High-accuracy measurement of the blackbody radiation frequency shift of the ground-state hyperfine transition in ^{133}Cs

S.R. Jefferts[1], T.P. Heavner[1], T.E. Parker[1], J. Shirley[1], E. A. Donley[1], N. Ashby[1], F. Levi[2], D. Calonico[2], G.A. Costanzo[3]

[1]Time and Frequency Division, NIST, Boulder, Colorado USA
[2]Tempo e Frequenza, INRIM, Torino, Italy
[3]Department of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy

Email: steven.jefferts@nist.gov

The black-body radiation (BBR) shift causes a well-known bias of the hyperfine ground-state transition frequency in ^{133}Cs used in the SI system to define the second. Uncertainty in this frequency shift is an important systematic uncertainty in many of the best primary frequency standards.

Uncertainty in the BBR frequency shift correction has led to its being the focus of intense theoretical effort by a variety of research groups. Our experimental measurement of the shift used three primary frequency standards operating at different temperatures. We achieved an uncertainty a factor of five smaller than the previous best direct measurement. These results tend to validate the claimed accuracy of the recently calculated values. The BBR fractional frequency shift is often written in the form,

$$\frac{\delta\omega}{\omega_o} = \beta\left(\frac{T}{T_o}\right)^4\left[1+\varepsilon\left(\frac{T}{T_o}\right)^2\right], \qquad (1)$$

where $\delta\omega/\omega_o$ is the BBR fractional frequency shift, T_o is generally specified as 300 K, T is the actual temperature of the radiation field seen by the atoms, and β, ε are coefficients generated by theoretical calculation.

We present here a measurement of the coefficient β in (1) using the US primary frequency standards, NIST-F1 and NIST-F2 at NIST (National Institute of Standards and Technology) and the Italian primary frequency standard, IT-CSF2 (Istituto Nazionale di Ricerca Metrologica) at INRIM. The ^{133}Cs primary frequency standards all operate at different temperatures, NIST-F1 is operated at a temperature of 317.35(10)K while NIST-F2 operates at 81.0(10)K and IT-CSF2 operates at 89.4(10)K. A series of measurements were performed during which at least two of the standards were operated simultaneously. Both NIST standards are referenced to the same hydrogen maser and the two data sets (NIST-F1 and NIST-F2 vs. maser for example) are typically differenced on a second by second basis, thereby eliminating the hydrogen maser as a source of noise and producing a direct measurement of the uncorrected frequency of NIST-F1 against the uncorrected frequency of NIST-F2. In the case of IT-CSF2, which is located in Torino, IT, the comparison to NIST-F1 is via two-way satellite time-transfer and the comparison is typically over the entire run of the fountains (typically 20 days or so).