Minutes of the CCL/CCTF Frequency Standards Working Group Meeting

BIPM, 2nd June 2009

Agenda

1. Welcome to attendees.
2. Approval of the agenda, appointment of rapporteur.
3. Terms of reference of the CCL/CCTF Frequency Standards WG.
4. Consideration of returns from NMIs to WG questionnaire.
5. Consideration of additions/updates to the revised single list of frequencies including secondary representations of the second and frequencies for the realisation of the definition of the metre.
6. Report on key comparison CCL-K11.
7. Consideration of possible new comparisons.
8. Detailed discussion on the possible revision of the single list of radiations to be published in Metrologia, including structure and contents.
9. Report on the CCU discussion on a redefinition of the second, possibly as soon as 2015, in view of recent developments in the use of optical transitions.
10. Preparation of WG recommendations to the CCL and CCTF.
11. Other business.

Attendees

Prof. Dr Michael Kühne (Deputy Director of the BIPM)
Dr Attilio Sacconi, INRIM, Turin (President of the CCL)
Mr Luc Erard, LNE, Paris (President of the CCTF)
Dr Patrick Gill, NPL, Teddington (Co-chair)
Dr Fritz Riehle, PTB, Braunschweig (Co-chair)
Mr Raymond Felder, BIPM, Sèvres (Executive secretary of the CCL)
Dr Elisa Felicitas Arias, BIPM, Sèvres (Executive secretary of the CCTF)

Delegates: Dr Petr Balling (CMI), Dr James Bergquist (NIST), Dr Yury Domnin (VNIIFTRI), Dr Aldo Godone (INRIM), Dr Ramiz Hamid (UME), Dr Feng-Lei Hong (NMIJ/AIST), Mr Michito Imae (NMIJ/AIST), Dr Patrick Juncar (LNE-INM/CNAM), Dr Taeg Yong Kwon (KRISS), Dr Pierre Lemonde (LNE-SYRTE), Dr Tianchu Li (NIM), Dr José Mauricio López-Romero (CENAM), Dr Alan Madej (NRC-INMS), Dr Helen Margolis (NPL), Mr Chris Matthee (NMISA) Dr Mikko Merimaa (MIKES), Dr Vitaly Palchikov (VNIIFTRI), Dr Steven Van den Berg (VSL), Dr Bruce Warrington (NMIA), Dr Elena Zagirova (VNIIFTRI), Dr Massimo Zucco (INRIM).

Guests: Dr Michael Matus (BEV), Ms Siew Leng Tan (A*STAR, Singapore)

BIPM members: Dr Gianna Panfilo, Dr Gérard Petit, Dr Lennart Robertsson.

1. Welcome to attendees

Dr Riehle opened the meeting by welcoming the delegates, the guests and the BIPM representatives to the meeting and in particular the deputy director of the BIPM (Dr Kühne) and the presidents of the CCTF (Mr Erard) and the CCL (Dr Sacconi).

Dr Arias welcomed delegates to BIPM and provided some practical information.

Dr Kühne introduced himself to the meeting as the new deputy director of the BIPM, who is due to take over from Dr Wallard as director at the end of 2010. The other delegates and guests to the meeting briefly introduced themselves.

2. Approval of the agenda, appointment of rapporteur.

Dr Riehle presented the proposed agenda for the meeting (CCL-CCTF/09-01). He suggested that the order of items 8 and 9 would be best reversed as a result of a recommendation made by the CCU. The agenda was accepted with this change made. This re-ordering of agenda items is reflected in these minutes with the original item numbers retained.

Dr Margolis was appointed as rapporteur for the meeting.

3. Terms of reference of the CCL-CCTF Frequency Standards WG

Dr Riehle presented the provisional terms of reference agreed by the CCL in September 2007. These were:

i. To make recommendations to the CCL for radiations to be used for the realisation of the definition of the metre and to make recommendations to the CCTF for radiations to be used as secondary representations of the second.
ii. To maintain the list of recommended frequency standard values and wavelength values for applications including the practical realisation of the definition of the metre and secondary representations of the second.
iii. To ask BIPM to discuss the provisional terms of reference with the CCTF and if necessary to add further terms of reference which again should be communicated to the CCL for their approval.

Mr Erard asked for a discussion of the term of office for the WG chair. One proposal was that this might alternate between the CCL and the CCTF but Dr Gill pointed out that this distinction was largely historical and was less relevant now. Dr Arias mentioned that BIPM are presently working on a draft document with general guidelines for working group membership, terms of office etc and that although a recommendation could be made now the decision should be reviewed later to see whether it met the guidelines.

