Suppressing Loss of Ions in an Atomic Clock

Ion traps are excited at two different frequencies.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improvement has been made in the design of a compact, highly stable mercury-ion clock to suppress a loss of ions as they are transferred between the quadrupole and higher multipole ion traps. Such clocks are being developed for use aboard spacecraft for navigation and planetary radio science. The modification is also applicable to ion clocks operating on Earth: indeed, the success of the modification has been demonstrated in construction and operation of a terrestrial breadboard prototype of the compact, highly stable mercury-ion clock.

Selected aspects of the breadboard prototype at different stages of development were described in previous *NASA Tech Briefs* articles. The following background information is reviewed from previous articles: In this clock as in some prior ion clocks, mercury ions are shuttled between two ion traps, one a 16-pole linear radio-frequency trap, while the other is a quadrupole radio-frequency trap. In the quadrupole trap, ions are tightly confined and optical state selection from a ^{202}Hg lamp is carried out. In the 16-pole trap, the ions are more loosely confined and atomic transitions are interrogated by use of a microwave beam at approximately 40.507 GHz. The trapping of ions effectively eliminates the frequency pulling that would otherwise be caused by collisions between clock atoms and the wall of a gas cell. The shuttling of the ions between the two traps enables separation of the state-selection process from the clock microwave-resonance process, so that each of these processes can be optimized independently of the other. This is similar to the operation of an atomic beam clock, except that with ions the "beam" can be halted and reversed as ions are shuttled back and forth between the two traps.

When the two traps are driven at the same radio frequency, the strength of confinement can be reduced near the junction between the two traps, depending upon the relative phase of the RF voltage used to operate each of the two traps, and can cause loss of ions during each transit between the traps and thereby cause loss of the 40.507-GHz ion-clock resonance signal.

The essence of the modification is to drive the two traps at different frequencies — typically between 1.5 and 2 MHz for the quadrupole trap and a frequency a few hundred kHz higher for the 16-pole trap. A frequency difference of a few hundred kHz ensures that the ion motion caused by the trapping electric fields is small relative to the diameter of the traps. Unlike in the case in which both traps are driven at the same frequency, the trapping electric fields near the junction are not zero at all times; instead, the regions of low electric field near the junction open and close at the difference frequency. An additional benefit of making the 16-pole trap operate at higher frequency is that the strength or depth of the multipole trap can be increased independent of the quadrupole ion trap.

This work was done by John Prestage and Sang Chung of Caltech for NASA's Jet Propulsion Laboratory.

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Simplified Vicarious Radiometric Calibration

At-sensor radiance is estimated more directly than in prior methods.

Stennis Space Center, Mississippi

A measurement-based radiance estimation approach for vicarious radiometric calibration of spaceborne multispectral remote sensing systems has been developed. This simplified process eliminates the use of radiative transfer codes and reduces the number of atmospheric assumptions required to perform sensor calibrations. Like prior approaches, the simplified method involves the collection of ground truth data coincident with the overpass of the remote sensing system being calibrated, but this approach differs from the prior techniques in both the nature of the data collected and the manner in which the data are processed.

In traditional vicarious radiometric calibration, ground truth data are gathered using ground-viewing spectroradiometers and one or more sun photometer(s), among other instruments, located at a ground target area. The measured data from the ground-based instruments are used in radiative transfer models to estimate the top-of-atmosphere (TOA) target radiances at the time of satellite overpass. These TOA radiances are compared with the satellite sensor readings to radiometrically calibrate the sensor.

Traditional vicarious radiometric calibration methods require that an atmospheric model be defined such that the ground-based observations of solar transmission and diffuse-to-global ratios are in close agreement with the radiative transfer code estimation of these parameters. This process is labor-intensive and complex, and can be prone to errors. The errors can be compounded because of approximations in the model and inaccurate assumptions about the radiative coupling between the atmosphere and the terrain. The errors can increase the uncertainty of the TOA radiance estimates used to perform the radiometric calibration.

