Deep Space Atomic Clock

Information for Discovery Proposers
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At the time of this release, this document contains the information that can be publicly cleared without ITAR issues. Future information and details can be obtained by engaging the DSAC Project contact directly (see below). If substantial information or data is required, then some arrangement between the DSAC Project and the Proposer will have to be made regarding official support (e.g. funding) for such an activity.

Introduction

Ground-based atomic clocks are the cornerstone of spacecraft navigation for most deep-space missions because of their use in forming precision two-way coherent Doppler and range measurements. The Deep Space Atomic Clock (shown in Figure 1) will provide an equivalent capability on-board a spacecraft for forming precision one-way radiometric tracking data (i.e., range, Doppler, and phase). By virtually eliminating spacecraft clock errors from this data, DSAC enables a shift to a more flexible and extensible one-way navigation architecture that delivers more data, is more accurate, and reduces operational costs.

The DSAC flight demonstration in 2016/2017 will prove the clock's functionality and suitability for a variety of future space missions. A successful conclusion of the mission's space operation will bring DSAC to a NASA Technology Readiness Level of 7 from its present day level of 5: DSAC will be an advanced prototype mercury ion space clock that can be engineered into a flight instrument for a specific mission with minimal additional investment and minimal risk. In addition to validating the clock's performance in an operational space environment (thermal, vacuum, vibration, magnetic, radiation, and zero-g), the on-orbit experiment will validate DSAC as a viable navigation instrument in a system end-to-end navigation demonstration.

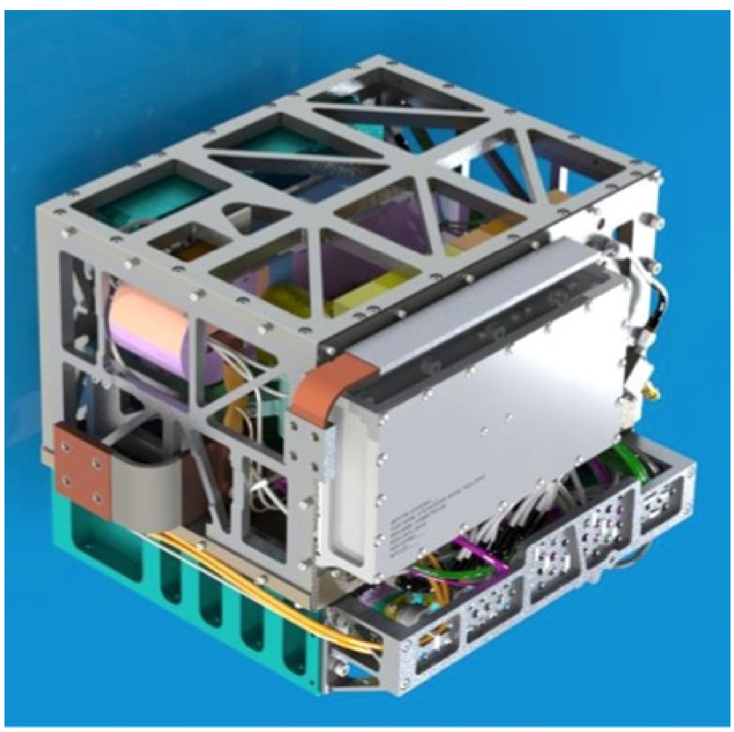

Figure 1. DSAC prototype flight unit.

DSAC will enable numerous opportunities for navigation and science enhancements, new missions, and mission cost savings. DSAC-enabled high-quality one-way signals for deep-space navigation and radio science can

- Improve data quantity and quality, even during low-signal-to-noise scenarios
- Enhance tracking architecture flexibility and robustness
- Enhance radio science at Europa, Mars, and other solar system bodies
- Enable fully-autonomous onboard absolute radio navigation

DSAC is superior to other competing space-based clocks because it requires no consumables and utilizes modern vacuum tube fabrication, enabling long-lived operations; it is radiation tolerant; it has low temperature sensitivity; and it offers unmatched stability in a small, lightweight package.

DSAC Payload Description

The DSAC payload consists of an ultrastable quartz oscillator (USO), the ion clock, and flight software (Figure 2). The ion clock contains a physics package (the core technology), a power conditioning unit, a synthesizer, and a clock controller that interfaces with the DSAC flight software.

