

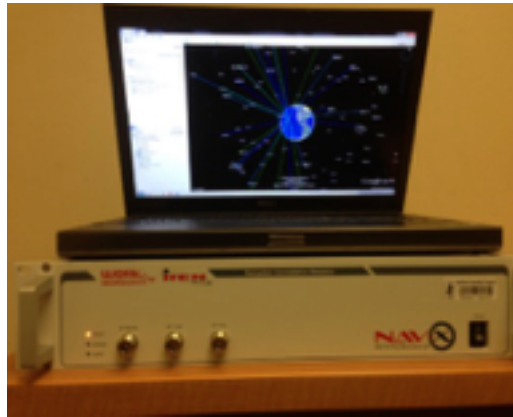


Distributed Timing and Localization (DiGiTaL)

A Precision GNSS-Navigation System for Nanosatellites

The Distributed Timing and Localization (DiGiTaL) system provides nanosatellite formations with unprecedented, centimeter-level navigation accuracy in real time and nanosecond-level time synchronization. This is achieved through the integration of a multi-constellation Global Navigation Satellite System (GNSS) receiver, a Chip-Scale Atomic Clock (CSAC), and a dedicated Inter-Satellite Link (ISL). In comparison, traditional single spacecraft GNSS navigation solutions are accurate only to the meter-level due to the sole usage of coarse pseudorange measurements. To meet the strict requirements of future miniaturized distributed space systems, DiGiTaL uses powerful error-cancelling combinations of raw carrier-phase measurements which are exchanged between the swarming nanosatellites through a decentralized network. A reduced-dynamics estimation architecture on board each individual nanosatellite processes the resulting millimeter-level noise measurements to reconstruct the full formation state with high accuracy.

Although carrier-phase measurements offer millimeter-level noise, they are subject to an offset, also called integer ambiguity, which is an unknown integer number of cycles. These ambiguities must be resolved in real time on board the spacecraft to meet the accurate relative positioning goals of this project. As this is a very computationally intensive task, it is often beyond the capability of spaceborne microprocessors. In contrast to standard offline approaches, DiGiTaL leverages diverse combinations of measurements from new L2M and L5 GPS frequencies and frequencies from the Galileo and Beidou navigational satellite systems. This will create wide-lane data types to efficiently resolve integer ambiguities.



A multi-GNSS dual-output signal simulator is used for the hardware-in-the-loop validation of DiGiTaL.

The estimation architecture is embedded in a distributed network of nanosatellites and is intended to support all operational scenarios, while coping with data handling and communication constraints. To this end, each DiGiTaL instance processes measurements from only a limited number of satellites simultaneously. The resulting estimates produced by each nanosatellite are then combined in a dedicated swarm orbit determination algorithm to provide full formation orbit knowledge. Contingency scenarios are aided by a near-omnidirectional antenna system and a CSAC, which supports accurate orbit propagation and faster convergence times in GNSS-impaired scenarios.

DiGiTaL is motivated by two key technologies which are revolutionizing the way humans conduct spaceflight: the miniaturization of satellites and the distribution of payload tasks among multiple coordinated units. The combination of these techniques is leading to a new generation of space architectures, so-called distributed space systems which promise breakthroughs in space, planetary and earth

science, as well as on-orbit servicing, and space situational awareness. However, current technologies for satellite navigation and timekeeping are insufficient to support NASA's future mission concepts. DiGiTaL responds to this need by providing the navigation and timing accuracy required for multiple nanosatellites to act in unison as a large aperture spacecraft. Some specific mission applications include, but are not limited to, synthetic aperture radar interferometers, differential gravimeters, starshade/telescope systems for the direct imaging of the star vicinity, and autonomous assembly of larger structures in space.

DiGiTaL is developed by the Space Rendezvous Laboratory (SLAB) at Stanford University's Department of Aeronautics and Astronautics in partnership with NASA Goddard Space Flight Center and Tyvak Nano-Satellite Systems, LLC. The project leverages algorithms, software, and hardware developed by the proposing team and demonstrated on formation-flying missions such as the Prototype Research Instruments and Space Mission technology Advancement (PRISMA) mission, Magnetospheric Multiscale (MMS) Mission, and the CubeSat Proximity Operations Demonstration mission (CPOD).

The DiGiTaL project is managed and funded by the Small Spacecraft Technology Program (SSTP) within the Space Technology Mission Directorate. The SSTP expands U.S. capability to execute unique

missions through rapid development and in space demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space sector. The SSTP will enable new mission architectures through the use of small spacecraft with goals to expand their reach to new destinations, and challenging new environments.

For more information about the SSTP, visit:
www.nasa.gov/directorates/spacetech/small_spacecraft/

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DiGiTaL consists of a plug-in ready multi-GNSS hardware/software 0.5U unit capable of integration with most satellites enabling peer-to-peer decentralized navigation accuracy at the centimeter-level over separations up to hundreds of kilometers.

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