CubeSat Handling of Multisystem Precision Time Transfer

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Mission

Overview

CHOMPTT is a precision timing satellite being developed at University of Florida's Precision Space Systems Laboratory and is equipped with atomic clocks to be synchronized with a ground clock via laser pulses. [1]

"CHOMPTT will demonstrate technology for enhanced GPS and future disaggregated navigation systems."

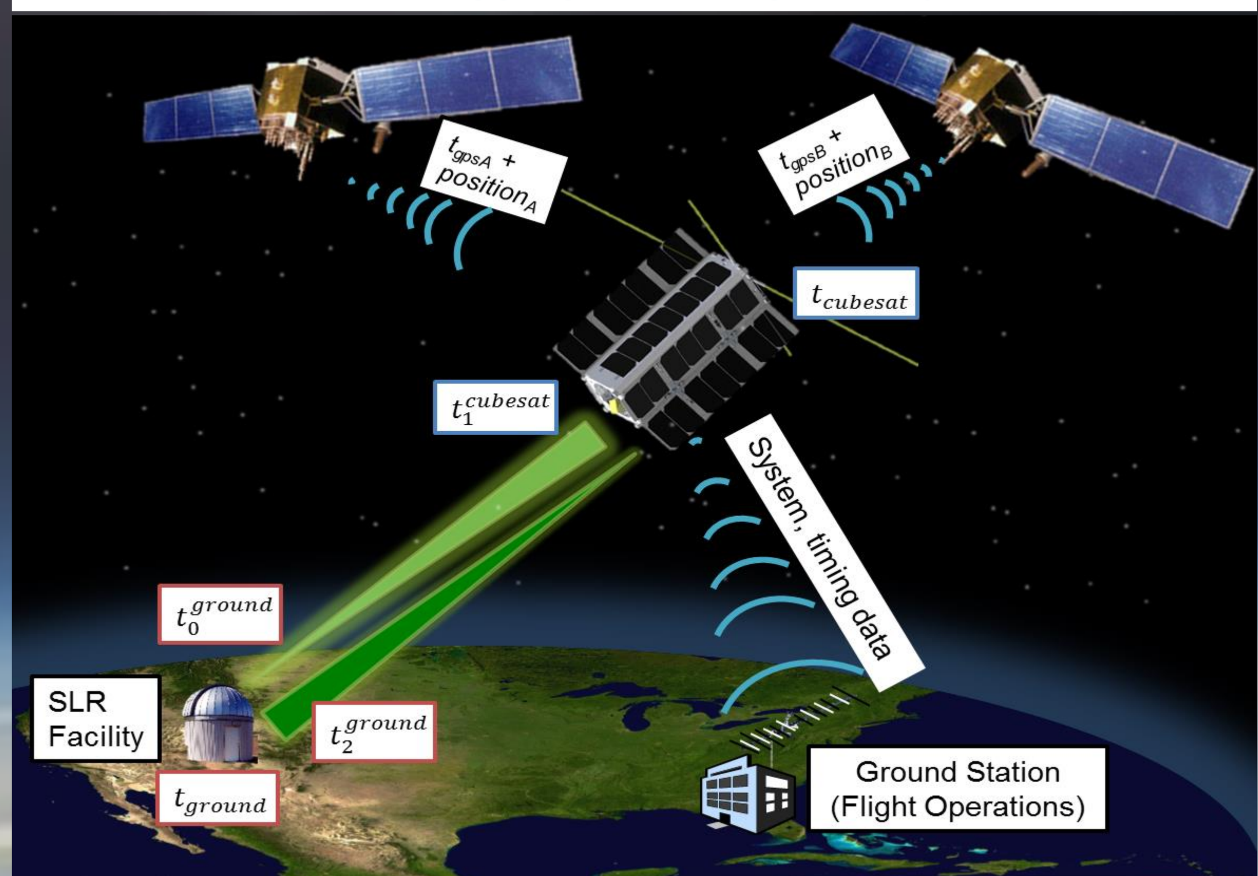

Fig. 1 CHOMPTT mission time transfer concept to calculate the clock discrepancy between a clock on the ground and a clock in space.