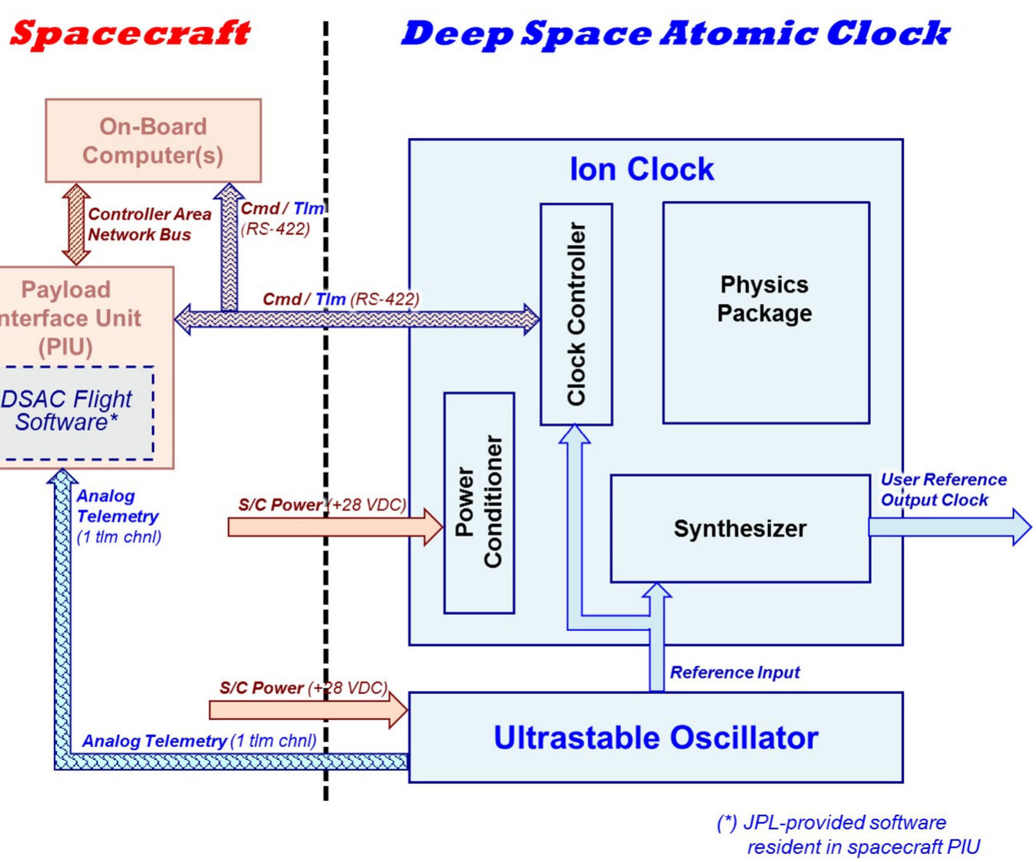

Figure 2. The DSAC payload with spacecraft interfaces.

USOs typically reach their best frequency stability at 10 – 100 seconds and then drift over longer timescales to different oscillation frequencies. DSAC uses the precise resonant frequency of mercury ions to measure and correct these slow frequency changes. Inside the physics package, the frequency signal from the USO is used to excite a cloud of mercury ions every 10 seconds, causing them to emit photons. The amount of fluorescence is a measure of how the USO has drifted and how the reference output clock needs to be corrected. This error signal is sent to the synthesizer, which updates the output clock frequency accordingly.

The physics package is sensitive to voltage changes, thermal environments, and external magnetic fields, but DSAC payload components—in particular, the power conditioning unit, active heater elements, and magnetic shielding—mitigate these sensitivities for certain mission environments.

Current best estimates of key DSAC specifications are given in Tables 1 and 2. DSAC payload-spacecraft interfaces are given in Table 3.

Table 1: Key DSAC payload hardware specifications.

Parameter (units)	Ion Clock	USO
Size (mm)	300 x 275 x 230	195 x 65 x 150
Mass (kg)	15.9 (CBE)	1.5
Power (W, CBE)	Nominal: 44 With heaters: 51.5	Nominal: 4.5 Warmup: 13.3
Allan deviation	$< 3e-15$ for $\tau = 1$ day	$< 5e-13$ for $\tau = 1000$ s

Table 2: Key DSAC payload software specifications.

Parameter (units)	Flight software
Memory (kBytes)	Data: 4 Program: 32
Lines of code	< 500

Table 3: DSAC payload-spacecraft interfaces.

DSAC Payload Interface	Description
Command and data	Ion clock: asynchronous RS422 USO: analog voltage line
Temperature (°C)	Operational: -20 to +45 Non-operational: -20 to +50
Thermal stability (°C/minute)	Ion clock: < 0.1 USO: < 0.07
Power (VDC)	28
Data volume (MBytes/day)	20