

BUREAU INTERNATIONAL DES POIDS ET MESURES

# Consultative Committee for Electricity and Magnetism (CCEM)

Report of the 25th meeting  
(15–16 March 2007)  
to the International Committee for Weights and Measures



Comité international des poids et mesures

Bureau  
international  
des poids  
et mesures

Organisation  
intergouvernementale  
de la Convention  
du Mètre

Note:

Following a decision made by the International Committee for Weights and Measures at its 92nd meeting in October 2003, reports of meetings of Consultative Committees will henceforth be published only on the BIPM website in the form presented here.

Full bilingual printed versions in French and English will no longer appear.

A.J. Wallard,  
Director BIPM

**LIST OF MEMBERS OF THE  
CONSULTATIVE COMMITTEE FOR  
ELECTRICITY AND MAGNETISM  
as of 16 March 2007**

**President**

Dr B.D. Inglis, member of the International Committee for Weights and Measures, National Measurement Institute of Australia, Lindfield.

**Executive Secretary**

Dr T.J. Witt, International Bureau of Weights and Measures [BIPM], Sèvres.

**Members**

Centre for Metrology and Accreditation [MIKES], Helsinki.

CSIR – National Metrology Laboratory [CSIR-NML\*], Pretoria.

D.I. Mendeleev Institute for Metrology, Rostekhnregulirovaniye of Russia [VNIIM],  
St Petersburg.

Danish Institute of Fundamental Metrology [DFM], Lyngby.

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Justervesenet [JV], Kjeller.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

Measurement Standards Laboratory of New Zealand [MSL], Lower Hutt.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Institute of Japan, AIST [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Physical Laboratory of India [NPLI], New Delhi.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.

Swiss Federal Office of Metrology [METAS], Bern-Wabern.

Technical Research Institute of Sweden [SP], Borås.

The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

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\* Renamed National Metrology Institute of South Africa (NMISA).

### **Observers**

Centro Español de Metrología [CEM], Madrid.

Czech Metrology Institute [CMI], Prague.

Instituto Nacional de Tecnología Industrial [INTI], Buenos Aires.

National Institute of Metrology, Standardization and Industrial Quality [INMETRO], Rio de Janeiro.

National Metrology Institute of Turkey [UME], Gebze-Kocaeli.

### **CCEM Working Group on Low Frequency Quantities**

as of 13 March 2007

### **Chairman**

Dr H. Bachmair, Physikalisch-Technische Bundesanstalt, Braunschweig.

### **Members**

D.I. Mendeleev Institute for Metrology [VNIIM], St Petersburg.

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

National Institute of Standards and Technology [NIST], Gaithersburg.

Nederlands Meetinstituut/Van Swinden Laboratorium [NMI VSL], Delft.

National Metrology Institute of Japan [NMIJ/AIST], Tsukuba.

National Measurement Institute, Australia [NMIA], Lindfield.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC-INMS], Ottawa.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Technical Research Institute of Sweden [SP], Borås.

International Bureau of Weights and Measures [BIPM], Sèvres.

## **CCEM Working Group on Radiofrequency Quantities**

as of 12 March 2007

### **Chairman**

J. Randa, National Institute of Standards and Technology, Boulder.

### **Members**

Institute for Physical-Technical and Radiotechnical Measurements [VNIIFTRI],  
Rostekhregulirovaniye of Russia, Moscow.

International Union of Radio Science [URSI].

Istituto Nazionale di Ricerca Metrologica [INRIM], Turin.

Korea Research Institute of Standards and Science [KRISS], Daejeon.

Laboratoire National de Métrologie et d'Essais [LNE], Paris.

National Institute of Metrology [NIM], Beijing.

National Institute of Standards and Technology [NIST], Gaithersburg.

National Measurement Institute of Australia [NMIA], Lindfield.

National Metrology Institute of Japan, AIST [NMIJ/AIST], Tsukuba.

National Physical Laboratory [NPL], Teddington.

National Research Council of Canada [NRC], Ottawa.

Nederlands Meetinstituut, Van Swinden Laboratorium [NMI VSL], Delft.

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig.

Standards, Productivity and Innovation Board [SPRING Singapore], Singapore.

Swiss Federal Office of Metrology [METAS], Bern-Wabern.

Mr Luc Érard, LNE.

The Director of the International Bureau of Weights and Measures [BIPM], Sèvres.