Clock discrepancy, $\chi = t_{space} - t_{ground}$

$$\chi = t_1^{\,space} - \frac{t_0^{\,ground} + t_2^{\,ground}}{2} + Correctional\ Terms$$

Objectives:

- 200 ps short term ground to space time transfer accuracy
- Real-time calculation of CubeSat clock discrepancy on-board
- 20 ns long term accuracy over 1 orbit

Concept of Operations

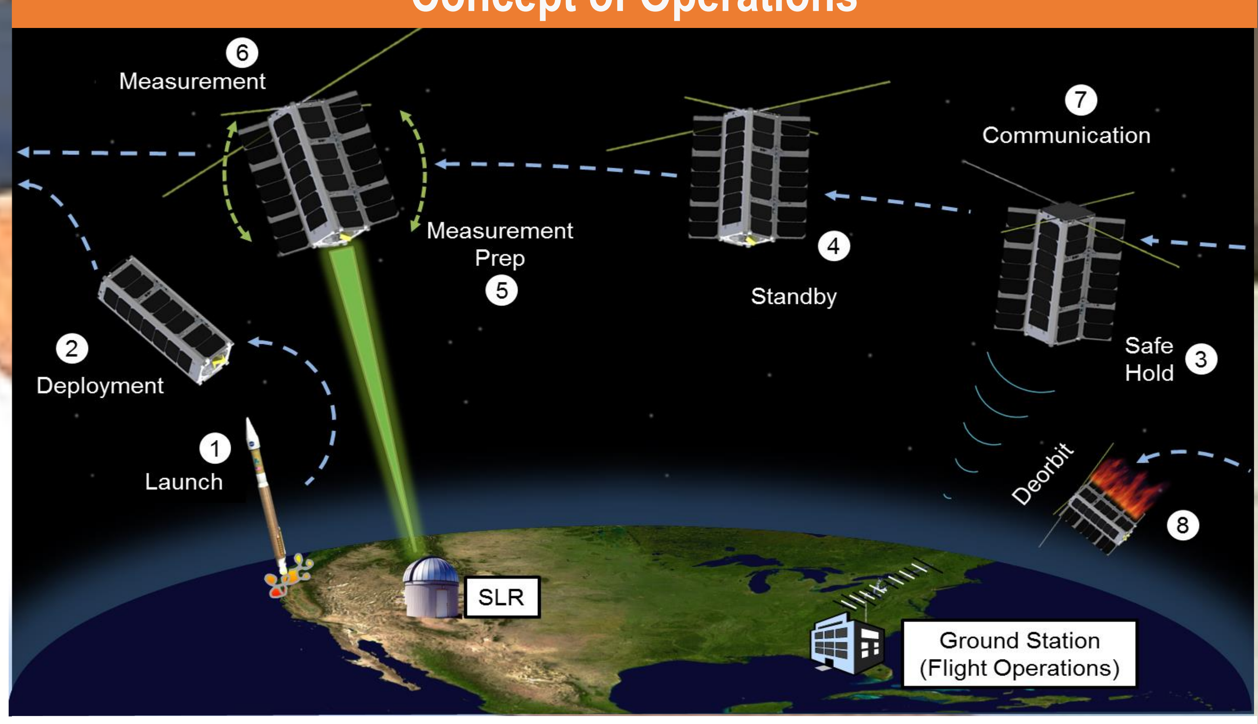

Fig. 2 CHOMPTT concept of operations for the mission duration, keeping on-board time with reference to the space clock and determining clock discrepancy during time transfers with the Satellite Laser Ranging (SLR) facility.

Optical Precision Time-transfer Instrument (OPTI)

