CHOMPTT (CubeSat Handling of Multisystem Precision Timing Transfer): From Concept to Launch Pad

SmallSat 2017: August, 6th 2017

Presenter: Seth Nydam²

Watson Attai¹, Nathan Barnwell², Maria Carrasquilla², Jonathan Chavez², Olivia Formoso¹, John Hanson¹, Belgacem Jaroux¹, Asia Nelson², Anh N. Nguyen¹, Tyler Noel², Seth Nydam², Ken Oyadomari¹, Jessie Pease², Frank Pistella², Cedric Priscal¹, Tyler Ritz², Steven Roberts², Paul Serra², Jan Stupl¹, Evan Waxman², Jasper Wolfe¹, and John W. Conklin²

1. NASA Ames Research Center
2. University of Florida
Agenda

• Mission Overview
• Payload Design History
• Flight Payload Overview
• Spacecraft Overview
• SLR (Satellite Laser Ranging) Facility Overview
• Current Status
Background and Motivation

- Initial proposal for CHOMPTT in Fall 2012 for UNP8
- Application of precision time transfer to space:
  - Satellite navigation system
    - Beyond LEO
  - Global time standards
  - Test of general relativity
  - Satellite encryption/authentication
  - Communications and Networking
- Optical time transfer
  - More resilient to ionospheric effects than RF ($\propto 1/f^2$)
  - CNES T2L2 (2008), hosted payload on Jason-2

T2L2 mission [P. Guillemot et al 2006]
Mission Overview

Terminator SLR Pass

GS Pass

Clock Discrepancy, $\chi$

$\chi = t_{\text{space}} - t_{\text{ground}}$

$\chi = \frac{t_{1,\text{space}}}{2} - \frac{t_{2,\text{ground}} + t_{0,\text{ground}}}{2}$

+ Correctional Terms (known)

**Single Time-Transfer**  <200 ps time transfer error, < 20 ns clock drift after 1 orbit

CHOMPTT: From Concept to Launch
OPTI 1.0

(Optical Precision Timing Instrument)

- Design based on AFRL UNP Mission Requirements
- Key Technologies: Precision timing electronics, a Chip Scale Atomic Clock (CSAC), Avalanche Photodetector
- Successful laboratory testing of breadboard

Measured timing error:
- 100 ps (3 cm) @ 1 sec
- 20 ns (6 m) @ 6000 sec
• EDU unit for the UNP8 unit configuration
• Much higher power ~8W average because of Miniature atomic clock
• 1.5 U form factor with reconfigurable clocks
• Power regulation and distribution
• High Altitude Balloon Test
  • ~100,000 ft. for 6+ hours
  • Obtained system health data
  • Successful power cycle test
• UF planned to design entire CubeSat
NASA Ames/Advanced Exploration Systems began CHOMPTT support

- NASA Ames bus: EDSN Derived Bus (Summer 2015)
- New low-power mission requirements from bus (<2 W average)
- Decrease size to 1U
- Key technologies: precision timing electronics, two CSACs, APD, single 1 in. retroreflector design

EDU Unit for current flight version
OPTI 3.1 (FlightPayload)

- New/defined SLR requirements
- Include beacon laser diodes
- Include additional debug ports and test points
Flight Channel Board

• Responsible for Precision Timing

• Key Components:
  • TDC-GPX
    • Integrated solution
    • Measurement based on propagation delay
    • Autonomous temperature compensation using DLL
    • 10 ps single shot accuracy
  • MSP430
    • Microcontroller, Provides course clock counts
  • CSAC (Chip Scale Atomic Clock)
    • Low size, power, and weight so minimal budget impact
    • Allan Deviation: $3.26 \times 10^{-12}$ after one orbit
  • Avalanche Photodetector
    • InGaAs APD with wavelength detection 900-1630 nm
    • High gain, small package with TEC included

CHOMPTT: From Concept to Launch
Channel Board Results

Measured timing error:
150 ps (4.5 cm) @ 1 sec
3.5 ns (1 m) @ 1000 sec

- Less optical received than on orbit
- Timestamped all ~15000 pulses with no artifacts

CHOMPTT: From Concept to Launch
Flight Supervisor Board

- Data management and storage between the two channel boards
- Current driver for laser diodes
- Key Components
  - Custom current driver on board (4X)
  - N25Q00AA 1 Gb NOR Flash Memory
  - MSP430
Flight Optical Assembly

• Hollow Retroreflector Array (HRA): Six (6) Ø 0.40 [10mm] Clear Aperture
  • Individual Retroreflector Accuracy: 15 arc seconds.

Testing at:

• Laser Diodes
  • 4X 808 nm
  • 4X 500 mW optical power
Spacecraft

- 3U CubeSat form factor
- 3.9 kg
- <2 W orbit average
SLR Facility (TISTEF/UCF)

Coherent Flare 50/50
- 1064 nm
- 1 mJ
- Linear Polarized

CHOMPTT: From Concept to Launch
Status

• ElaNa XIX Launch
  • Rocket Labs LV
  • Electron, Mahia NZ
  • Low Earth Orbit:
    • 500 km x 85 deg
  • Delivery: Q4 2017
  • Launch: Q1 2018

• Finished conformal coating and functional testing of flight boards
• Working towards final integration and verification tests
• Shake and Bake this month
• Final testing in FL with SLR and ground station in Sept.
Postdoc, Scientist positions

- Positions available in the following areas:
  - Digital & analog electronics/avionics for space
  - Optics, photonics, lasers and detectors
  - Control & estimation techniques applied to complex systems

- Contact: jwconklin@ufl.edu

Inertial sensors, drag-free systems

Precision timing, Opto-electronics

Geodesy & Gravitational waves

Navigation & Optical Comms

LIGO

LISA
Gravitational Wave Observatory
Vibrational Testing

• Vibration testing to GEVS specs on all three axis
• All four beacons were functional to spec after the vibrational test