In comparison, the simplified approach does not use atmospheric radiative transfer models and involves fewer assumptions concerning the radiative transfer properties of the atmosphere. This new technique uses two neighboring uniform ground target areas having different reflectance values. The target areas can be natural or artificial and must be large enough to minimize adjacent-pixel contamination effects. The radiative coupling between the atmosphere and the terrain needs to be approximately the same for the two targets. This condition can be met for relatively uniform backgrounds when the distance between the targets is within a few hundred meters.

For each target area, the radiance leaving the ground in the direction of the satellite is measured with a radiometrically calibrated spectroradiometer. Using the radiance measurements from the two targets, atmospheric adjacency and atmospheric scattering effects can be subtracted, thereby eliminating many assumptions about the atmosphere and the radiative interaction between the atmosphere and the terrain. In addition, the radiometrically calibrated spectroradiometer can be used with a known reflectance target to estimate atmospheric transmission and diffuse-to-global ratios without the need for ancillary sun photometers.

Several comparisons between the simplified method and traditional techniques were found to agree within a few percent. Hence, the simplified method reduces the overall complexity of performing vicarious calibrations and can serve as a method for validating traditional radiative transfer models.

This work was done by Thomas Stanley of Stennis Space Center and Robert E. Ryan, Kara Holekamp, and Mary Pagnutti of Science Systems and Applications, Inc.

Inquiries concerning this technology should be addressed to the Intellectual Property Manager, Stennis Space Center, (228) 688-1929. Refer to SSC-00301-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Phase-Conjugate Receiver for Gaussian-State Quantum Illumination

Active optical sensors have application in military surveillance.

NASA's Jet Propulsion Laboratory, Pasadena, California

An active optical sensor probes a region of free space that is engulfed in bright thermal noise to determine the presence (or absence) of a weakly reflecting target. The returned light (which is just thermal noise if no target is present, and thermal noise plus a weak reflection of the probe beam if a target is present) is measured and processed by a receiver and a decision is made on whether a target is present.

It has been shown that generating an entangled pair of photons (which is a highly nonclassical state of light), using one photon as the probe beam and storing the other photon for comparison to the returned light, has superior performance to the traditional classical-light (coherent-state) target detection sensors. An entangled-photon transmitter and optimal receiver combination can yield up to a factor of 4 (i.e., 6 dB) gain in the error-probability exponent over a coherent state transmitter and optimal receiver combination, in a highly lossy and noisy scenario (when both sensors have the same number of transmitted photons). However, the receiver that achieves this advantage is not known. One structured receiver can close half of the 6-dB gap (i.e., a 3-dB improvement). It is based on phase-conjugating the returned light, then performing dual-balanced difference detection with the stored half of the entangled-photon pair.

Active optical sensors are of tremendous value to NASA's missions. Although this work focuses on target detection, it can be extended to imaging (2D, 3D, hyperspectral, etc.) scenarios as well, where the image quality can be better than that offered by traditional active sensors. Although the current work is theoretical, NASA's future missions could benefit significantly from developing and demonstrating this capability.

This is an optical receiver design whose components are, in principle, all implementable. However, the work is currently entirely theoretical. It is necessary to:

1. Demonstrate a bench-top proof of the theoretical principle,
2. Create an operational prototype off-the-bench, and
3. Build a practical sensor that can fly in a mission.

This work was done by Baris I. Erkmen of Caltech and Saikat Guha of BBN Technologies for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47152

Improved Tracking of an Atomic-Clock Resonance Transition

The resonance frequency is repeatedly estimated from sequences of three measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method of making an electronic oscillator track the frequency of an atomic-clock resonance transition is based on fitting a theoretical nonlinear curve to measurements at three oscillator frequencies within the operational frequency band of the transition (in other words, at three points within the resonance peak). In the measurement process, the frequency of a microwave oscillator is repeatedly set at various offsets from the nominal resonance