A MERCURY **LINEAR** ION TRAP **FREQUENCY STANDARD FOR THE USNO***

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Abstract

A frequency standard for the USNO based on mercury ions in a Linear Ion Trap is operational. Initial measurements of the new standard LITS-3 against an active hydrogen maser gives a fractional frequency stability of $\sigma_y(\tau)=7.5\times10^{-14}/\tau^{1/2}$ for measuring intervals up to 10,000 seconds Stability measurements for longer averaging intervals against another ion trap standard have commenced.

Introduction

One of the most important roles of atomic frequency standards is to provide for long term definition and maintenance of time scales. The USNO maintains the United States master clock, providing the national time reference and the center of all Department of Defense timed systems. it consists of a H-maser steered to a mathematical time scale based on a large number of different clocks, primarily hydrogen masers. For an individual clock the major source of frequency error for long averaging times are systematic in nature. The achievable long term stability is directly related to the size of the frequency offsets and the degree they are measured and controlled

Mercury trapped ion standards are particularly attractive for long term stability needs because of the large atomic mass and ground state hyperfine splitting (≈ 40.5 GHz). Sensitivity to thermal effects and magnetic field fluctuations are reduced from standards using lighter atoms. Confinement in an ion trap eliminates hard to control wall shifts and allows long interrogation times. Using a ^{202}Hg lamp for atomic state selection, and helium buffer gas for ion cooling, continuous operation is practical. These advantages were recognized some years ago and trapped ion standards developed by Hewlett Packard for the USNO based on the traditional hyperbolic ion trap [1,2]. More recently, the development of the linear ion trap [3] at JPL allows for significantly improved short term performance of $\sigma_y(\tau)= 7\times10^{-14}/\tau^{1/2}$ [4] and thus an improved capability for measuring systematic effects and sensitivity to long term perturbations.

Long Term Stability Measurements of LITS-2

Typical operating parameters and environmental sensitivity of our first two research standards LITS-1 and LITS-2 have been previously published [4,5]. The original research standards have no direct regulation of ion number, and both have only three magnetic shields providing a shielding factor of 800. Measurements were performed in a thermal chamber controlled to 0.05 °C.

Figure 1 shows the first measurement between LITS-2 and LITS 1 over a longer 24 day interval. The measurement was performed in an environment where occasional movement of a steel electronic rack perturbed the frequency of LITS-1, With a shielded sensitivity of 5×10^{-16}/mG, the stability around 100,000 seconds, typically about 5×10^{-16} is degraded in part due to magnetic perturbations.

Also shown in Figure 1 is the stability of LITS-2 measured against two hydrogen masers, SAO-26 [6] and a cavity tuned maser STSC-1 [7]. The average differential drift between LITS 2 and the STSC-1 maser over the 146 day measurement interval was measured to be $(2.1\pm0.8)\times10^{-16}$ /day The measured long term stability of the hydrogen masers shown in Figure 1 is characteristic of the technology [8,9] Even though little effort was spent regulating and isolating LITS-1 and LITS-2 from environmental perturbations, the ion trap stability exceeds H-maser stability for averaging times between 10,000 and 10^6 seconds

Initial Measurements with LITS-3

In the current mode of operation, the largest sensitivity that could lead to long term variation of the 40.5 GHz frequency is to variations in the external magnetic field and/or the trapped ion number (through the second order Doppler shift) A number of improvements have been incorporated into the standard for the USNO (LITS-3) including improved stability of the trapping potentials and electron current to load ions The trap resides in five layers of magnetic shielding increasing the longitudinal shielding factor from 800" to >17.000 The bias magnetic field has been reduced from 80 to 40 mG, reducing the Sensitivity to ambient magnetic