Instrument Block Diagram

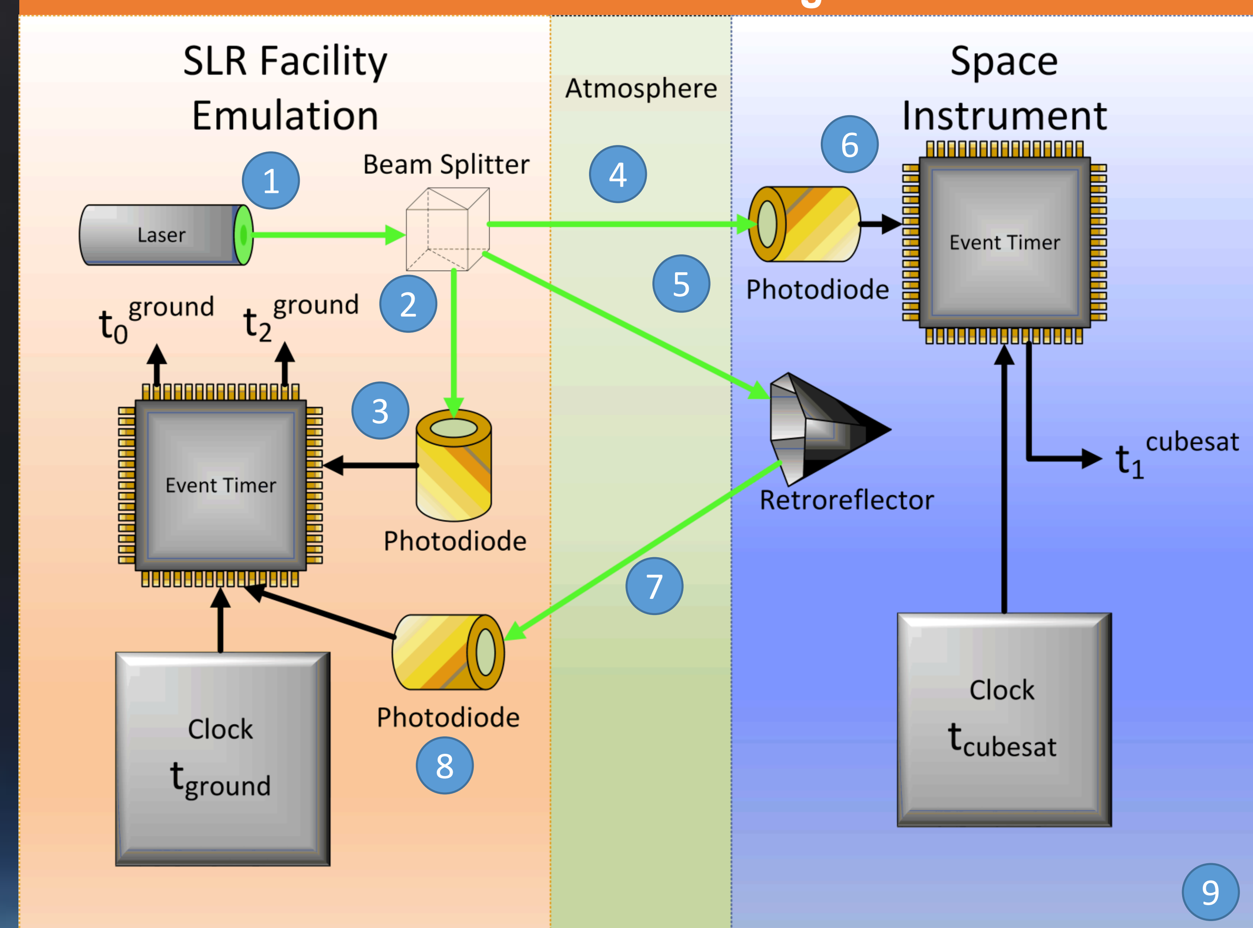

Fig. 3 Laboratory emulation of the time transfer between ground (left) and space (right): **1)** SLR facility laser is emitted **2)** Laser pulse is split by the beam splitter **3)** The less intense portion of the laser pulse triggers the first ground photodiode and gets timestamped by the event timer as time t_0 with respect to the ground clock **4)** The more intense portion of the laser pulse is diffused as it travels through the atmosphere (via diffusing lens in a laboratory setting) **5)** The pulse arrives at the retroreflector and space instrument photodiode simultaneously. **6)** The space instrument photodetector is timestamped by the space event timer as time t_1 with respect to the clock in space **7)** The laser pulse is reflected to ground via the retroreflector **8)** The second ground photodetector is triggered by the pulse and timestamped as time t_2 with respect to the ground clock **9)** Ground timestamps relayed to the space instrument and the discrepancy between the space and ground clocks is calculated on board the spacecraft.

