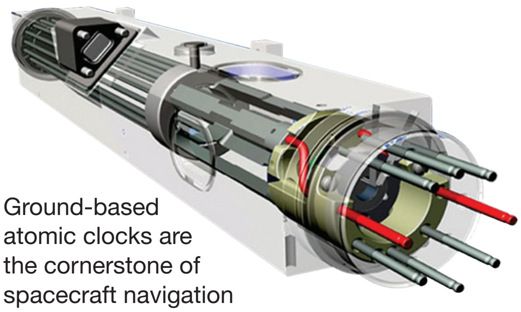
National Aeronautics and Space Administration

Deep Space Atomic Clock



Ground-based atomic clocks are the cornerstone of spacecraft navigation for most deep-space missions because of their use in generating precision two-way tracking measurements. These typically include range (the distance between two objects) and Doppler (a measure of the relative speed between them). A two-way link (a signal that originates and ends at the ground tracking antenna) is required because today's spacecraft clocks introduce too much error for the equivalent one-way measurements to be useful. Ground atomic clocks, while providing extremely stable frequency and time references, are too large for hosting on a spacecraft and cannot survive the harshness of space. New technology is on the horizon that will change this paradigm. NASA's Deep Space Atomic Clock (DSAC) project is developing a reduced-size mercury ion atomic clock that is as stable as a ground clock, small enough to be hosted on a spacecraft, and able to operate in deep space.

Deep Space Navigation and Science with DSAC

In today's two-way architecture, spacecraft are tracked by Earth-based antennas, and a team of navigators processes the data and uploads navigation commands to the spacecraft. By virtually eliminating spacecraft clock errors, DSAC enables a shift to a more efficient, flexible and scalable one-way tracking architecture that will benefit future navigation and radio science. Here are some examples of how one-way deep-space tracking with DSAC can improve navigation and radio science that is not supported by current two-way tracking.

1. Simultaneously track two spacecraft on a downlink with the Deep Space Network (DSN) at destinations such as Mars, and nearly double a space mission's tracking data because it no longer has to "time-share" an antenna.

2. Improve tracking data precision by an order of magnitude using the DSN's Ka-band downlink tracking capability.

3. Mitigate Ka-band's weather sensitivity (as compared to two-way X-band) by being able to switch from a weather-impacted receiving antenna to one in a different location with no tracking outages.

4. Track longer by using a ground antenna's entire spacecraft viewing period. At Jupiter, this yields a 10 to 15 percent increase in tracking; at Saturn, it grows to 15 to 25 percent, with the percentage increasing the farther a spacecraft travels.

5. Make new discoveries as a Ka-band—capable radio science instrument with a 10 times improvement in data precision for both gravity and occultation science and deliver more data because of one-way tracking's operational flexibility.

6. Explore deep space as a key element of a real-time autonomous navigation system that tracks one-way radio signals on the uplink and, coupled with optical navigation, provides for robust absolute and relative navigation.

Key Facts

- Current ground-based atomic clocks are fundamental to deep space navigation; however, they are too massive to be flown in space. This results in tracking data being collected and processed here on Earth for most deep-space navigation applications.
- The Deep Space Atomic Clock (DSAC) is a miniaturized atomic clock that has been ruggedized for spaceflight. It will improve the precision of deep-space navigation, enable more efficient use of tracking networks, and — looking forward — serve as a key component to onboard deep-space navigation with radios.
- DSAC could be used to improve the performance of the Global Positioning System (GPS) and the accuracy of the navigation service it provides to the world.

NASAfacts

These benefits can be applied directly to missions being contemplated by NASA. For instance, a Mars orbiter would obtain direct benefit from DSAC with improved navigation and gravity science that combine the Ka-band and the simultaneous tracking benefits. If this orbiter were to aerobrake (i.e., use the Martian atmosphere to slow down to a final science orbit), one-way tracking on an uplink, coupled with an onboard guidance, navigation and control system, would make it possible to do this operation autonomously and yield a significant reduction in ground support operations. Studies of Europa flyby mission gravity science have shown that one-way Ka-band tracking with DSAC would result in a robust, weather-tolerant method for determining Europa's gravity field. Any mission concept with DSAC would greatly simplify spacecraft-based timekeeping — it is expected that DSAC would incur no more than 1 microsecond of error in 10 years of operations. Looking to the future, DSAC coupled with an onboard navigation system would be fundamental to human explorers requiring real-time navigation data.

Near Space Navigation with DSAC

Looking closer to Earth, DSAC is more stable and accurate than the atomic clocks that currently fly on the GPS satellites. As the Department of Defense plans to upgrade GPS to improve its performance and ensure the health of the nation's clock industrial base that supplies GPS, DSAC is a key technology that can be used to meet these needs.