**CCEM Working Group on the Coordination of the Regional Metrology Organizations**  
as of 14 March 2007

**Chairman**

G. Marullo Reedtz, Istituto Nazionale di Ricerca Metrologica, Turin.

**Members**

Chairpersons of the Regional Metrology Organizations' Technical Committees for Electricity  
and Magnetism

Chairpersons of the Working Groups on Low Frequency Quantities and on Radiofrequency  
Quantities

Executive Secretaries of the CCEM and the Joint Committee of the Regional Metrology  
Organizations and the BIPM

The coordinator of the BIPM key comparison database

## 1 **OPENING OF THE MEETING; APPOINTMENT OF RAPPORTEURS; APPROVAL OF THE AGENDA**

The Consultative Committee for Electricity and Magnetism (CCEM)\* held its twenty-fifth meeting on 15-16 March 2007 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, at Sèvres, France.

The following were present: E. Afonso (INMETRO), W.E. Anderson (NIST), H. Bachmair (PTB), L. Christian (MSL), S.W. Chua (SPRING), J.P.M. de Vreede (NMI VSL), E. Dressler (CSIR-NML), Q. Gao (NIM), G. Genevès (LNE), B.D. Inglis (member of the CIPM, NMIA, President of the CCEM), D. Inglis (NRC-INMS), B. Jeckelmann (METAS), H. Jensen (DFM), T.-W. Kang (KRISS), A. Katkov (VNIIM), K.-T. Kim (KRISS), K. Komiyama (NMIJ/AIST), G. Kyriazis (INMETRO), Z. Lu (NIM), A. Manninen (MIKES), G. Marullo Reedtz (INRIM), J. Melcher (PTB), Y. Nakamura (NMIJ/AIST), H. Nilsson (SP), J.K. Olthoff (NIST), F. Piquemal (LNE), U. Pogliano (INRIM), J. Randa (NIST), B. Ricketts (NMIA), G. Rietveld (NMI-VSL), I.A. Robinson (NPL), A.K. Saxena (NPLI), Y.P. Semenov (VNIIM), S. Singh (CSIR-NML), H. Slinde (JV), Y. S. Song (KRISS), J. Streit (CMI), J. Williams (NPL), B. Wood (NRC-INMS), A.J. Wallard (Director of the BIPM), Z. Zhang (NIM).

Invited: J. Valdés (INTI, member of the CIPM).

Also present: T.J. Quinn (Director Emeritus of the BIPM); R. Chayramy, N. Fletcher, R. Goebel, S. Solve, M. Stock, C. Thomas (KCDB Coordinator), T.J. Witt (Executive Secretary of the CCEM) (BIPM).

The President of the CCEM opened the meeting at 9.00 a.m. and welcomed the participants.

Forty-one working documents were presented to the meeting for consideration by the CCEM and four more have been added since the meeting started. A list is given in Appendix E 1.

H. Slinde was appointed rapporteur.

The draft agenda was considered and approved by the members.

## 2 **MATTERS RELATED TO FUNDAMENTAL CONSTANTS AND THE SI**

### 2.1 **Report of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram (WGKG)**

I. Robinson reported from the meeting of June 2006 held during the CPEM 2006 in Turin. The following is a summary of the progress achieved in the different experiments.

- In the PTB ion deposition experiment, the ion source and vacuum balance is ready and the atomic mass of bismuth has been measured with a relative uncertainty of 5 parts in  $10^4$ .

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\* For the list of acronyms, [click here](#).

There are some problems with back-scattering of neutralised atoms and contaminant adsorption remains. The project will not contribute to the 2010 CODATA adjustment and will be terminated at the end of 2007.

- The Avogadro collaboration project has prepared a  $^{28}\text{Si}$  boule, which will be used to make two 1 kg spheres, plus samples for lattice spacing and purity measurements. The polishing of the samples will take place early in 2007 and results, with an expected uncertainty of 2 parts in  $10^8$  are expected in 2009. A contribution to the 2010 CODATA adjustment is planned. The project has adequate resources and funding.
- In the BIPM cryogenic watt balance experiment, the two phases of the experiments will be combined into one. The magnet has been designed, the interferometer and beam vertical measurement system and coil suspension and motion control system has been prototyped. A room temperature prototype is planned by 2008-2009. No contribution to the 2010 CODATA adjustment is planned. Funding and resources equivalent to 1.8 full time staff are assigned to the project.
- In the LNE watt balance experiment, the magnet and improved drive stage have been assembled, and the current source and second prototype balance beam constructed. The interferometer is to be moved to Trappes. A SINIS Josephson reference bias source is used, a collaboration project with NPL. Gravitational checks have been performed on the slabs. Mass materials from EUROMET project 734 will be used. Characterisation of the system is planned for 2007-2008. A contribution to the 2010 CODATA adjustment is planned. The project is fully funded.
- In the METAS experiment, the suspension has been modified and a mass exchanger added. The mass comparator has been modified and measurements of 50 g and 100 g masses show reasonable agreement. Further improvements are in hand and results for the 2010 CODATA adjustments are planned. The project has 1 fulltime staff and support from others at METAS.
- The NIST group has published two results with uncertainties of 52 nW/W and 36 nW/W in 2005 and 2007, respectively. Several improvements have been made, such as transfer of  $g$ , magnetic susceptibility of the mass and resistance transfer. NIST is aiming for a result with an uncertainty close to 20 nW/W by mid 2007, which will contribute to the 2010 CODATA adjustment. Resources equivalent to 2 full time staff with good funding are available.
- At the NPL work has proceeded in parallel on the Mk II and Mk III balances. The design of the MK III is complete. Improvements and upgrades to the Mk II have resulted in good agreements between 1 kg weights of Au/Cu and 500 g of Au/Cu and Si. Each of the principal uncertainties can be reduced to below 1 in  $10^8$ . Unfortunately, funding beyond March 2007 is not available.
- The NIM recently proposed a watt balance experiment, which eliminates the need to move the coil by varying the flux at a constant rate and measuring the constant voltage induced. Contribution to the 2010 CODATA adjustment is not planned and funding and resources are secure for three years.
- The MSL in New Zealand are considering starting a watt balance project.
- In the MIKES/VNIIM collaboration on levitated mass, results from studies on a first set of Nb coils show losses, which will limit accuracy to 1 in  $10^6$ . Other materials may give better results, but the instrument will not be constructed in the near future due to lack of funding.
- The gravimeter comparison ICAG 2005 showed good agreement and differed from the 2001 result by 3 in  $10^9$ . The next comparison is planned for late 2009.