Laboratory Breadboard Demonstration

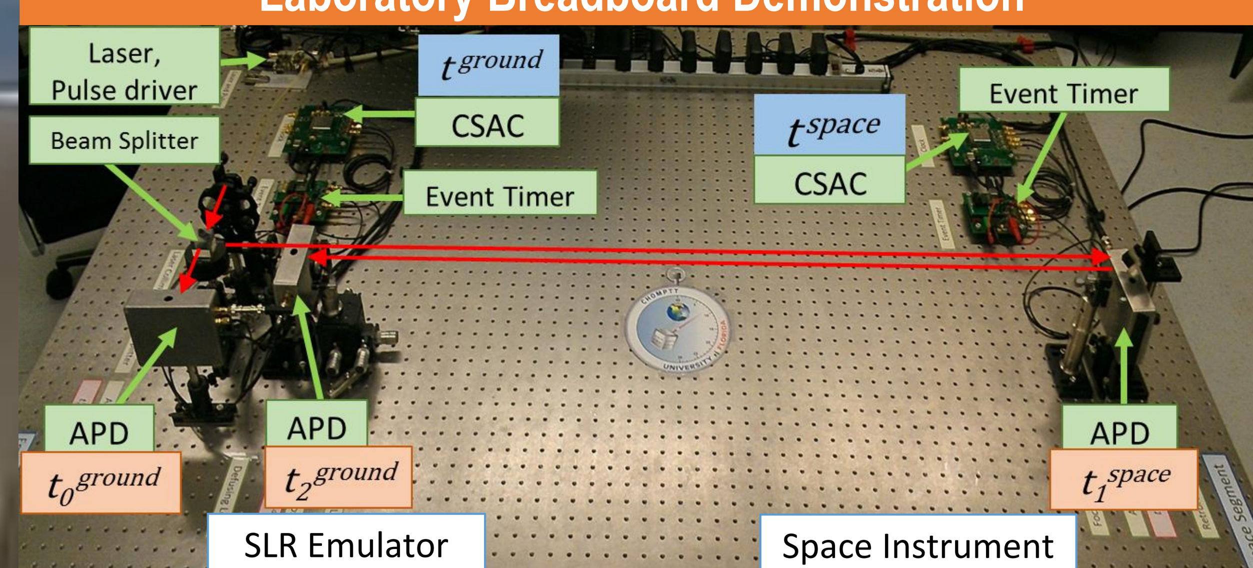

Fig. 4 Laboratory breadboard demonstration of the CHOMPTT mission, which validates time transfer functionality and performance characterization.

Time to Digital Converter

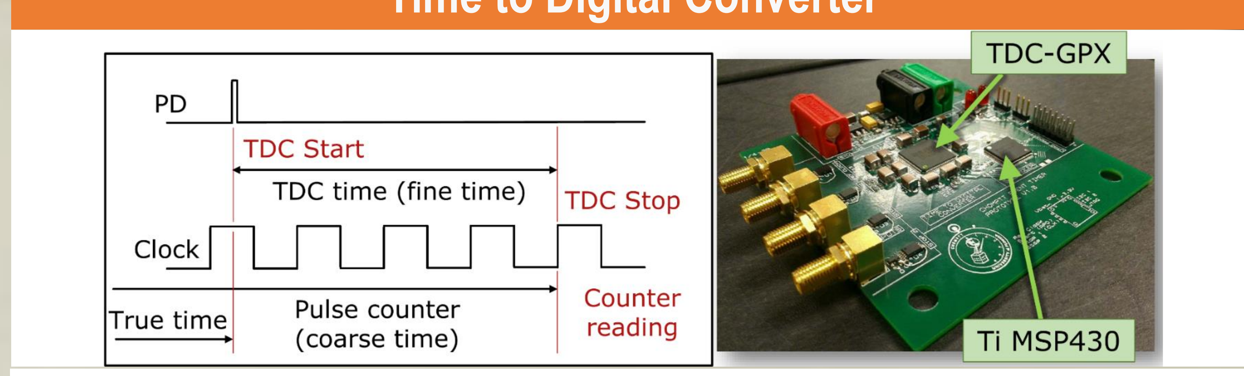

Fig. 5 Time stamping scheme (left) and Breadboard version of TDC-GPX (fine time) and MSP430 (coarse time) event timer (right).

