Geodetic Reference Instrument Transponder for Small Satellites (GRITSS)

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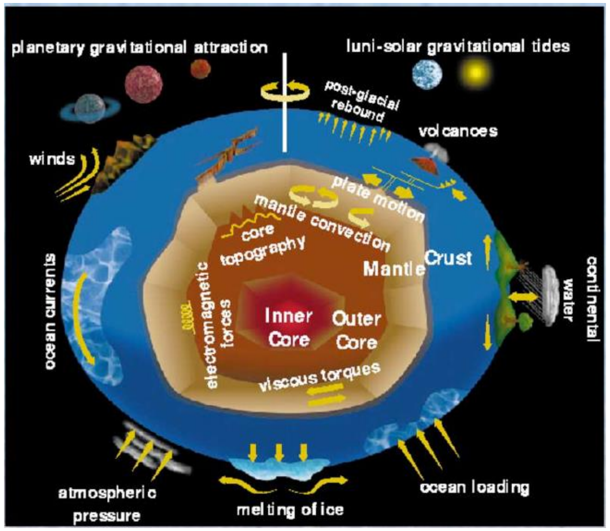
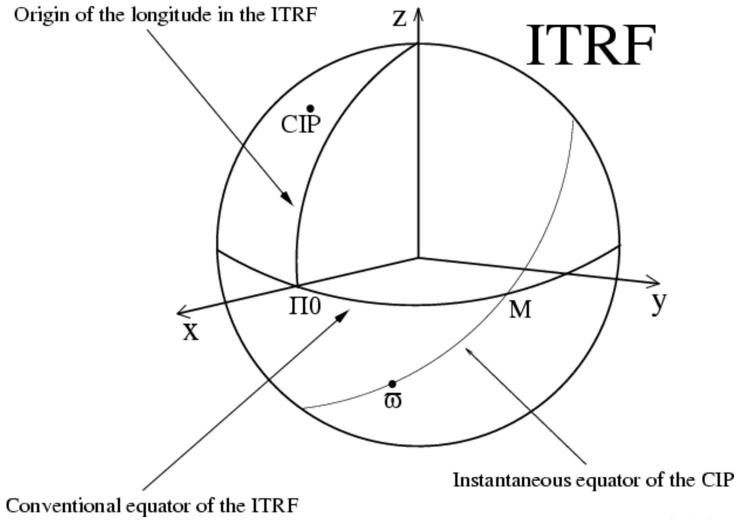
Enhancement of Geodetic Site Ties

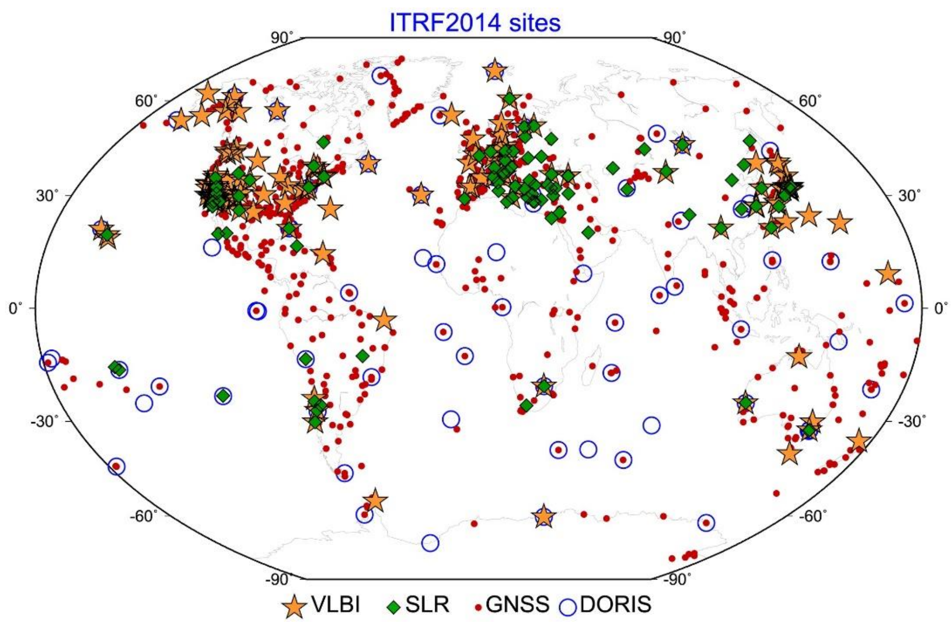
- Geodesy: measurement of Earth's shape, orientation and gravitational field
- International Terrestrial Reference Frame defines a coordinate system fixed to the Earth
- How is the ITRF defined?