In summary, five groups plan to have results for the 2010 CODATA adjustment, which should make a significant contribution.

## 2.2 Report of the CCEM Working Group on Proposed Changes to the SI (WGSi) and CCEM response to CIPM Recommendation 1 (CI-2005)

Following the CIPM Recommendation 1 (CI-2005), that preparative steps should be taken towards new definitions of kilogram, the ampere, the kelvin and the mole in terms of fundamental constants and a response published in *Metrologia*<sup>1</sup>, a working group was formed in 2006 at the request of the CIPM, to solicit opinion from the electrical community and to make a recommendation for the CCEM's consideration in 2007. Members of the group were B. Jeckelmann (METAS), F. Piquemal (LNE), B. Ricketts (NMIA), I. Robinson (NPL), J. Melcher (PTB), M. Stock (BIPM), C. Thomas (BIPM), E. Williams (NIST), T.J. Witt (BIPM), and B. Wood (NRC, Chairman).

The group has had three meetings, in March 2006 at BIPM, at CPEM 2006 in Turin and in January 2007 at BIPM. M. Stock and T.J. Witt have also published in *Metrologia*<sup>2</sup> the CPEM "round table discussion" of the issue. B. Wood presented a summary of the work and considerations of the group, and gave a firm background for the discussions on the CCEM response.

The group proposes to modify the SI by fixing the values of a set of fundamental constants (the speed of light ( $c$ ), the Planck constant ( $h$ ), the elementary charge ( $e$ ), the Boltzmann constant ( $k$ ) and the Avogadro constant ( $N_A$ )) and to make the SI units consistent with these values.

The following general considerations were taken into account:

- Whether the redefinition should be adopted, in 2011 or later in 2015. Any decision by the CIPM must be ratified by the CGPM.
- Which values should be adopted for the fundamental constants? The most recent CODATA values is one alternative.
- What will be the implications on the other physical constants ( $\epsilon_0, \mu_0, \alpha$ , etc.).
- The new definition will cause increased uncertainties in some quantities.
- The definitions of some units will have to be reworded.
- Some "old measurements" will have to be reinterpreted (for example, the quantum Hall resistance and the Thompson Lampard experiments).
- The inconsistency of the present determination of the fundamental constants.
- The publicity and education needed to implement prepare for the change.
- Justification and funding for present and planned projects.

Various ways were explored to redefine the SI with respect to fundamental constants and to assess their impact on electrical metrology. Most alternatives involve  $e$ ,  $h$ ,  $N_A$  and  $\mu_0$ , or

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<sup>1</sup> Redefinition of the kilogram, ampere, kelvin and mole: a proposed approach to implementing CIPM Recommendation 1 (CI-2005)", I.M. Mills, T.J. Quinn, B.N. Taylor and E.R. Williams, *Metrologia*, 2006, **43** (3), 227-246.

<sup>2</sup> CPEM 2006 round table discussion 'Proposed changes to the SI' ", T.J. Witt and M. Stock, *Metrologia*, 2006, **43** (6), 583-587.

combinations of these (e.g. the Planck charge...). The history and present status of the SI focusing on the evolution of mass metrology and correspondingly developments in electrical metrology over the last 30 years were reviewed. The Josephson and quantum Hall effects with regard to the accuracy and completeness of their theoretical foundation, the accuracy and reproducibility of their practical realizations, their cost, ease of use, and the extent to which they are in use worldwide were considered.