100 ps *measured* short-term time transfer accuracy

Laboratory Breadboard Timing Budget

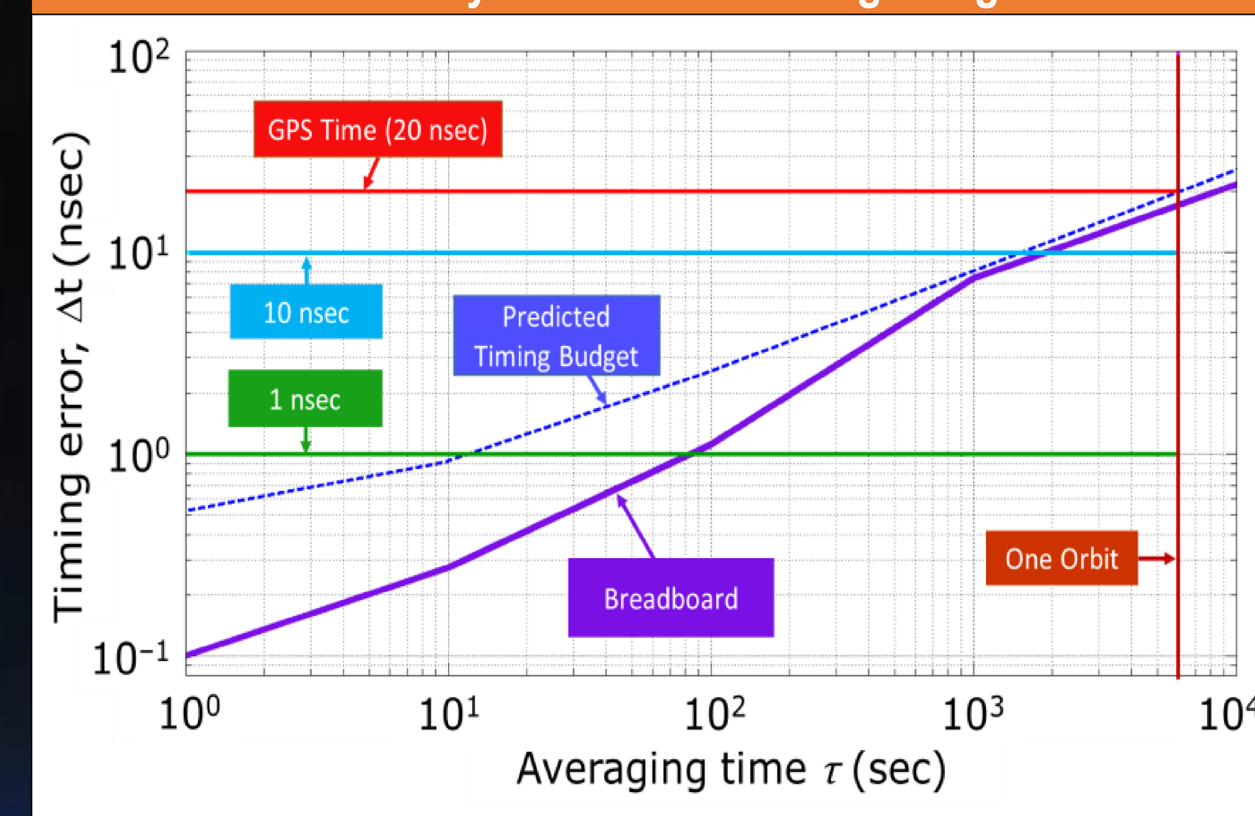

Fig 6. Timing uncertainty of the entire breadboard experiment with 1 orbit (6000 s) between time transfers. OPTI has a better timing uncertainty than GPS (20 ns).

