# 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 (1$\sigma$) 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 $^{2}S_{1/2}$ (F = 0) — $5d^{9}$ $6s^{2}$ $^{2}D_{5/2}$ (F = 2), $\Delta m_F$ = 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.
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> The trapped and cooled strontium ion $^{88}Sr^{+}$, 5s $^{2}S_{1/2}$ – 4d $^{2}D_{5/2}$ 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.
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> The trapped and cooled ytterbium ion $^{171}Yb^{+}$, 6s $^{2}S_{1/2}$ (F = 0, $m_F$ = 0) — 5d $^{2}D_{3/2}$ (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 No **x**

   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 No **x**

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 No **x**

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?

Yes **x** 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.

**$^{199}Hg^{+}$, $5d^{10}\ 6s\ ^2S_{1/2}$ (F = 0) — $5d^9\ 6s^2\ ^2D_{5/2}$ (F = 2), $\Delta m_F = 0$ 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. A new measurement of the mercury ion clock frequency was made last fall and reported in the 14 July 2006 issue of the Physical Review Letters, W. H. Oskay, *et al.*, Phys. Rev. Lett. 97, 020801 (2006). The absolute frequency was measured versus cesium to be:**

**f = 1 064 721 609 899 144.94 (97) Hz.**

**A copy of the PRL is attached.**

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 **x** No

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

**The latest results of three different international efforts toward building neutral Sr optical lattice clocks were presented by representatives of the**

**three groups at the Symposium on Frequency Control held in Miami, 5-7 June 2006. More recently, at the International Conference for Atomic Physics (ICAP) held in Innsbruck (July, 2006), Dr. Jun Ye reported not only the latest absolute frequency measurements made by his group but also those of the Japanese and the French groups. Although those results have been summarized and compared in Dr. Ye's submission to the soon to be published Proceedings of ICAP 2006, I will only report the JILA measurement here. I presume that the French and Japanese results will be reported by representatives of those groups. The absolute frequency of the $^{87}Sr$ $^1S_0$ - $^3P_0$ optical clock transition reported by the JILA group is:**

**f = 429 228 004 229 871.4 (±0.4) Hz**

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

Yes **x** No

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

**We are working on a single $Al^+$ ion optical clock using quantum logic. In our implementation of this clock, a laser-cooled $Be^+$ ion is trapped in a linear Paul trap simultaneously with an $Al^+$ ion. The Coulomb interaction between the ions allows us to cool sympathetically $Al^+$ via $Be^+$. Using quantum logic techniques, we map the internal state of the $Al^+$ ion onto the $Be^+$ ion, where it is then detected with high efficiency. $Al^+$ is an excellent candidate for a high accuracy optical clock: the clock transition has a very high Q-factor of about $2 \times 10^{17}$ and a small black-body radiation shift. We have used quantum logic based spectroscopy to operate an Al frequency standard by stabilizing a narrow-linewidth interrogation laser to the mean transition frequency of the $m_F = \pm 5/2$, $\Delta m_F = 0$ clock transitions. Using a femtosecond frequency comb, we have measured the ratio of its frequency to that of a single $Hg^+$ ion optical frequency standard. Largely owing to the higher frequencies in the optical domain, the fractional frequency instability of the $Al^+/Hg^+$ optical frequency comparison is improved by more than 1 order or magnitude over the radio frequency measurement. After an averaging time of approximately 30 000 s, a fractional frequency uncertainty of $4 \times 10^{-17}$ is reached. An absolute frequency measurement of the $Al^+$ clock transition frequency is currently being pursued.**

**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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