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Optical frequency references for space applications

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1. **Introduction**

Frequency references have made an enormous contribution to scientific research and technological advances. The impact on everyone's life is demonstrated with every navigation handheld device or smartphone. The primary frequency standard nowadays (since 1967) is based on the caesium atomic clock, developed 1955. In space applications, the two commonly used technologies are the passive H-maser and the rubidium frequency references.
The current development achieves fractional frequency instabilities at the 10^{-18} level. With this performance, the definition of the SI second will be adapted within a few years.
Furthermore the great stability opens up new and better measurements, ranging from fundamental science to life sciences and navigation. A variety of future space missions rely on the availability of high-performance optical clocks with applications in fundamental physics, geoscience, Earth observation and navigation and ranging. Examples are the gravitational wave detector LISA (Laser Interferometer Space Antenna), the Earth gravity mission NGGM (Next Generation Gravity Mission) and missions, dedicated to tests of Special Relativity, e.g. by performing a Kennedy- Thorndike experiment testing the boost dependence of the speed of light.

2. Space frequency references

Optical frequency references based on Doppler-free spectroscopy of molecular iodine near 532nm are a well-proven technology developed in several laboratories for many years. We will present our compact Iodine absolute frequency reference, which is optimized for energy consumption, compactness and robustness [1]. The Iodine reference reaches a relative frequency stability at the 10^{-15} level from 1 second to several thousands seconds. Its optical bench for the spectroscope setup is made of glass material such as fused silica or OHARA Clearceram, which exhibits a CTE comparable to ULE. The mirrors and lenses are made of fused silica and fixed by adhesive bonding technology with space-qualified two-component epoxy resulting in a semi-monolithic optical assembly [2]. The dimensions of the setup on engineering model are 18cm x 38cm x 4cm. With this kind of compact frequency reference, a satellite mission to perform a Kennedy-Thorndike experiment is currently proposed.
For this kind of experiment, one needs another frequency reference, which has to be sensitive within first-order for a dependency of the velocity of light from the relative movement of the laboratory, e.g. the satellite with respect to the microwave background. A proposed orbit would give an orbit time of 90 minutes. Our mission would use an optical resonator as the heart of an ultra-stable laser system. It will reach a fractional frequency stability below 10^{-15} at the orbit time (5400 seconds). Several space ready optical cavity systems have been proposed, and for various reasons we chose the cavity design by NPL (3). To ensure the desired long term stability, FEM calculations have been done in order to design a thermal shielding. With five layers made of Aluminium and an active stabilization of the outermost shield, the thermal fluctuations in the vacuum chamber will be damped sufficiently to allow the performance needed.

4. References

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