DRAQANE: Quantum-Synchronised Navigation from a VLEO Formation

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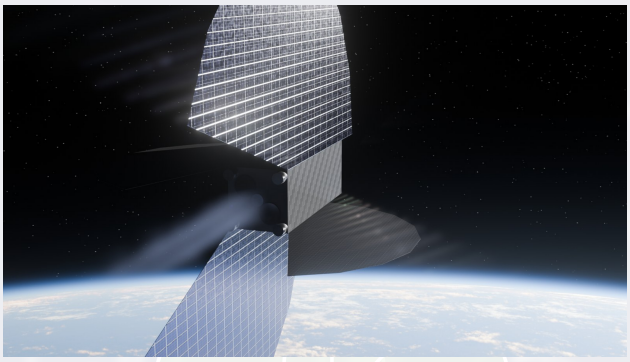


Render of a DRAQANE satellite in VLEO with deployed solar arrays.

INTRODUCTION

Satellite constellations uphold modern society: Positioning, navigation and timing services are crucial in many industries, from transportation and finance to cellular networks and power grids. Yet, today’s Global Navigation Satellite Systems are vulnerable to jamming and spoofing. Very Low Earth Orbit (VLEO) satellites offer significant benefits: The signals are about ten times stronger, the fast motion shortens the convergence time, and the large Doppler-shift makes spoofing detectable. Additionally, increased accuracy in all aspects can be achieved with quantum clock synchronization between satellites in a navigation fleet. The Drag-compensation Residual-atmosphere Air-breathing Quantum Array Navigation Experiment (DRAQANE) combines these advantages while conquering the unforgiving environment of VLEO.

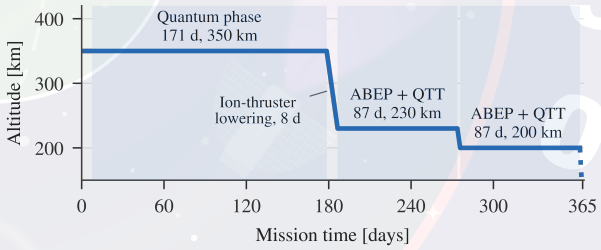
MISSION OBJECTIVES

DRAQANE’s primary objectives are

1. to validate inter-satellite quantum clock synchronisation in VLEO and
2. to provide nanosecond-level timing to ground navigation receivers.

The secondary objective is the in-situ comparison of different ABEP intakes at different altitudes.

MISSION SCENARIO



Mission profile over one year of operations.

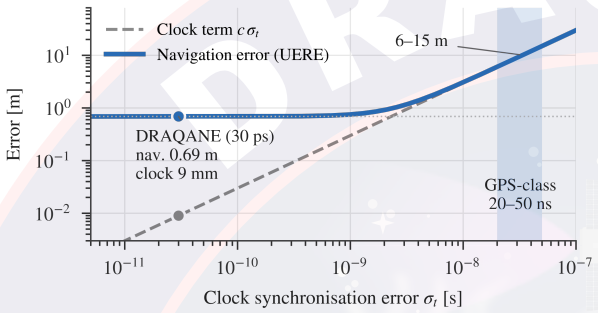
The DRAQANE constellation is planned to launch on an RFA One rocket before the end of 2030 and will operate for at least one year. At the beginning of the mission the three satellites will fly in a dawn-dusk sun-synchronous orbit with 10° (about 1170 km) in-plane separation. After commissioning, the quantum phase runs for 171 days at 350 km. The ion thrusters then lower the formation to 230 km within eight days, followed by two 87-day ABEP phases at 230 km and 200 km with continued quantum operations.

SPACECRAFT DESIGN

Payload

Each of the three DRAQANE satellites carries a payload that synchronises their on-board clocks via two-way quantum time transfer using entangled photon pairs. The same

photons generate QKD keys that encrypt the timing and orbit data exchanged over optical inter-satellite links, and each satellite broadcasts the synchronised time and orbit to users as an L-band navigation signal. The expected 30 ps synchronisation removes clock deviations from the navigation error budget, reducing the positioning error from 6 m to 15 m to about 0.7 m. Signal strengths are expected to exceed to GPS minimum by 17 dB.

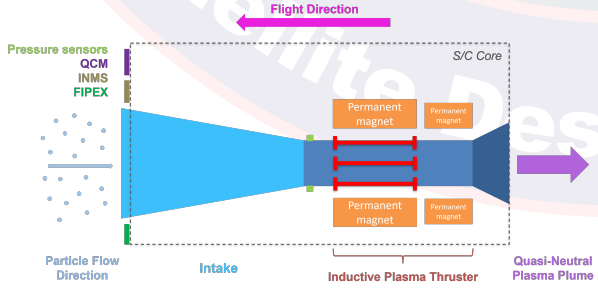


Anticipated clock and navigation error.

Compared with 20 ns to 50 ns for GPS-based synchronisation and 5 ns to 10 ns for Galileo-based synchronisation, the 30 ps precision reduces the corresponding clock term from 6 m to 15 m for GPS and 1.5 m to 3 m for Galileo to 9 mm, resulting in a navigation error of 0.69 m, now limited by the orbit error.

Propulsion

The propulsion architecture pairs a flight-proven QinetiQ T5 ion thruster for station-keeping across all three VLEO test altitudes, with a dedicated Atmosphere-Breathing Electric Propulsion (ABEP) payload on each spacecraft. The ABEP system collects and ionizes the residual thermosphere through an intake and an RF inductive plasma thruster, demonstrating propellant-free thrust generated directly from the ambient atmosphere. Three distinct ABEP intake concepts are demonstrated across the formation and their in-flight performance and degradation are evaluated using an ion and neutral mass spectrometer (INMS), a quartz crystal microbalance (QCM) to evaluate the erosion of coatings, four FIPEX sensors for atomic oxygen density, and pressure sensors in the discharge chamber of the thruster.



Schematic view of an ABEP system.

Satellite Bus

The primary structure of each satellite consists of a coated carbon-fiber sandwich structure. 10 m^2 of triple junction solar cells deliver 3.4 kW at beginning of life to the bus which consumes an average of 1.88 kW. The solar arrays and two dedicated radiator wings provide passive attitude stability. An active control architecture ensures fine control. During payload operations, the AOCS ensures the required pointing accuracy and maintains the relative positions of the satellites to one another.

Two XLink-S transceivers with two redundant channels each form the baseline of the robust S-band TM/TC communication system. The up- and downlink margins exceed 6 dB.

Operations

Ground services on demand are used for operations. Because contacts in VLEO are short and frequent, station keeping, formation control, battery management and fault recovery run autonomously, with ground intervention required at most every seven days. The mission is planned near solar minimum, where the atmosphere is less dense. The Δv budget nevertheless is sufficient to survive 5 days of a 50 % density increase at 200 km, as observed in the 2022 storm that deorbited Starlink satellites.

Budgets

With 5 % to 15 % contingency and 15 % system margin, each satellite has a mass of 377.3 kg. Total program costs are estimated at 643.76 M$. The cost estimation is split across development, manufacturing, and operations.

Mass per satellite incl. contingency and margin [kg].

Structure	164.0	ABEP experiment	38.0
AOCS	54.7	Main propulsion	32.1
Power	46.3	Payload	24.1
Thermal	15.2	Communication	3.0
Total per satellite			**377.3**

CONCLUSION

DRAQANE demonstrates quantum-secure clock synchronization in VLEO, turns it into a timing service for ground users and compares ABEP intakes in flight, paving the way for a resilient, quantum-secured navigation.