The group noted that the Josephson and quantum Hall effects are in regular use at relative uncertainties of the order of  $10^{-9}$  (similar to the fractional uncertainty of mass measurements) and that:

- Essentially all international comparisons have agreed within their uncertainties.
- All standards report the same values (as opposed to mass artefacts).
- There is a large worldwide infrastructure supporting the use of these effects.
- Their use as primary references is expected to continue for at least another 20 years.

Mass metrology, watt balance experiments, Avogadro experiments, ion accumulation, magnetic levitation, fundamental constants, etc, were also reviewed.

The group has the view that the definitions of a base unit and the seven present base units do not indicate why they are base units – they are not characteristic specific. Still, there are three general concepts associated with base units:

- *Independence*: The original four base units were independent of each other and all measured SI quantities could be described as functions of just those base units: “the base units spanned the parameter space”. The present base units do not have this independent characteristic. However, the proposed set of fixed fundamental constants does have this characteristic. Independence is a desirable but not a necessary characteristic of base units. This is demonstrated by the present situation.
- *Apex of traceability*: Traceability extends all the way to the base units and then stops. The base units are the final reference in any SI traceability chain. This is functionally true today with the possible exception of the electrical units. This concept of the apex of traceability is still needed, but it can be embodied in units and/or fundamental constants. We probably would need to change the definition of base units.
- *Dimensional analysis*: The base units are commonly used for dimensional analysis and a common set of units is convenient for this purpose. This set has to span the measurement parameter space. The units of the set do not have to be independent. The existing base units satisfy these criteria, but so do other sets. We should consider modifying the definition of the base units or adding a new definition for the use of dimensional analysis.

The CCEM WGSI has the opinion that defining both  $h$ , and  $e$  are essential to realize the full benefit of the Josephson and QHR experiments. The Josephson and QHR experiments are demonstrated to provide consistent worldwide traceability through a large infrastructure of installations. The advantages of defining  $h$  and  $e$  outweigh the concerns of having a definition that may be difficult to understand by the public. The possible inconsistency of the  $N_A$  and the watt balance measurements has little technical significance to electrical metrology.

The group has the following comments about the conditions of disagreement that could be tolerated, but still may be acceptable:

The OIML tolerance of E1 class masses is  $0.08 \times 10^{-6}$ . Then within the last five years before the change of the SI, at least one watt balance determination of  $h$ , with uncertainty of

$h \leq 0.08 \times 10^{-6}$  is needed. Also, at least one other watt balance determination of  $h$  within the combined uncertainties must be available. Consistency with results from the determination of  $N_A$  is desirable but not necessary for electrical consistency.

B. Wood presented the draft for Recommendation E 1 (2007) and printed copies were handed out.

There were a few brief comments to the presentation, but none expressed any real disagreement with the proposal.

The President informed the meeting that a comment from INRIM had also been received and should be taken into consideration (CCEM/07-31). He also encouraged the participants to discuss the proposal during the breaks and that the theme would be taken up for final consideration on the second day of the meeting.

The matter was taken up again on the second day and the details of the proposal were discussed. Some minor changes were made.

J. Valdés commented that the mass community may be reluctant to fix the values of  $h$  and  $e$ , because this will have important implications on the definition of the mass. The President answered that the units are only to be established within certain uncertainties and that the recommendation is the view of the CCEM, which represents the “electrical community”.

The final version of the CCEM response to CIPM Recommendation 1 (CI-2005) was agreed and is available in the appendix.

### **2.3 Advances in the realizations of the SI electrical units and of $K_J$ and $R_K$**

No new developments in addition to the ones mentioned in Section 11 were reported.

## **3 REPORT FROM THE WORKING GROUP ON MEASUREMENTS OF THE QUANTIZED HALL RESISTANCE WITH ALTERNATING CURRENT AND RELATED MEASUREMENTS**

J. Melcher summarized the progress in the work of the CCEM Working Group on Measurements of the Quantized Hall Resistance with Alternating Current and Related Measurements (WGACQHR):

- The group proposed to extend the scope to also include items such as quantum electrical standards and calculable capacitors. If so a new name should also be considered.
- A compendium with Guidelines for accurate ACQHR measurements is being prepared and will be presented at the CPEM 2008 in Boulder (United States).
- An internet page on diverse practical issues will be installed.

D. Inglis commented that possibly the working group should be terminated when it had fulfilled its purpose.

The President agreed and encouraged the group to convene in a break of the meeting for a discussion among the WGACQHR members present.