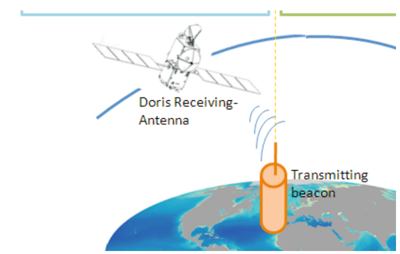


Enhancement of Geodetic Site Ties

- International Terrestrial Reference Frame (ITRF):
  Description (e.g. ITRF2014): ~1000 reference locations on the Earth with accurate coordinates, consisting of four separate networks: GPS, VLBI, DORIS, and SLR.



SLR



DORIS

GNSS

VLBI

Altamimi, Z., et al. (2016), J. Geophys. Res. Solid Earth, doi:10.1002/2016JB013098.

Science Missions Dependent on Space Geodesy

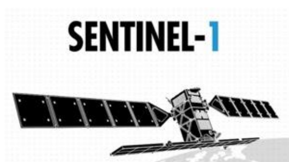
Ocean topography, mean sea level

SWOT: Surface Waters, Ocean Topography

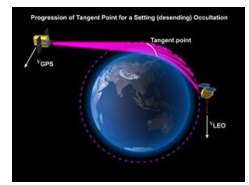
Polar Ice Sheet and Glacier changes, sea-ice thickness, Vegetation canopy ht.

3D-Vegetation canopy structure; Forest carbon sources & sinks; Surface topography

Mass change (cryosphere, hydrology, solid earth, oceans)



Ice-sheet collapse; Ecosystem disturbances; Natural Hazards (Volcanos, earthquakes, landslides)



GNSS RO satellites: Weather forecasting; Climate studies; Global ionosphere models

Extreme weather prediction

All these missions have Precision Orbit Determination and geolocation requirements that depend on a stable & precise Terrestrial Reference Frame and accurate Earth Orientation Parameters. SLR data to geodetic satellites determines the geocenter and low degree gravity terms which are a vital input to POD and to measurements of global mass change.

Enhancement of Geodetic Site Ties

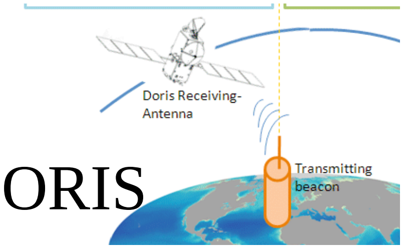
- NRC → Improve ITRF to modernize Geodesy and enable future sea level measurements
  - Nerem et. al. “Climate-change-driven accelerated sea level rise…” PNAS 2018
- Performance goals for the future of the ITRF
  - 1mm accuracy on decadal scales
  - 0.1mm/year stability on annual scales
- <u>Factor of 10-20</u> beyond capabilities of current Geodetic Infrastructure
  - In ITRF2014, the discrepancy between space geodesy and local tie measurements (e.g. GNSS and SLR & VLBI points) is often at the level of 10 mm.
- What are the limiting factors?

Enhancement of Geodetic Site Ties

Combining the Techniques for the ITRF:

- Measurement of local ties via optical surveys is the only way; *The tie vectors are introduced mathematically when an ITRF solution is derived*.
- Surveys can determine physical locations of reference points with mm accuracy.
- For the radio techniques, determining the electromagnetic phase center at the mm level is not yet possible.