DSAC's Technology

The DSAC technology uses the property of mercury ions' hyperfine transition frequency at 40.50 GHz to effectively "steer" the frequency output of a quartz oscillator to a near-constant value. DSAC does this by confining the mercury ions with electric fields in a trap (see Figure 1) and protecting them by applying magnetic fields and shielding. This provides a stable environment for measuring the hyperfine transition very accurately and minimizes sensitivity to temperature and magnetic variations. Coupling this with the fact that the DSAC technology has almost no expendables enables development of a clock suitable for very long-duration space missions.

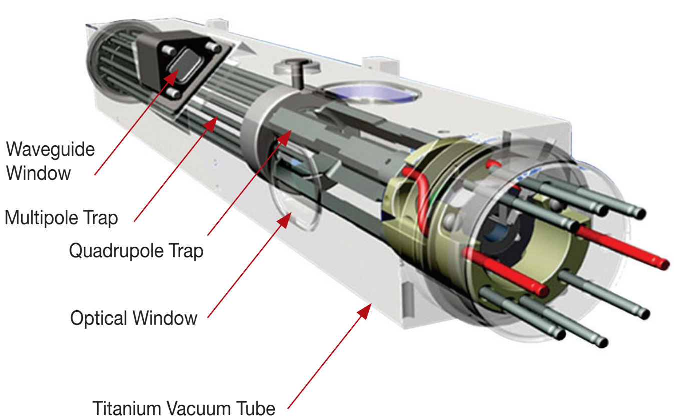


Figure 1. Drawing of the DSAC mercury-ion trap showing the traps and the titanium vacuum tube that confine the ions. The quadrupole trap is where the hyperfine transition is optically measured and the multipole trap is where the ions are "interrogated" by a microwave signal via a waveguide from the quartz oscillator.

Demonstrating the World's Most Stable Small Space Clock

The DSAC project is currently building a demonstration unit (see Figure 2) and payload that will be hosted on a spacecraft provided by Surrey Satellite Technologies US LLC, Englewood, Colo. It will launch in 2015 into Earth orbit. The DSAC payload will be operated for at least a year to demonstrate its functionality and utility for one-way-based navigation. Figure 3 illustrates the on-orbit mission architecture, where the plan is to collect measurements between GPS and the host spacecraft using a GPS receiver connected to DSAC. The data will be processed on the ground by the DSAC team to validate the clock's in-space performance.

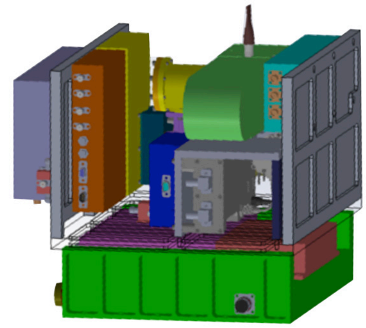


Figure 2. Preliminary design of DSAC with the outer cover removed, showing the internal components.

DSAC is a cross-cutting technology that has the potential to change the "calculus" of spaceflight. As one of NASA's Technology Demonstration Missions, a key objective of the project is to demonstrate DSAC's performance and operability

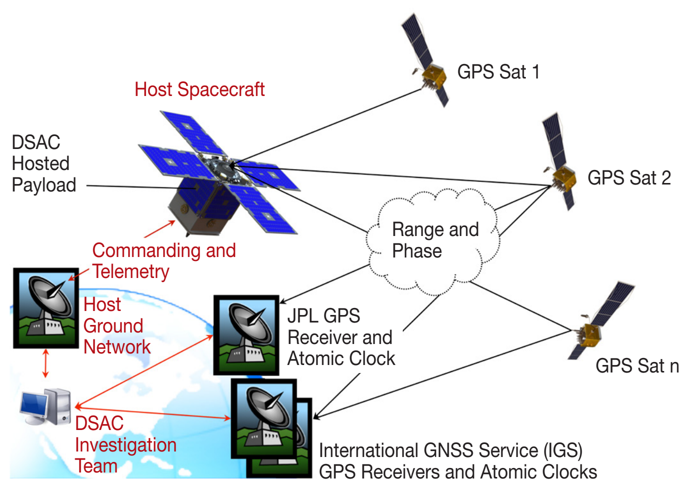


Figure 3. DSAC on-orbit demonstration mission architecture.

in space, and develop the technology to a point where it can be transitioned to industry for commercial production. DSAC's space demonstration will have proven its flight worthiness and will radically reduce risk to future missions that adopt it.

The DSAC project is sponsored by the NASA Space Technology Mission Directorate and managed by NASA's Jet Propulsion Laboratory in Pasadena, Calif.

For more information about the Deep Space Atomic Clock project, please see **http://www.nasa.gov/mission_pages/tdm/clock/**