<20 ns of *measured* timing accuracy at 6000 s

OPTI Design

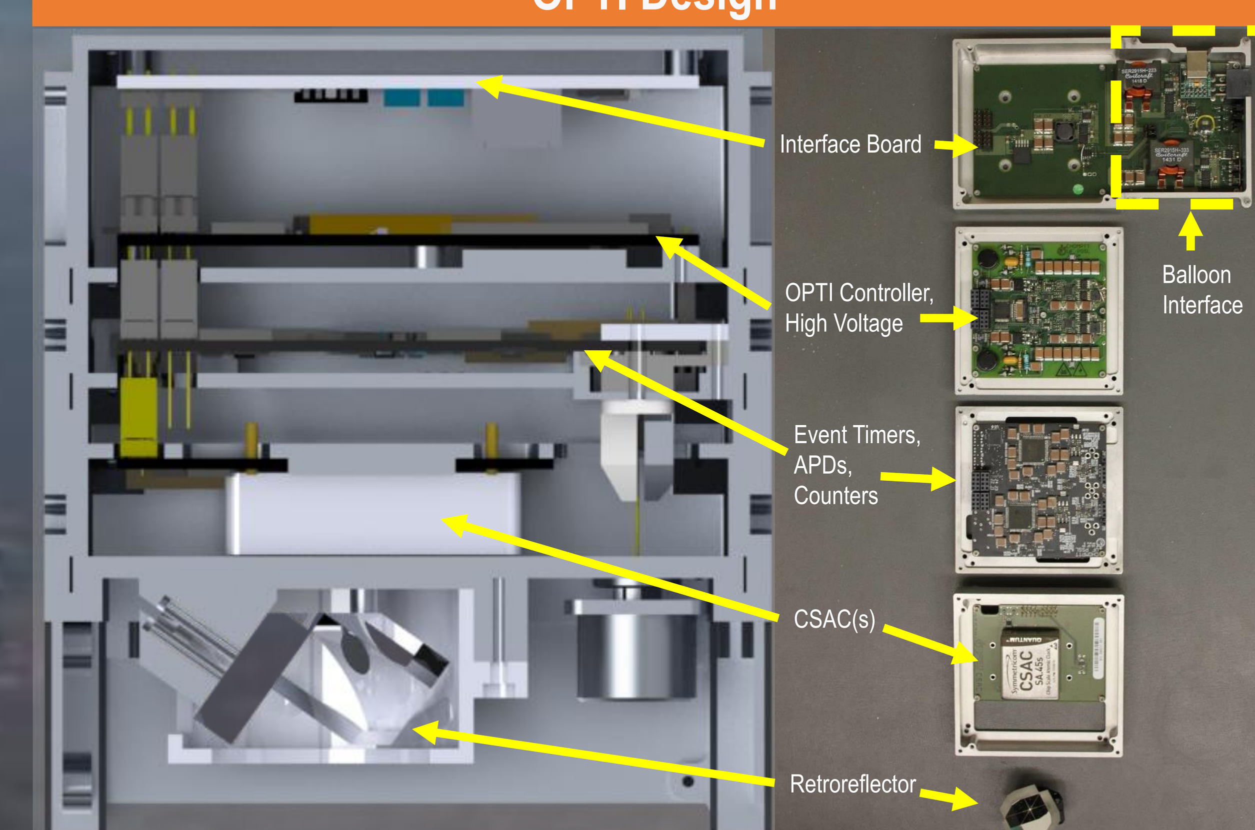

Fig. 7 OPTI 1U section view of stack (left) and OPTI high altitude balloon configuration (right). The balloon interface portion was required for the high altitude balloon flight and has been removed for the flight version.

Avalanche Photodetector and Optics

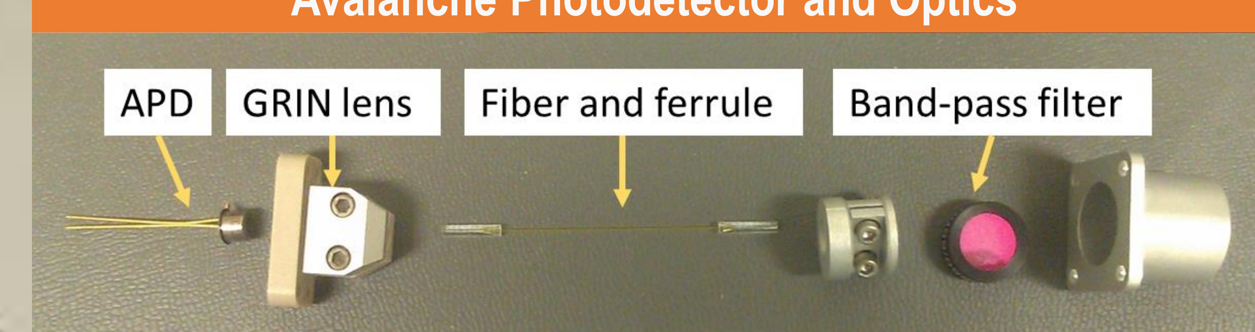

Fig. 8 Avalanche photodetector (APD) and light collection assembly.