SLR



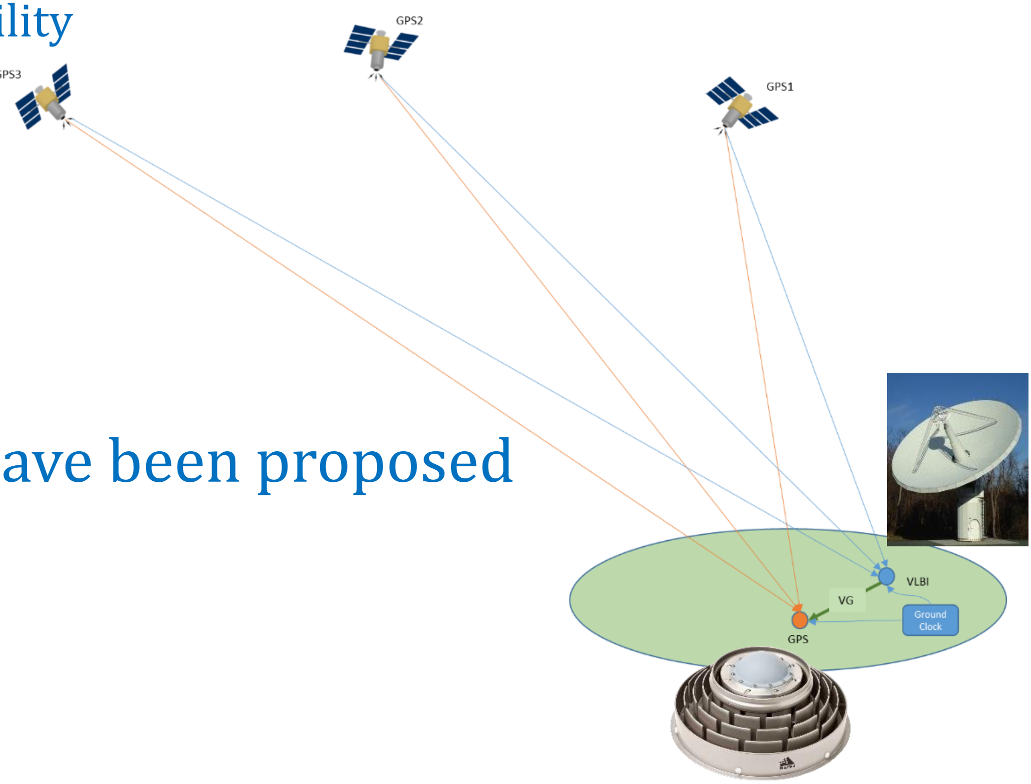
DORIS

VLBI GNSS

- **A methodology that provides a common radio basis for both GPS and VLBI is needed to assert co-location delay closure**