Dr Sacconi felt that the emphasis in point (ii) was incorrect, because the other applications are mentioned before the major applications of practical realisation of the definition of the metre and secondary representations of the second. He suggested that the wording should be revised to start with the primary focus.

Dr Madej suggested that the term “vacuum wavelength” should replace “wavelength”.

It was agreed that Dr Riehle and Dr Gill should prepare a suitably revised draft of the terms of reference for further discussion by the delegates under agenda item 10.

4. Consideration of returns from NMIs to WG questionnaire

Dr Felder presented a summary of the responses to the JWG questionnaire. No proposals had been made for new entries in the list of recommended frequencies relating to the practical realisation of the definition of the metre, but several had been made relating to secondary representations of the second. There were also several proposals for additions of new frequency values that did not fall into either category and Dr Gill pointed out that the questionnaire did not properly cater for such cases.

There were a number of proposals for updates to existing values and/or uncertainties in the list, namely the $5s^2\ ^1S_0 - 5s5p\ ^3P_0$ transition in ^{87}Sr, the $6s\ ^2S_{1/2}$ (F=0) – $5d\ ^2D_{3/2}$ (F=2,M_F=0) transition in $^{171}Yb^+$, the $4f^{14}6s\ ^2S_{1/2}$ (F=0) – $4f^{13}6s^2\ ^2F_{7/2}$ (F=3, M_F=0) transition in $^{171}Yb^+$ and the $^{13}C_2H_2$, P(16) ($\nu_1+\nu_3$) band transition.

Proposals for frequencies to be added to the list were the $5s^2\ ^1S_0 - 5s5p\ ^3P_0$ transition in ^{88}Sr, the $4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ transition in $^{40}Ca^+$ and the $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ transition in ^{171}Yb.

No response to the questionnaire had been received from NIST, but Dr Bergquist confirmed that after discussions they had decided not to recommend any additions to the list at the present time.

5. Consideration of additions/updates to the revised single list of frequencies including secondary representations of the second and frequencies for the realisation of the definition of the metre

After some discussion it was agreed that the WG should strictly implement the requirement for frequency measurements to be published in a peer-reviewed journal before they can be considered for updates or additions to the list of recommended frequency values. Some delegates were initially concerned that if a frequency had been in the list for many years then new values may not be published; however Dr Riehle expressed the view that if new results were significant enough to change the value and/or uncertainty of the frequency in the list then they would be accepted by a referee as worthy of publication.

It was also agreed that where possible a laboratory should send the supporting publications to the BIPM at least 2-3 weeks before the meeting. Exceptions would only be made for papers that were accepted for publication in the interim period between the deadline and the WG meeting. The suggestion of an earlier deadline was discussed but not favoured because it would mean that the WG could be discussing out-of-date results.

Dr Arias suggested that it might be a good idea to establish some communications by e-mail to look at publications which appear between WG meetings, to improve preparation for the main meeting. Documents could be posted on the restricted website and comments to the co-chairs invited. After some further discussion it was proposed that the WG should meet at least

once a year. This could be either at BIPM or at a conference, or could be a virtual meeting via e-mail.

$5s^2\ ^1S_0 - 5s5p\ ^3P_0$ transition in ^{87}Sr

Dr Hong gave a short presentation on recent frequency measurements of the ^{87}Sr standard carried out using a 120 km optical fibre link between the University of Tokyo and Tsukuba. He compared their most recent frequency value with those from SYRTE and JILA and showed that the three results were in excellent agreement.

It was agreed that the recommended frequency value and uncertainty should be updated. A sub-group was delegated to report back later in the day with a recommendation for the frequency value and uncertainty that should be used.

$6s\ ^2S_{1/2}\ (F=0) - 5d\ ^2D_{3/2}\ (F=2, M_F=0)$ electric quadrupole transition in $^{171}Yb^+$
and
$4f^{14}6s\ ^2S_{1/2}\ (F=0) - 4f^{13}6s^2\ ^2F_{7/2}\ (F=3, M_F=0)$ electric octupole transition in $^{171}Yb^+$

Dr Margolis presented a brief summary of the latest frequency measurements of these transitions at NPL.

For the quadrupole transition, it was agreed that no recommendations for changes should be made, because although there are new results from both PTB and NPL, these have not yet been accepted for publication in a peer-reviewed journal.