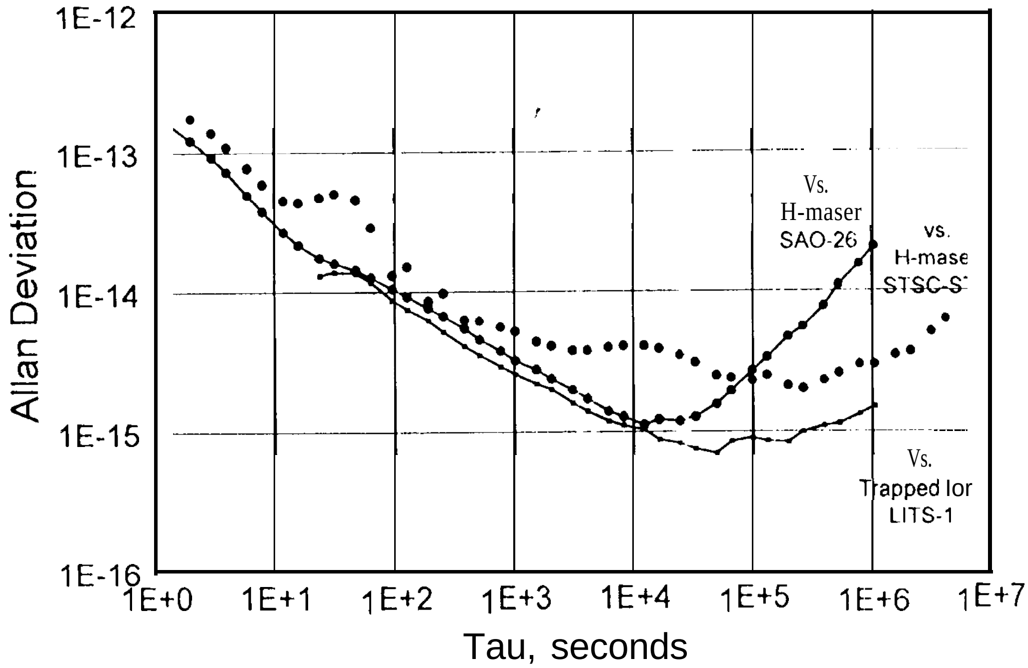

Figure 1 Fractional frequency stability of the research Hg+ standard LITS-2 compared to (a) the ion trap standard LITS-1 for 24 days, (b) a cavity tuned Hydrogen maser for 146 days, and (c) an active Hydrogen Maser

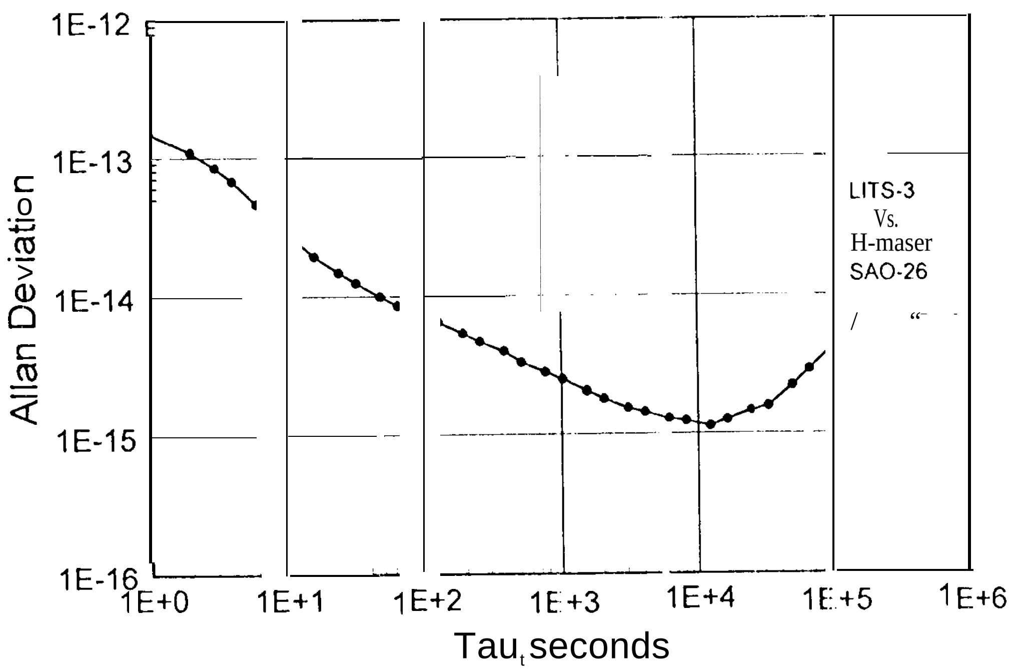

Figure 2 Short term stability of LITS-3 with a H-maser. A short term stability of $\sigma_y(\tau)=7.5\times10^{-14}/\tau^{1/2}$ is shown. The stability measurement past 10,000 seconds is limited by the H-maser reference standard

fluctuations to Ix 1 0^{-17}/mG. The enclosure containing the trap and vacuum assembly is thermally regulated to O. I .°C allowing the frequency standard to be portable.

In Fig 2, a five day measurement of the new standard against an active I l-maser is shown. The short term Allan deviation shown of $\sigma_y(\tau) = 7.5 \times 10^{-14}/\tau$ "2 is accomplished with an 8 second microwave interrogation time, a factor of two shorter than used in 1.1'1'S-1 and 1.1'1'S-2 for a comparable stability. Past 10,000 seconds the measurement is limited by the stability of the hydrogen reference maser. i .ong term stability measurements of LITS-3 compared with the older research ion trap standards have commenced.

in the future, improving the magnetic field homogeneity should allow operation at still lower fields, further reducing magnetic sensitivity. Using the new extended trap (1 .ITE) configuration [1 ()], the magnetic shields wiii be much smaller Another benefit of the LITE allows performing the microwave interrogation at reduced linear ion densities, This reduces sensitivity to ion number fluctuations without compromising, signal to noise and should provide even better long term stability

*'1 his work was performed at the Jet Propulsion 1 .aboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

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