --- 1kHz to minimum the short term stability

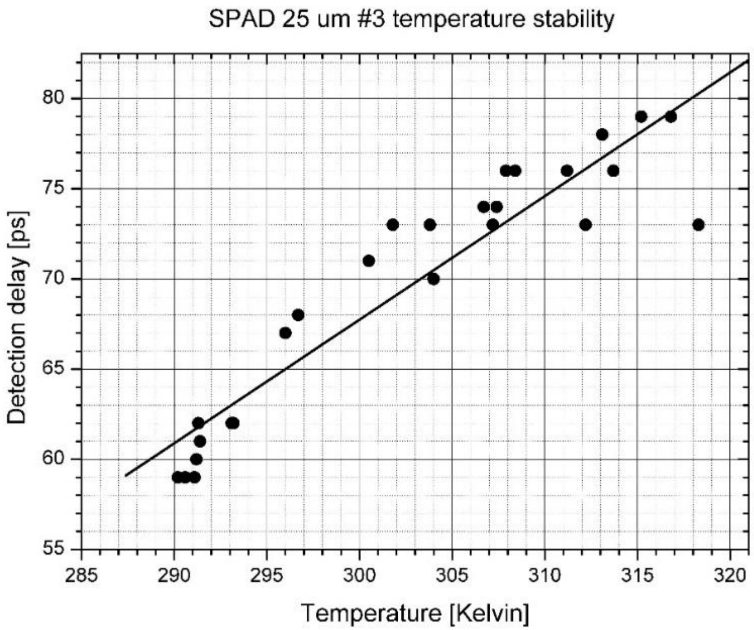
compact design of LRA and detector

Design of onboard LTT

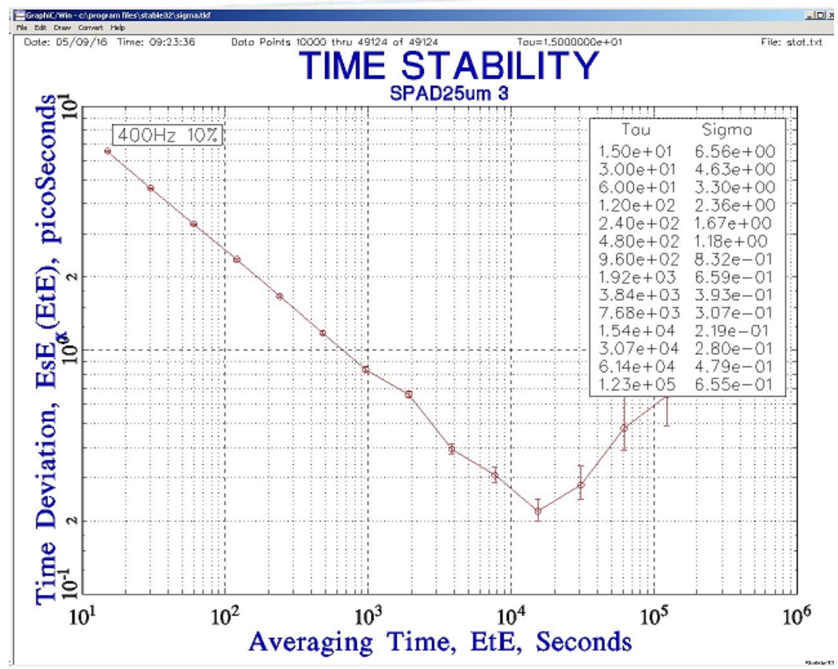
Single photon detector

- K14 from Czech Technical University
- 40um (25um effective)
- Precision <30ps
- Timing stability <1 ps @300s





SPAD detection delay temperature dependence, slope corresponds to +0.68+- 0.1 ps/K.



normal laboratory conditions +/- 1.5 K.
Note the stability TDEV = < 1ps @ 700s to 3 days

Design of onboard LTT

Timer

Based on the timer from Institute of Electronics and Computer Science, Latvia.