The new NPL frequency measurement of the octupole transition has, however, been published and the recommended frequency value and uncertainty should be updated accordingly. A sub-group was delegated to report back later in the day with a recommendation for the frequency value and uncertainty that should be used.

$^{13}C_2H_2$, P(16) ($\nu_1 + \nu_3$) band transition

Dr Madej noted that there had been several new measurements of this transition frequency and that the scatter on the values was low. A sub-group was delegated to report back later in the day with recommendations as to whether the frequency value and uncertainty in the list should be updated.

$5s^2\ ^1S_0 - 5s5p\ ^3P_0$ transition in ^{88}Sr

There are currently two measurements for this transition frequency. One is an absolute frequency measurement from the LNE-SYRTE group. The other result, from the University of Tokyo, is an isotope shift measurement relative to the same transition in ^{87}Sr.

It was agreed that this transition should be added to the list of recommended frequency values. A sub-group was delegated to report back later in the day with a recommendation for the frequency value and uncertainty that should be used.

$4s\ ^2S_{1/2} - 3d\ ^2D_{5/2}$ transition in $^{40}Ca^+$

Three values are available from this transition frequency, one from the Innsbruck group and two from the NICT group. However the more accurate of the two measurements from the NICT group has only been published in conference proceedings which were not peer reviewed and so it was agreed that this should not be considered. The remaining two results have rather different uncertainty (2.4 parts in 10^{15} for the Innsbruck measurement and 4.4 parts in 10^{14} for the NICT measurement). It was suggested that a weighted mean be used, meaning that the Innsbruck result dominates the final value and uncertainty. The factor by which to increase the uncertainty was discussed, and there was general support for a factor of three multiplication factor.[1]

$6s^2\ ^1S_0 - 6s6p\ ^3P_0$ transition in ^{171}Yb

This transition frequency has recently been measured in a 1D optical lattice clock at NMIJ with an uncertainty of 28 Hz (fractional uncertainty of 5.4×10^{-14}). This measurement was accepted for publication in Appl. Phys. Express just prior to the WG meeting (27th May).

It was agreed that this transition should be added to the list of recommended frequency values. A sub-group was delegated to report back later in the day with a recommendation for the frequency value and uncertainty that should be used, bearing in mind that there is only a single published value from one group.

6. Report on key comparison CCL-K11

Dr Matus gave a short status report on the operation of the CCL-K11 key comparison. The main activity undertaken during the period 2007/2008 was the preparation of the technical protocol, which took as its basis the protocol for the BIPM.L-K11 key comparison and incorporated the comments formulated at the 12th WGDM meeting. The new technical protocol CCL-K11_Technical_Protocol.pdf is now available on the Key Comparison Database (BIPM website). The main change compared to BIPM.L-K11 is the way in which the key comparison reference value (KCRV) is defined. For CCL-K11 the KCRV is the measured frequency, possibly corrected for the nominal working parameters, and is different for each participant. The results are compared using the degree of equivalence relative to the KCRV, with the linking being via the SI second. This allows different radiations to be compared.

The CCL-K11 is designed to provide a technical basis for the review of CMCs in the field of standard-based optical frequency/wavelength calibrations (in particular those that are important for the field of dimensional metrology). Only laboratories with CMCs in the field of standard-based optical frequency/wavelength calibrations need take part in the key comparison. Laboratories using a frequency comb for this type of calibration may take part, but in this case they must do so using a laser as an artefact. The participating laboratory must submit in advance values for the expected frequency value of the standard and the relevant operational parameters, together with an uncertainty estimate. The measurements performed as part of the key comparison are blind measurements, and thus the results are communicated to the participant only after the measurements have been completed.

[1] Further discussions of a small sub-group during the CCTF decided to adopt a larger uncertainty equal to the uncertainty of the NICT frequency value.

So far two measurement campaigns have been carried out under CCL-K11, at MIKES in December 2007 and at BEV in March 2009. NRC has also recently put out a call to which some NMIs have responded.

Following on from the presentation by Dr Matus there was some discussion about whether NMIs using a comb for optical frequency/wavelength calibrations should take part in CCL-K11, and if so, how. There was interest expressed by several labs in a method for validating combs at an accuracy level better than what could be achieved by transport of a stabilized laser. One possibility would be a BIPM travelling comb. Dr Arias stated that BIPM would consider putting this forward to the CIPM as part of their proposed future work programme if the relevant consultative committees made clear recommendations that such a comb was needed. This would not just be for occasional use but only if there was sufficient interest, which could involve remote frequency transfer for comparison of optical clocks as well as length metrology applications.