Enhancement of Geodetic Site Ties

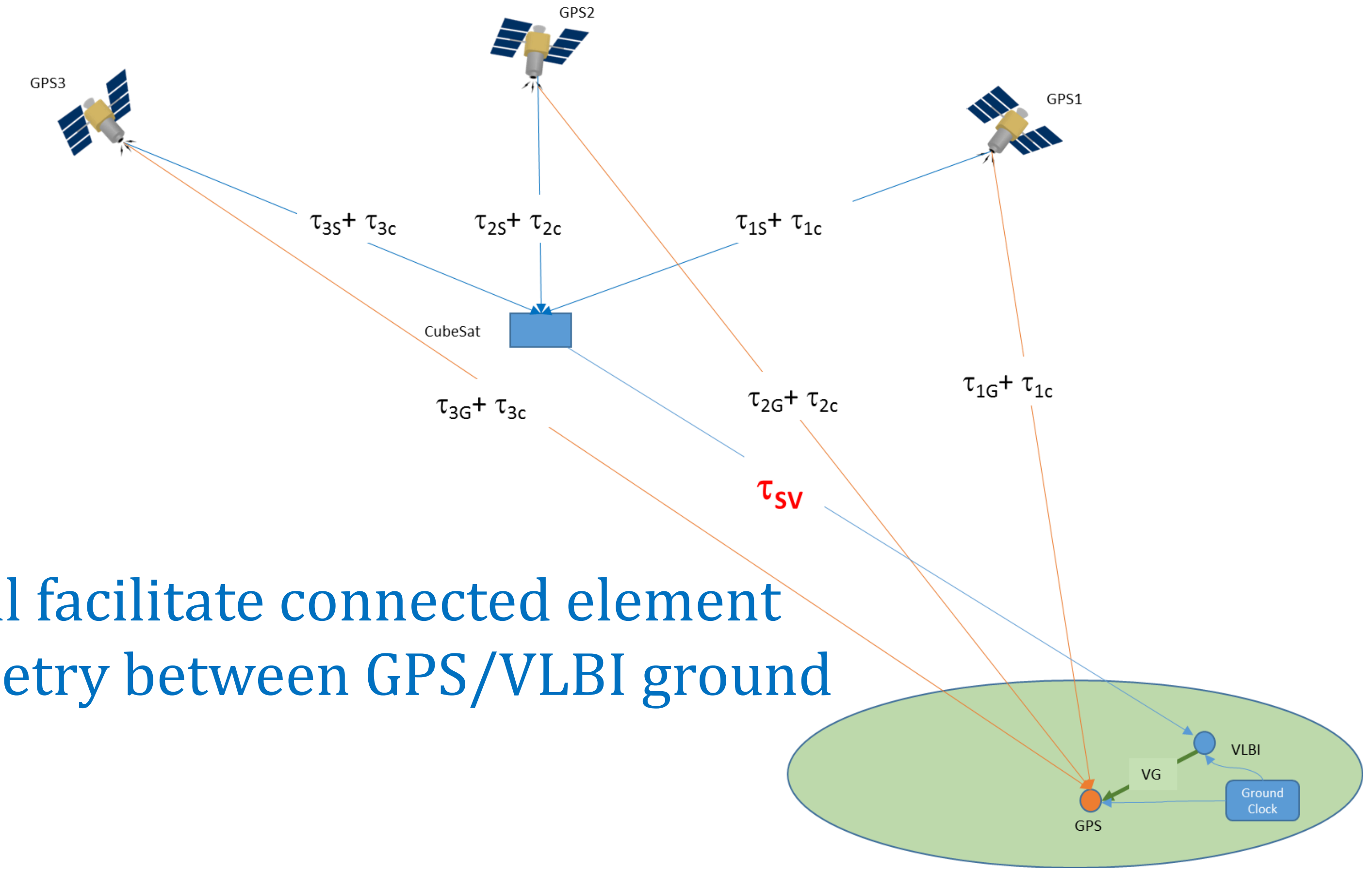
- Obvious solution: observe GPS with the VLBI antenna
  - SGP issue of spectral compatibility
    - GPS: 1.2/1.5 GHz
    - VLBI: 2-14 GHz (3-14 GHz)
  - VLBI antenna very directional
  - GPS antenna omnidirectional



- Various other techniques have been proposed with limited success

GRITSS Technology

- GRITSS circumvents spectral incompatibility and directionality with the introduction of a small transponder satellite