Following their discussion, J. Melcher summarized the conclusions:

- The NIM is interested in joining the group.
- The group will continue its work until the next CCEM meeting. A WGACQHR meeting is planned during the CPEM 2008.
- It is important to keep the working group focused and to finish the work according to the terms of reference given by the CCEM. This includes formulating Guidelines for precision ac measurements of the QHR.
- If it is felt that more than a compendium is needed, a new set of terms of reference should be agreed by the CCEM.

It was agreed that the working group should finish its work and report back at the next CCEM meeting.

## **4 EXPERIENCES WITH AND THE AVAILABILITY OF CRITICAL DEVICES FOR ELECTRICAL METROLOGY**

### **4.1 Unbiased and programmable arrays of Josephson junctions**

S. Solve gave a short presentation on the quality of the presently available arrays of SIS Josephson junctions. At the BIPM, arrays are exposed to severe conditions, with regular thermal cycling. Tests were made on arrays from two commercial manufacturers presently supplying them and it was found that arrays from both of these sources are unsatisfactory. One type shows sloped steps, indicating resistive segments in the array. As for those from the second source, the manufacturer specifies that the microwaves must be switched off during polarity changes. This implies longer measurement times and possibly variations of the thermal electromotive forces following each polarity change.

H. Bachmair mentioned that PTB can lend out a very few sample chips for testing and comparison measurements. Only SINIS type arrays are now in use. The PTB will also sell some 1 V programmable chips, but the prices quoted will be high.

A. Manninen informed the meeting that VTT had manufactured a batch of 1.5 V programmable arrays and 10 V conventional arrays for MIKES. A few samples may be available to others.

G. Rietveld said that there is cooperation on ac Josephson standards between NMi VSL, PTB and NIST. Pulse drive electronics is being developed, which can be used for generating ac Josephson voltages up to ~100 mV. Further details are given in the NMi VSL progress report (CCEM/07-35).

J. Williams informed the meeting that in the iMERA European collaboration there is also a project on developing a Josephson power source: "Binary array Josephson power standard" (CCEM/07-38).

J. Olthoff mentioned that NIST had performed the first ever calibration of an ac-dc voltage transfer standard for a commercial customer using a quantum voltage standard.

T.J. Witt encouraged all NMIs who experience problems with Josephson chips to report their results to S. Solve at the BIPM.

## 4.2 Quantum Hall devices

The PTB can produce devices for quantum Hall experiments on specific demands, but only for dc. Generally the availability is very limited.

D. Inglis informed the meeting that NRC most probably will produce quantum Hall devices for dc within the next twelve months, and possibly also devices for ac.

The LNE has some arrays produced for a research project. Possibly there will be a project for the production of samples for QHE within the framework of the European Metrology Research Program (EMRP).

## 4.3 Planar multi-junction thermal voltage converters

H. Bachmair informed the meeting that the situation for planar multi-junction thermal converters is similar to the one for quantum Hall devices. Very few devices are available and further units will only be produced on demand. The devices are produced at the IPHT in Jena, but the production depends upon the availability of one specific person. A list of interested NMIs will be made at the next EUROMET low-frequency expert meeting at MIKES in the second half of June 2007.

The PTB will send out the specifications of the converters to the CCEM members and Regional Metrology Organization (RMO) chairpersons soon after the CCEM meeting. The TC chairpersons from RMOs outside Europe and the NMIs are encouraged to widely circulate the specifications along with the information about the planned production run. Interested NMIs should give feedback to T.J. Witt, T. Funck at the PTB or K.E. Rydler at SP (the EUROMET LF Electricity Convener) by June 2007.

## 5 REPORT OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES

H. Bachmair summarised the outcome of the 9th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) on 13-14 March 2007 at the BIPM. A more detailed report is available as document CCEM/07-42 and as an annex to this report.

The CCEM approved the proposal for new procedures for the BIPM bilateral comparisons of Josephson voltage standards, [BIPM.EM-K10.a](#) and [BIPM.EM-K10.b](#). In the modified procedure not only the final results, but also the preliminary results from the bilateral comparisons will be published, if there are significant differences between the two. The final results will be considered as a follow-up comparison, and only these will be displayed in the comparison graphs in the KCDB. A support group for this comparison is being created to help settle any possible disagreements about results. BIPM will write a new protocol for these comparisons and the support group will be asked to approve it. The new procedures will then be applied to future comparisons.

A.J. Wallard commented that this “will bring the BIPM bilateral comparisons further in line with the CIPM recommendations”.

The CCEM approved the key comparisons [CCEM-K11](#) and [CCEM-K11.1](#) (ac/dc voltage transfer difference at low voltages (10 mV and 100 mV)).

The WGLF had no proposals for new comparisons.

The proposed update of the CCEM classification scheme for calibration services was approved (the proposal had also been discussed and agreed with the Working Group on Radiofrequency Quantities and the Working Group on RMO Coordination).