- Single-shot RMS resolution: <10ps
- Accuracy of time interval measurements (expected RMS resolution): < 10 ps
- Average measurement rate: >10KPS
- Integral non-linearity: <2 ps RMS
- Single-input offset drift: <0.5 ps/^{0}C

Design of onboard LTT

LRA

A compact design

Size: (150mm±1mm)×(150mm±1mm)×(61±1mm)

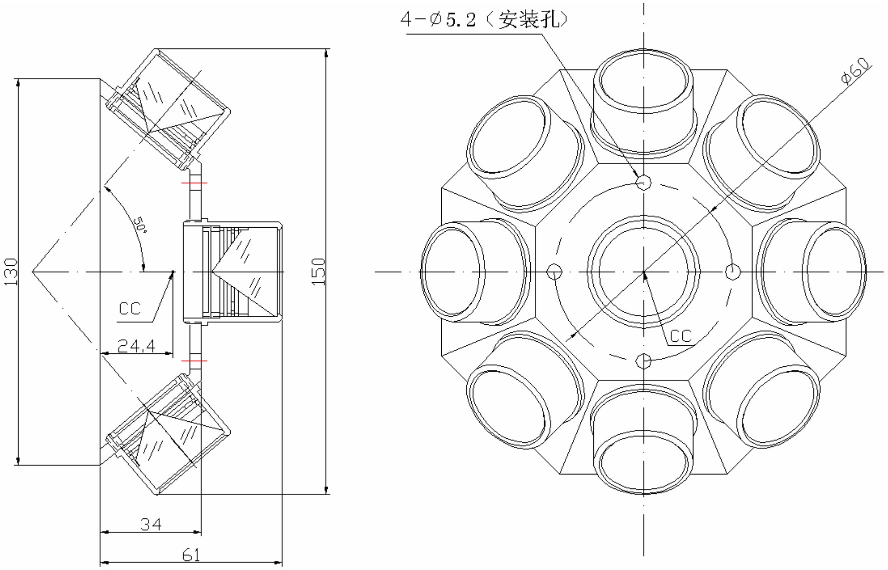
Diameter of corner cube: 28mm

Number of corner cube: 9

Effective reflective area: ≥4.9cm^2（@FOV）

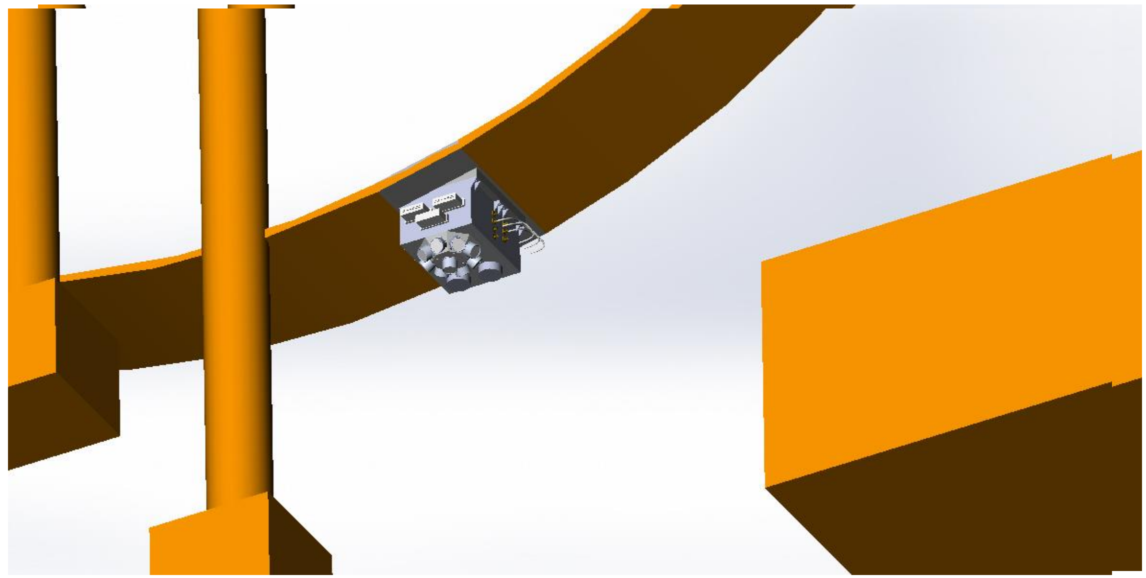
Dihedral offset: 14″±2″

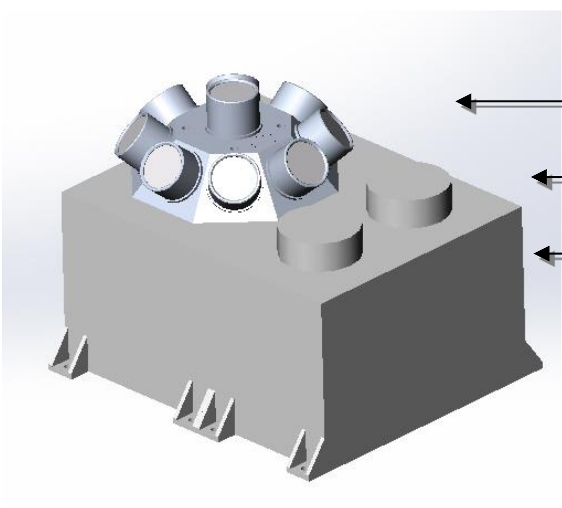
FOV: ≥±64°



Design of onboard LTT

LTT instruments outside the CCS





LRA
Detector
Timer

Ground station

Ground station in the future

1.C-spad and quick start detector
2.Event timer A033 with ps precision
3.Laser: 10ps , 1kHz
4.Frequency standard : H-maser, cold atom clock, optical clock

Recent update plan in Shanghai

1.Optic fiber link to transfer H-Maser to SLR station (~2km away from VLBI station to SLR station)
2.All the instruments include detectors, timer, frequency standard, frequency distribution systems, cables are put in temperature controlled room
3.Laser start detector < 1ps
4.Laser energy controlled by half-wave plate
5.Receive optic path and terminal box move to temperature stable room