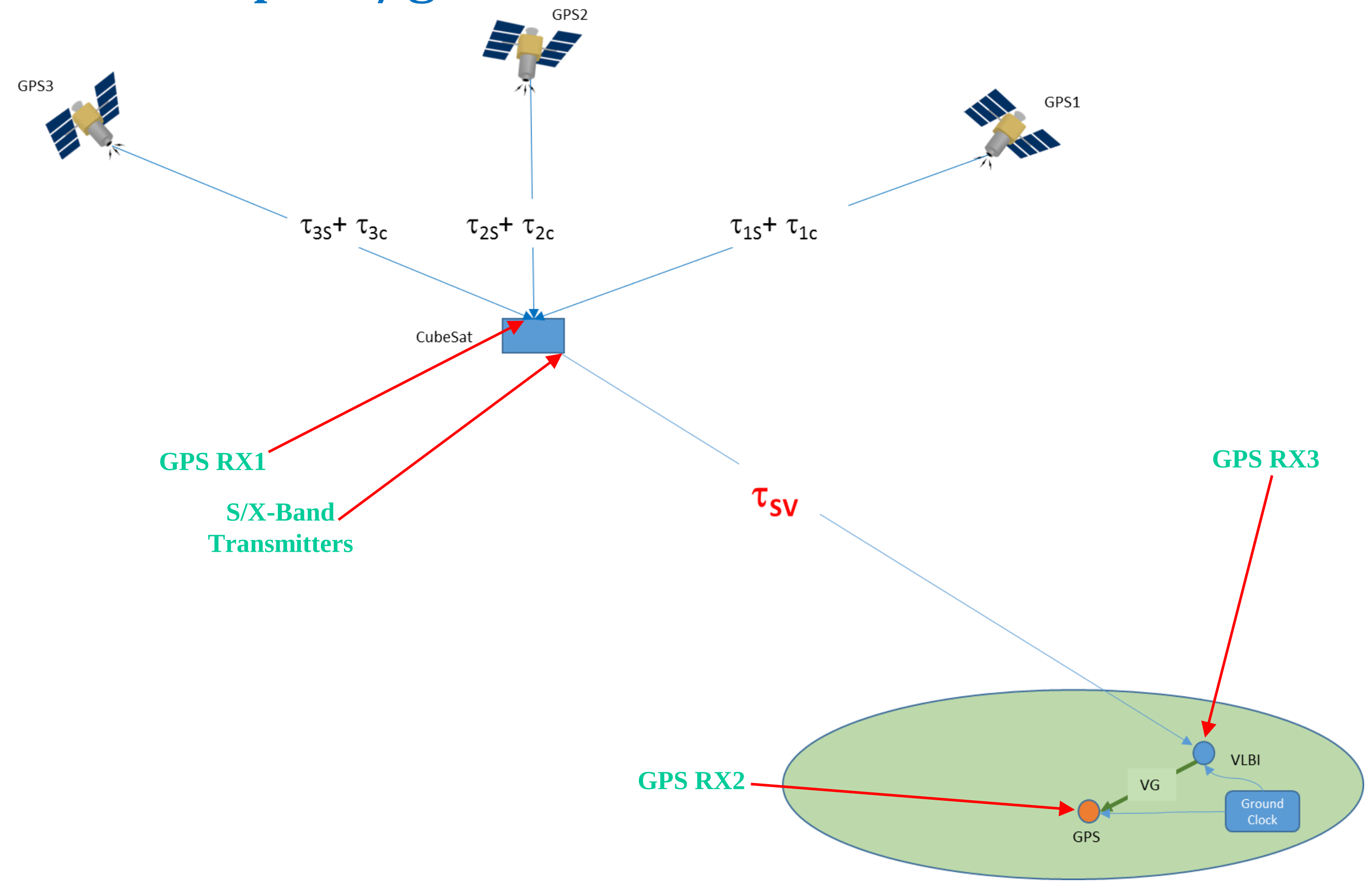


- GRITSS will facilitate connected element interferometry between GPS/VLBI ground receivers

- Differencing allows direct suppression of common clock terms

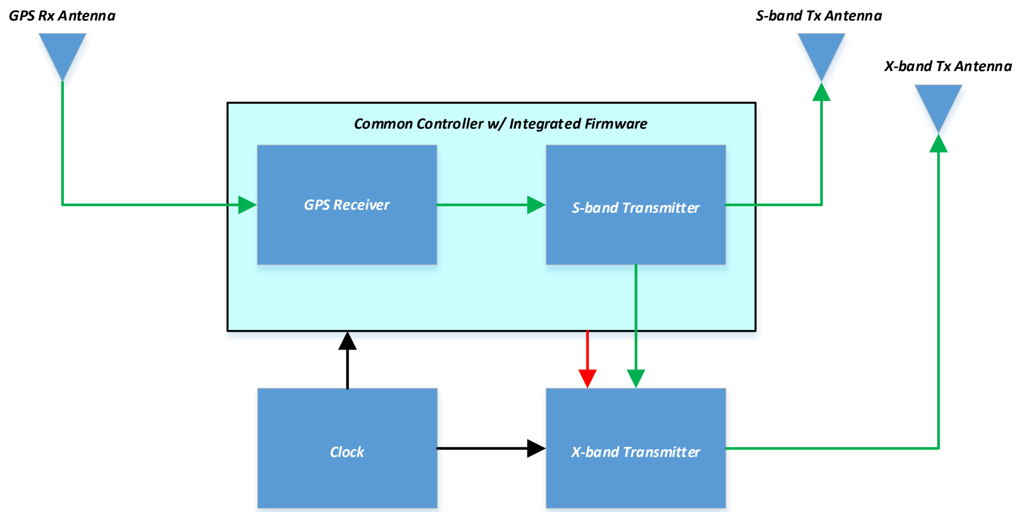
GRITSS Technology

- τ_{sv} observable is a TOF observable that is tightly coupled to difference between space/ground GPS receiver clock biases