The CCEM approved the proposed revision of the CCEM Guidelines on comparisons. The revision takes into account the need to harmonise the comparison identifiers for regional comparisons by adopting the CCEM identifier scheme, and the impact of comparison results on the CMC claims of the participants. The revised Guidelines are now published on the BIPM website.

D. Inglis commented that it can also be of some help for comparison participants if some of this is written in the protocol. A.J. Wallard added that the NMIs could also indicate in their report which CMCs the comparison results support.

To lower the workload on the Electricity section of the BIPM, the WGLF proposed to invite delegates and guests through the chairperson of the WGLF instead of sending out an official convocation to the directors of the NMIs through the Director of the BIPM. The invitation would be sent to people who participated in the last meeting with a copy to the directors of the respective institutes. The CCEM approved the proposal.

H. Bachmair, the present chairperson of the WGLF, is retiring at the beginning of 2008, but will be able to continue until the next meeting in 2009. The CCEM decided to nominate J. Williams as the new chairperson from 2009, thus enabling a reasonable time for overlap.

## 6 REPORT OF THE CCEM WORKING GROUP ON RADIO FREQUENCY QUANTITIES

J. Randa reported on the meeting of the CCEM Working Group on Radio Frequency Quantities (GT-RF) held on 12 March at the BIPM (see the minutes from the meeting in the appendix).

The CCEM took the following actions that were discussed and recommended by the GT-RF.

It approved for full equivalence the following key comparisons:

- [CCEM.RF-K3.F](#) (horn antenna gain, 26.5 GHz, 33 GHz and 40 GHz); and
- [EUROMET.EM.RF-K8.1.CL](#) (rf power, 10 MHz – 18 GHz).

During its meeting, the GT-RF postponed the approval of one key comparison (KC) and took notice of the status of four currently running GT-RF KCs. The GT-RF proposed one new KC ([APMP.EM.RF-K3.F](#), antenna gain at 26.5 GHz, 33 GHz and 40 GHz), which CCEM approved. Another suggested KC was postponed, due to incomplete protocol. All the seven key quantities are now covered by finished or running KCs.

## 7 GENERAL DISCUSSION ON KEY COMPARISONS

The President expressed the need for a general open discussion about KCs. The enormous time and effort going into key and supplementary comparisons is very much appreciated. We should ask ourselves in which areas the KCs are really needed and if we are putting the effort into the right areas. We should have “a wide view” when we are proposing and selecting KCs and remember the consequences.

J. Williams expressed that there is generally a long and elaborate process with KCs and it takes a very long time before the feedback to the participants is received. Possibly the approach to the KCs could be changed along the lines of the BIPM bilateral comparisons? In such a case specific NMIs could be made responsible for specific quantities for given periods of time.

H. Bachmair commented that it would be very difficult to change the system, but that perhaps the key quantities are in need of re-evaluation.

Generally there are also the challenges of keeping “the scale” of a given key quantity in the time between KCs and the linking between RMOs.

The President encouraged the chairpersons of the working groups to take the expressed views and challenges into account for their next meetings.

## 8 REPORT OF THE CCEM WORKING GROUP ON RMO COORDINATION

H. Bachmair, acting as Chairman of the Working Group for RMO Coordination (WGRMO) in the absence of G. Marullo Reedtz, reported from the WGRMO established during the last CCEM meeting. The following is a short summary; a more detailed report is available in the appendix.

Regarding the traceability for NMIs' CMCs, the JCRB Secretary has clearly stated, that an NMI can only seek traceability from another NMI, which participates in the CIPM MRA. Certificates from manufacturers are not accepted (even if accredited), except for secondary standards, which do not substantially influence the uncertainty (i.e. for monitoring environmental conditions).

The members of the WGRMO consider the necessity of having a comparison executive report from each comparison, which contains the statements of the participating laboratories concerning their CMC claims. The participants should also declare which of their CMCs have been checked in the light of their comparison results. This was also discussed in the WGLF and GT-RF meetings, and taken into the agreed revision of the CCEM Guidelines on comparisons (c.f. section 5 above).

The update of the “Electricity and Magnetism Supplement Guide to the JCRB Instructions for Appendix C of the MRA” (CCEM/07-06 and CCEM/07-08) was approved.

The term for the present chairperson of the WGRMO has ended, and the WGRMO proposed S.W. Chua from SPRING as new chairperson for CCEM. The CCEM approved the proposal.

## 9 REPORT OF THE CCEM WORKING GROUP ON STRATEGIC PLANNING

W. Anderson reported from the CCEM Working Group on Strategic Planning (WGSP). The WGSP was established during the last CCEM meeting in March 2005 and had its first meeting in October 2005. The WGSP has had two more meetings: at the CPEM 2006 in Turin and in March 2007 at the BIPM.