Instruments of Frequency and Time transfer over a Fiber Link optic link by Shanghai Institute of Optics and Fine Mechanics (SIOM) , 3-4*10-14@1s， 7-8*10-17@day, 50ps accuracy

4. Project plan

Onboard system

1. End of 2016 Optic design and experiment
2. End of 2017 primary design of detector, timer, LRA
3. End of 2018 system experiment
4. End of 2019 secondary design of LTT onboard instrument
5. End of 2020 final design of LTT instrument
6. ~2022 prepare to be launched

Ground station ?

4. Project plan

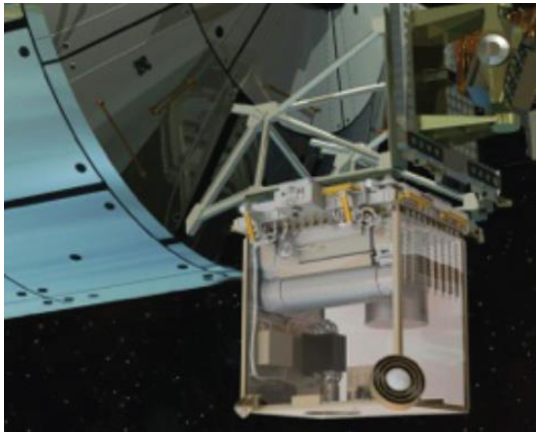
Laser time transfer campaign

We join in the Laser time transfer campaign:

T2L2 non-common view clock comparison between stations

ELT clock comparison campaign

The cooperation will prompt our laser time transfer technology and system design of LTT for CSS!



5. Summary

- A New laser time transfer link onboard China's space station is in design with timing stability less than 1ps.
- Onboard detector is designed with precision <30ps and timing stability <1ps @300s
- Onboard timer is designed with resolution <10ps
- Optic design is in experiment to maintain single photon level.
- Some updates such as fiber timer transfer are in process to support the LTT design, test and T2L2, ELT campaign.

Thank you for your attention！

Shanghai 60cm SLR station