- Fitting τ_{sv} to model given CubeSat POD yields VLBI position

GRITSS Technology



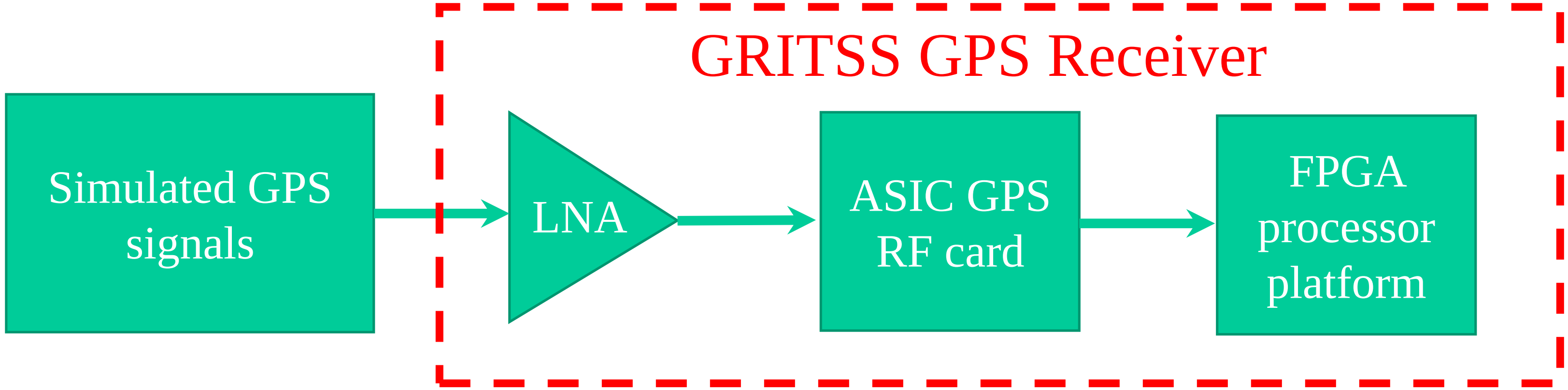
High Level Block Diagram

- GRITSS will transpond GPS to VLBI users over S/X band Channels
- GPS Receiver (GSFC-596) and S-band Transmitter (GSFC-567)
- X-band Transmitter and Clock (UML)

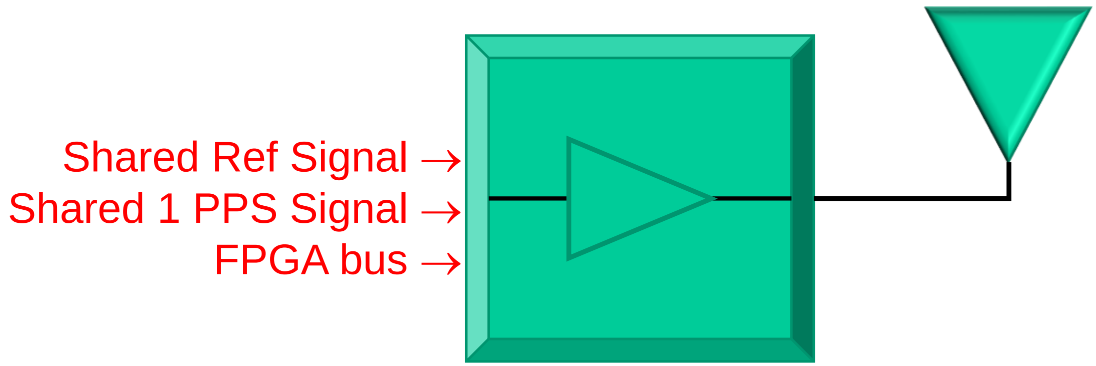
GRITSS Technology

GRITSS GPS Receiver Summary (TRL5)

- Rad-hard GPS RF front-end card design
  - Wide-band, dual-frequency GPS L1 C/A and L2C
- GPS software and firmware builds on proven GSFC MMS Navigator flight heritage
  - Fast acquisition/weak signal acquisition capabilities
  - Currently operating at 29.3 Re (halfway to the moon)
- Provides position, velocity, and time (PVT) and raw L1 C/A and L2C samples
- Provides 1 Pulse Per Second (1PPS) timing signal
- Supports onboard or an enhanced external reference clock