The purpose of the WGSP is to:

- Develop an international strategic plan for identifying and addressing “the big challenges” in electrical metrology;
- Promote electrical metrology;
- Promote strategic collaborations; and to
- Evaluate the BIPM electricity work plan in part to determine if it is consistent with the strategic plan.

The activities of the WGSP have so far covered:

- Approval of the BIPM workplan in light of the available resources;
- A survey distributed to all CCEM members to solicit interest in various metrology projects; and
- The development of “a big problems document”.

“The big problems document” treats the challenges facing the metrology community in areas such as: single electronics and photonics, quantum voltage generation and measurement, the electronic kilogram, quantum computing with superconducting qubits, nano bioelectronics, molecular electronics, nanoscale microwave metrology and spintronics, SI traceable high-frequency electromagnetic field measurements, traceable THz metrology and high speed communications and associated metrology. The next step now is to distribute the document to the NMIs, to determine their commitment to support each area.

The WGSP approved the BIPM workplan for 2009-2012 in its report (CCEM/07-04). This was the basis for the discussion reported in Section 10.

In the future, the WGSP will continue to evaluate the BIPM workplan, share the outcome of economic impact studies that support electrical metrology, facilitate collaborations and training opportunities between NMIs and update the strategic plan.

## 10 ACTIVITIES AND WORKPLAN OF THE ELECTRICITY SECTION OF THE BIPM

M. Stock and T.J. Witt summarized the work of the Electricity section since the last meeting of the CCEM in 2005 and the future plans (CCEM/07-02 and -03).

Since 1991, the BIPM Electricity section has had technical partnerships in the form of comparisons and calibrations with 85 % of the eligible members of the Metre Convention.



Calibrations have been provided on dc voltage, dc resistance and capacitance to NMIs in the Member States, many of who do not possess quantum standards.

The BIPM have ongoing key comparisons of the basic electrical units in dc voltage (Josephson and Zener standards), dc resistance (QHR and 1  $\Omega$  and 10 k $\Omega$  wirewound resistance standards) and capacitance (10 pF and 100 pF). These provide a nice demonstration of the key comparison model imagined at the beginning of the CIPM MRA. By 2008 it is planned that the travelling system used for the comparisons of Josephson standards will be replaced by a more easily transportable automated apparatus.

BIPM also continues to provide on-site comparisons with transportable Josephson and QHR standards. Following the retirement of D. Reymann in October 2006, S. Solve and R. Chayramy carried out a 10 V Josephson comparison at NMI VSL; demonstrating a successful transfer and maintenance of know-how. Collaborations with the LNE have been established for: the QHR onsite comparisons, research on possible alternative solutions using quantum Hall array resistance standards (QHARS) and the multiple-series connection technique developed at BIPM in the 1990s.

A BIPM link from the quantized Hall resistance to the 10 pF level has been in operation since 1997 and the extension to a calculable capacitor is under development. The link is essential for determinations of the von Klitzing constant from the calculable capacitor. Two new calculable capacitor systems are to be developed by the BIPM and NMIA. The target uncertainty is 1 in  $10^8$ , and the estimated date of completion is early in 2008. Recently also NRC joined the collaboration.

In the BIPM cryogenic watt balance experiment there has been considerable progress. Many of the parts of the system, which will be used at room temperature, have been prototyped and tested. No cryogenic systems have been developed yet; a room temperature prototype is planned by 2008-2009. Personnel from the Mass and Electricity section are cooperating and the activity was given the highest priority by the CIPM in October 2006.

The plan forward is to continue the improvement of the Josephson and QHR standards to provide:

- Support for the watt balance and the calculable capacitor projects; and
- Reference standards for a limited number of calibrations and the ongoing key comparison programme.

A limited number of calibration services and the present programme of ongoing BIPM key comparisons will be provided, as well as a focused research and development effort.

The CCEM discussed the concerns expressed by the WGSP about easing the work load of the Electricity section. At the request of B. Inglis, a slide was prepared to summarize staff resources and suggestions for easing the load (CCEM/07-43). It was suggested that to reduce the calibration load, the BIPM Electricity section should organize batch calibrations, diminish the calibration services and limit the frequency of calibrations to one every second year for each user.

Some concerns were expressed about the need to provide a calibration service and if it was possible to charge for it. The President said that such a step change would be difficult, but that there is a need to think about this and the effort spent in the coming years. T.J. Quinn made a comment that “small States expect limited free calibrations”.

A.J. Wallard informed the meeting that the resource situation is difficult across all areas at the BIPM. A modest increase in the budget will be proposed to the CGPM. The calibration service is a small activity, and is only available when it fits into other activities. Beside this it is sometimes difficult to distinguish between a calibration and bilateral comparisons.

The CCEM supports the work programme, but has concerns that there is a need for additional support for the watt-balance activity. The CCEM would also like to emphasize its concerns about the resource situation at the Electricity section to the CIPM.