Dr Riehle pointed out that in many cases neither a transportable comb nor a transportable laser were needed – combs could be validated by comparing measurements of the same frequency standard (e.g. a Sr lattice clock) made in different laboratories.

The difficulties of transporting frequency combs were also discussed and it was pointed out that this was potentially a rather expensive way of validating CMCs.

Dr Hong pointed out the importance of the frequency reference for the comb and that the link between how well the comb works at the remote laboratory and at the home laboratory may be very weak if different rf sources are used in the two locations.

Dr Arias suggested that the BIPM would circulate a questionnaire in the summer to all NMIs linked with length activities, in order to gauge the level of interest in a BIPM travelling comb, and that if they reacted quickly this would be in time to influence the first draft of the work programme for the CIPM. She requested that the WG provide a clear written request for this to happen. A sub-group was delegated to formulate the questionnaire, consisting of Dr Arias (BIPM), Dr Matus (BEV) and Dr Gill (NPL).

7. Consideration of possible new comparisons

In light of the discussions under the previous agenda item, Dr Gill suggested that the technical protocol for CCL-K11 could be updated to address some of the issues about comb validation.

Dr Robertsson expressed the opinion that it was not that simple because it is not immediately obvious what the measurand or the key comparison reference value are in the case of a comb validation. He suggested that it might be simpler to write a separate technical protocol to cover this case.

Dr Madej expressed concern that although the node laboratories have accepted responsibility for CCL-K11 comparisons of stabilised lasers, extending the protocol to cover comb validations would mean that the node laboratories gained additional responsibilities.

It was agreed that a sub-group should develop a new (separate) technical protocol on behalf of the WG. This sub-group would consist of Dr Matus (BEV), Dr Hong (NMIJ), Dr Warrington (NMIA), Dr Zucco (INRIM) and Dr Madej (NRC-INMS), together with Dr Lea who is the CCL-K11 coordinator at NPL.

9. Report on the CCU discussion on a redefinition of the second, possibly as soon as 2015, in view of recent developments in the use of optical transitions

Dr Riehle and Dr Gill were asked by Prof. Mills (president of the CCU) to report at last week's CCU meeting on a future redefinition of the second, possibly as soon as 2015. Dr Riehle gave a brief overview of their presentation to the CCU, which covered the Cs clock as the primary realization of the second, the concept of secondary representations of the second, the list of recommended standard frequencies and options and constraints for a new definition. The possibility of connecting time to fundamental constants (the Rydberg constant) was considered unfeasible at the present time because the fractional uncertainty of the Rydberg constant is limited to a few parts in 10^{12} at present. The more feasible option was a definition via a suitable optical frequency transition, but at present the best optical standards are at the most one order of magnitude better than the best microwave clocks, novel methods for time dissemination are needed and there is a large list of candidates with insufficient knowledge as yet about their limiting frequency shifts. Work to address these different issues was briefly summarised in the presentation to the CCU. A possible procedure for a new definition of the second was outlined, whereby one of the best optical standards is selected to define the second and its frequency is "frozen". The realization of the second would then be performed either by this standard or by secondary representations from a list of recommended standard frequencies (LoR). This would require a rigorous set of frequency ratios to be included in the LoR, to be updated regularly by the JWG and approved by the CCTF and CIPM. Alternatively the mean frequency of the best standards could be used for the definition of the second, with the advantage that this would provide the optimum realization at the time of the new definition, but with the disadvantage that it would be hard to cope with (different) improvements of (different) standards over time. Since the Cs definition is expected to meet industry needs for some time, and the current system of secondary representations serves science needs, and there is currently no strong argument for preferring either ions or atoms, it was suggested that 2015 might be too early for a redefinition of the second. Instead it was considered that the time would be right when progress with optical standards slows down and the problem of comparing remotely located optical frequency standards has been solved.

The response of the CCU to this presentation was that they encouraged laboratories to work on optical frequency standards for a new definition of the second (maybe in 2019). They also encouraged the Frequency Standards WG to list optical frequency ratios as well as the frequencies themselves. Finally they pointed out that the new definition of the SI base units kg, A, mol, K will also lead to a new phrasing of the definition of the metre and the second.

It was noted that the rephrasing of the definitions of the metre and the second had not yet been discussed by either the CCL and CCTF, and would have to be before such changes could be implemented.