GRITSS Technology

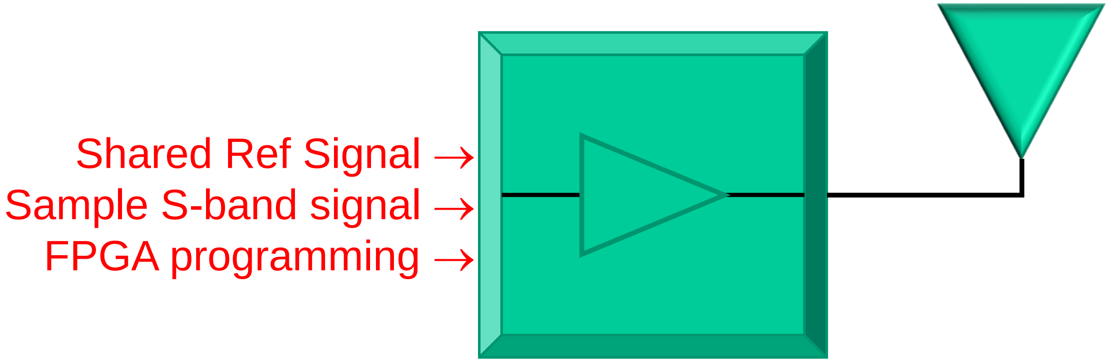


GRITSS S-band Transmitter Top-Level Block Diagram

GRITSS S-band Transmitter Summary (TRL5 → Sept 2021)

- Designed for GRITSS' mission requirements
  - Dedicated input for reference signal, common with other GRITSS subsystems
  - Dedicated input for 1 PPS signal, common with other GRITSS subsystems
  - Dedicated frequency of operation, but configurable over a wide range
  - Dedicated coupled output port and power level for the X-band transmitter system
- Shared resources with other GRITSS subsystems to minimize size, weight, and power
- Operation controlled through FPGA bus. Shared FPGA with other GRITSS subsystems
- Leveraged existing flight hardware designs
- Infused latest state-of-the-art technologies for performance and configurability

GRITSS Technology

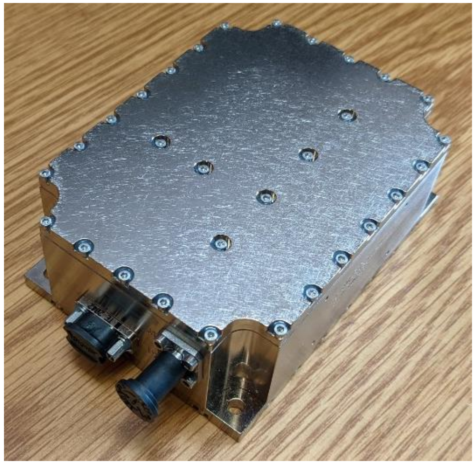


GRITSS X-band Transmitter Top-Level Block Diagram

GRITSS X-band Transmitter Summary (TRL5)

- Implemented as S-to-X-band Upconverter with Power amplifier
- Tune-able design to accommodate changes in transmission allocations.
- Designed as stand-alone module with well-defined interfaces to GSFC embedded controller

GRITSS Technology



Wenzel Ultra-stable Oscillator

Clock (TRL9)

- Wenzel Ultra-Stable Oscillator – COTS component with space mission heritage
- Measured ADEV: 2.24×10^{-13} @ 1sec, 4.17×10^{-13} @ 10sec, 1.61×10^{-12} @ 100sec
- Quiescent Power Consumption: 4.7 Watts @ 12 VDC

Latest Status

- Completed build and testing of TRL5 GPS Receiver and X-band Transmitter subsystems
- Completed build and testing of TRL4 S-band Transmitter subsystem and completion of the TRL5 unit scheduled for Sept 2021
- Integrated full GRITSS instrument using above systems and began system-level testing
  - Testing utilizes the Formation Flying Test Bed at GSFC to simulate on-orbit GPS signals
  - Test plan progressively increases level of complexity to fully demonstrate performance and validate the measurement concept
- Developed initial design of GRITSS integrated in a 6U CubeSat and completed Master Equipment List with resource requirements