Questionnaire previous to the 2006 meeting of the CCL/CCTF Joint Working Group

Summary of the previous meetings

The CCTF on its 16th meeting in April 2004 recommended that the unperturbed ground-state hyperfine quantum transition of ^{87}Rb may be used as a secondary representation of the second with a frequency of f_{Rb}= 6 834 682 610.904 324 Hz and an estimated relative standard uncertainty (1σ) of 3 x 10^{-15}, and submitted this recommendation to the CIPM.

The 2005 CCL/CCTF JWG adopted three optical frequency standards for recommendation to the CCTF as secondary representations of the second:

The trapped and cooled mercury ion $^{199}Hg^{+}$, $5d^{10}$ 6s $^2S_{1/2}$ (F = 0) — $5d^9$ $6s^2$ $^2D_{5/2}$ (F = 2), Δm_F = 0 transition for which the value f = 1 064 721 609 899 145 Hz with a relative standard uncertainty of 3 x 10^{-15}, applies to the unperturbed quadrupole transition.

The trapped and cooled strontium ion $^{88}Sr^{+}$, 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ transition for which the value f = 444 779 044 095 484.6 Hz with a relative standard uncertainty of 7 x 10^{-15}, applies to the radiation of a laser stabilized to the unperturbed transition and to the centre of the Zeeman multiplet.

The trapped and cooled ytterbium ion $^{171}Yb^{+}$, 6s $^2S_{1/2}$ (F = 0, m_F = 0) — 5d $^2D_{3/2}$ (F =2, m_F = 0) transition for which the value f = 688 358 979 309 308 Hz with a relative standard uncertainty of 9 x 10^{-15}, applies to the unperturbed quadrupole transition.

1. Frequency sources in the microwave domain

1.1. Have you made or are you aware of new absolute frequency measurements of the Rb hyperfine transition?

Yes $\boxed{\text{No}}$

If yes, please list the values and uncertainties obtained and refer to the publication in which they may be found. Please be sure to include measurements made in other laboratories.

1.2. Are you aware of absolute frequency measurements of other microwave standards that should be proposed as secondary representations of the second?

Yes $\boxed{\text{No}}$

If yes, please list the values and uncertainties obtained and the method used and refer to the publication in which they may be found. Please be sure to include measurements made in other laboratories in your country.

1.3. Are you currently developing new frequency sources in the microwave domain?

Yes $\boxed{\text{No}}$

If yes, please give a brief description of your experiment.

2. Frequency sources in the optical domain

2.1. Have you made or are you aware of new absolute frequency measurements of the three optical transitions adopted by the 2005 CCL/CCTF JWG?

$\boxed{\text{Yes}}$ No

If yes, please list the values and uncertainties obtained and refer to the publication in which they may be found. Please be sure to include measurements made in other laboratories.

No new measurements on the $^{88}Sr^{+}$ S-D reference transition have been performed at NRC /INMS since the 2005 CCL/CCTF JWG meeting. A series of publications have emerged which support the results obtained. These are:

1. P. Dubé, A.A. Madej, J.E. Bernard, and A.D. Shiner, "$^{88}Sr^{+}$ Single-Ion Optical Frequency Standard" , in *Proceedings of the 2006 IEEE International Frequency Control Symposium*, S.A. Diddams editor (IEEE Press, Piscataway NJ, USA , 2006) (in press).
2. P. Dubé, A.A. Madej, J.E. Bernard, L. Marmet, J.-S. Boulanger, and S. Cundy, " Electric Quadrupole Shift Cancelllation in Single –Ion Optical Frequency Standards", Phys. Rev. Lett. 95, 033001 (2005).
3. A.A. Madej, J.E. Bernard, P. Dubé, L. Marmet, and R.S. Windeler, "Absolute Frequency of the $^{88}Sr^{+}$, 5s $^2S_{1/2}$- 4d $^2D_{5/2}$ Reference Transition at 445 THz and Evaluation of Systematic Shifts", Phys. Rev. A. 70, 012507 (2004).

PDF versions of these documents are attached.

Based on the NRC results, the S-D center frequency is determined as:

f_{SD}= 444 779 044 095 484 ± 15 Hz

The updated error budget given for our current series of measurements are:

Source	**Shift of Line Center [Hz]**	**Uncertainty of Shift [Hz]**	**Fractional Magnitude of Error**
Statistical Uncertainty of Data	0	4.3	1.0×10^{-14}
Reference Maser Uncertainty in Absolute Measurements	0	5	1.1×10^{-14}
Micromotion induced Time Dilation and Stark Effect	-6	13	3×10^{-14}
Thermal Motion Contribution to Time Dilation shift	-0.011	0.006	1.3×10^{-17}
Thermal Motion Contribution to Stark shift	+0.010	0.005	1.1×10^{-17}
Blackbody AC Stark Shift	+0.30	0.11	2.5×10^{-16}
AC Stark Shift due to 674-nm probe light	+0.004	0.003	6.7×10^{-18}
Electric Quadrupole shift of the 4d $^2D_{5/2}$ level	0	0.002	5×10^{-18}
Ac field shift via linear Zeeman effect	0	0.2	4×10^{-16}
Quadratic Zeeman Effect due to Bias Field	+0.0005	0.0001	2×10^{-19}
Collisional Shifts	0	0.005	1×10^{-17}
Total Shifts	-5.7	15	3.4×10^{-14}

The shifts and uncertainties are based on our current measurement strategy of eliminating the Electric quadrupole shift and Tensor Stark shifts via averaging of the ($m_{J''}$, $m_{J'}$)=(±1/2,±1/2), (±1/2,±3/2), and (±1/2,±5/2) component pair frequencies (see Reference 2).

2.2. Have you made or are you aware of new absolute optical frequency measurements suitable to serve as secondary representations of the second?

Yes $\boxed{\text{No}}$

If yes, please list the values and uncertainties obtained and refer to the publication in which they may be found.

2.3. Are you currently developing new frequency sources in the optical domain?

$\boxed{\text{Yes}}$ No

If yes, please give a brief description of your experiment.

A project has begun at NRC to develop an optical atomic clock based on laser cooled neutral atoms held in an Optical Lattice potential and probed at ultra-high resolution. The current effort has chosen to study the Sr system reference transitions. Work has begun in the design and purchase of the necessary laser and experimental components.

P.S.: In your response please would you attach a pdf copy of the publication, preprint or internal report which describes the relevant information to assess the final values and uncertainties provided, as this is extremely useful for the JWG deliberation.

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