8. Detailed discussion on the possible revision of the single list of radiations to be published in Metrologia, including structure and contents

Dr Riehle presented the outline of the draft document he and Dr Gill had prepared for Metrologia. This began with an introduction and historical perspective, followed by the list of recommended frequencies. Appendix 1 specified which frequency standards could be used as secondary representations of the second (currently 5 – 1 microwave and 4 optical) while appendix 2 specified which were recommended for the practical realisation of the definition of the metre. Further appendices gave the source data for the recommendations and listed frequency intervals between the recommended frequency values and other frequencies. Following on from the CCU recommendations (agenda item 9) frequency ratios could be included in another appendix.

The best way in which to record frequency ratio information was discussed. Dr Madej expressed a concern that this could potentially bias the choice for a new definition of the second because some systems are easier to compare than others (if, for example, they are in the same place).

It was agreed that since there is presently only one high accuracy measurement of an optical frequency ratio, there is no immediate pressure to add them to the list now. For this reason a sub-group was assigned the task of discussing these issues and making a recommendation as to how best to include frequency ratios. This sub-group consists of Drs Bergquist (NIST), Madej (NRC-INMS), Lemonde (LNE-SYRTE), Hong (NMIJ), Riehle (PTB) and Gill (NPL).

10. Preparation of WG recommendations to CCL and CCTF

It was agreed to recommend terms of reference for the Frequency Standards WG as follows:

i. To maintain and update a list of recommended frequency standard values and wavelength values for the realisation of the definition of the metre and for secondary representations of the second, and for other applications.
ii. To make recommendations to the CCL for radiations to be used for the realization of the definition of the metre and to the CCTF for radiations to be used as secondary representations of the second.
iii. That the chairperson should be appointed jointly by the CCL and CCTF chairpersons for a period of four years (or at least two consecutive committee meetings) with the possibility of a second term.

It was further agreed that Dr Riehle and Dr Gill should (with the help of BIPM staff) harmonize these recommendations with the phrasing of other committees. The other terms of reference from the CCL 2007 meeting concerning the CCL-K11 key comparison should also be incorporated.

It was agreed to make the following recommendations for changes to the list of recommended frequencies:

$5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ transition in ^{87}Sr (update)
429 228 004 229 873.65 Hz uncertainty 1×10^{-15}
(weighted mean without expansion factor because all 3 measurements contribute significantly)

$5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ transition in ^{88}Sr (new)

429 228 066 418 012 Hz uncertainty 1×10^{-14}
(weighted mean, 3 × combined uncertainty of 2 measurements because one is much more accurate than the other)[2]

$6s^2\ {}^1S_0 - 6s6p\ {}^3P_0$ transition in ^{171}Yb (new)
518 295 836 590 864 Hz uncertainty 1.6×10^{-13}
(one measurement only, uncertainty increased by a factor of 3)

$4s\ {}^2S_{1/2} - 3d\ {}^2D_{5/2}$ transition in $^{40}Ca^+$ (new)
411 042 129 776 393 Hz uncertainty 4.4×10^{-14}
(weighted mean, uncertainty as in footnote 1 on p. 5)

$4f^{14}6s\ {}^2S_{1/2}$ (F=0) – $4f^{13}6s^2\ {}^2F_{7/2}$ (F=3, M_F=0) electric octupole transition in $^{171}Yb^+$
642 121 496 772 657 Hz uncertainty 6×10^{-14}
(one measurement only, uncertainty increased by a factor of 3)

(The sub-group designated to discuss acetylene recommended that no change to either the frequency value or uncertainty for the P(16) transition was required.)

No new secondary representations of the second were recommended.
No new radiations were recommended for realisation of the definition of the metre.

It was also agreed that a WG meeting should be held each year, either at BIPM or a conference or as a virtual meeting. Guidelines should be set up as to how to deal with new frequency values, i.e. to make changes in the list only as a result of refereed publications and to formulate the safety factors to be applied to the uncertainty in the case of a small number of independent measurements.

11. Other business

Dr Madej pointed out the need to update the recommendations from the last CCL meeting onto the BIPM website, including the tabulation of acetylene transition frequencies.

Dr Felder, who is due to retire in August, was thanked for his contribution as executive secretary to the CCL.

[2] In further discussions within a sub-group during the CCTF, it was recognised that just combining in quadrature the total uncertainties of all reported measurements, where several of these measurement uncertainties might be close to common systematic contributions such as that of the Cs primary frequency standard uncertainty or the blackbody shift, could lead to an uncertainty below those contributions. It was determined that this would be resolved by the inclusion of a common systematic contribution "floor" within the combined uncertainty.