High Altitude Balloon Testing

Fig. 9 Sage Cheshire high altitude balloon launch. Successful operation of OPTI in near space environment (no laser or time transfer test was performed).

NASA Ames EDSN Bus Integration

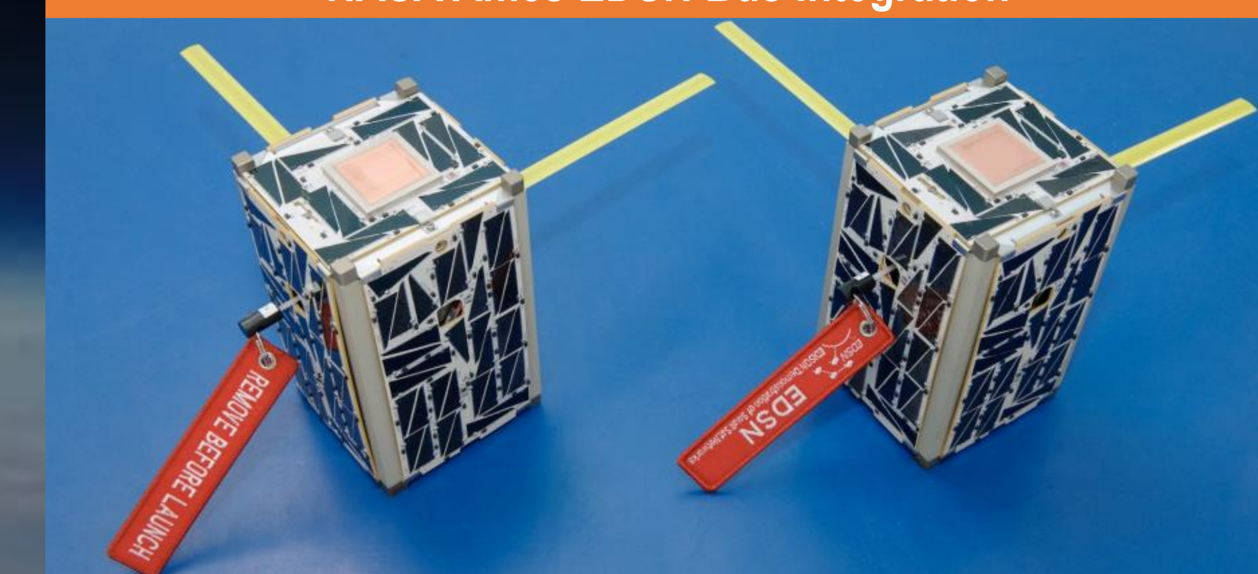

Fig. 10 OPTI is currently being integrated with the NASA Ames EDSN 1.5U bus. EDSN includes COTS components such as: Nexus S Phone (CDH), Stensat UHF (Beacon), AstroDev Li-1 UHF transceiver (uplink and downlink radio), Novatel OEMV-1 (GPS), and Li-Ion Batteries (2800 mAh). The entire bus consumes ~1 W orbit average power. [2]

Satellite Laser Ranging Facility at TISTEF

Fig. 11 Satellite Laser Ranging (SLR) facility operated by Townes Institute Science & Technology Experimentation Facility (TISTEF) managed by University of Central Florida at Kennedy Space Center. Collaboration includes a 1064 nm laser with 50 cm satellite tracking telescope and 1 km test range. [3]

References

[1] Conklin, John, Barnwell, Nathan, et al. "Optical time transfer for future disaggregated small satellite navigation systems." (2014).
[2] Chartres, James, Hugo Sanchez, and John Hanson. "EDSN Development Lessons Learned." (2014)
[3] "The Townes Laser Institute." *Townes Laser Institute*. Web. 17 July 2015. <http://www.townes.ucf.edu/istef.html>.