## 11 HIGHLIGHTS OF SCIENTIFIC DEVELOPMENTS FROM REPORTS FROM THE LABORATORIES ON NEW ACTIVITIES IN ELECTRICITY AND MAGNETISM

Members of the CCEM are expected to participate actively in the CIPM Mutual Recognition Arrangement (CIPM MRA) by taking part in key comparisons, and to give other evidence of competence in electricity and magnetism, such as publications in the area and participation in research and development. All members are therefore invited to submit written reports to each meeting of the CCEM. These serve to inform the members of the new or particularly interesting research areas in electricity and magnetism, and to inform of activities, including comparisons, or new investments, so as to support the confidence building mentioned in the CIPM MRA.

The following is a very brief summary of some of the main themes from the reports submitted by the participants to the meeting. Details can be found in the written reports.

In the field of Josephson arrays, most of the research effort has shifted from developing unbiased arrays towards programmable arrays. Binary divided arrays are being developed mostly for dc-applications and some ac-applications, and voltages up to 5 V and beyond have been generated. Ac pulse driven circuits are being developed for ac-applications, but the voltages obtained so far are in the 1 mV to 100 mV range. Some NMIs in Europe and the United States are cooperating with the aim of developing a power standard using two binary divided ac Josephson standards.

Arrays of QHE resistance standards are being developed at three NMIs, and a successful comparison of resistances in multiples of the QHE standard have been performed. Studies of the ac QHE are continuing and provide input to the CCEM WGACQHR.

Calculable capacitors are operational in seven NMIs, but only two NMIs have running research activities in the field. These cooperate with the BIPM to support the calculable capacitor project.

The closure of the “quantum metrology triangle” has been demonstrated by one NMI with an uncertainty of about  $1$  in  $10^6$ , while one other NMI expects to reach this level of uncertainty by 2008. The problem of increasing the current level available by SET pumps is still being pursued. Recent results from a new electron pumping mechanism in GaAs devices, which overcomes the upper frequency limit in earlier pumps, seem to be promising for the possible realization of a current standard for metrology.

Several laboratories have increased activity in the characterization of non-sinusoidal or distorted waveforms and are developing the capability to support the traceability of measurement of non-sinusoidal current, voltage and power for frequencies above the mains frequency. This is due to

increasing demands from customers and regulations enforced on the quality of electrical power by the authorities. Mainly precision digital sampling methods are used.

In the rf metrology field several laboratories reported extension of the range of their calibration capabilities. Traceability of the rise time of fast signals for the calibration of oscilloscopes and THz validation, on-wafer measurements and non-contacting measurements are some of the important themes for research and development. Two NMIs have received support from their government to extend the activity from “1f-metrology” to also include rf metrology.

Limited or no activity was reported in the field of micromechanical sensors for electrical metrology. A EU funded project ended in 2005 and resulted in the realization of a ac voltage reference and a high frequency power sensor. There are ideas for a follow up, but these have not yet materialized.

The President thanked the participants for submitting written reports about the technical activities and comparison activities of the NMIs. The reports were taken as read and were not presented in detail during the meeting. Some participants took the opportunity to highlight some of the projects going on in their institutes; the detailed information may be found in the written reports.

## 12 MISCELLANEOUS QUESTIONS

A.J. Wallard presented some general information to the delegates:

- He had been in contact with the world customs organization about customs problems when circulating metrological objects worldwide. He would like to set up a conference with the involved international agencies. Prof. Wallard encouraged NMIs to report cases where they had experienced customs problems for use as examples.
- Problems regarding the definitions of “best measurement capability” and “calibration and measurement capability” have been discussed with ILAC. Some recommendations will be proposed to the JCRB and CIPM meetings later. The best possible harmonisation is the intention.
- The BIPM will place some information regarding the calculation of uncertainties on the KCDB website, to help the NMIs with the documentation etc. of their traceability.
- Prof. Wallard encouraged scientists from NMIs to come and work at BIPM with the new watt balance. This would also be advantageous for the resource situation at the BIPM.

The meeting supported a proposal by the President that he should write a letter on behalf of the CCEM to the NPL, regarding the NPL watt balance. In the letter he shall point out the importance of the activity and the results obtained so far, and encourage NPL to continue the activity until the best possible results with the present version of the watt balance were obtained.

The President raised the question whether the NMI reports should be placed on the open or the restricted website. It was agreed to continue to put them on the restricted website. The “news” in the reports quickly become outdated and if they are left on the open website this may be misleading.

The present head of the BIPM Electricity section, T.J. Witt, is retiring this summer. The President warmly thanked him for all the valuable effort he has provided for all the years with the BIPM and wished him a successful retirement.

### **13 APPROXIMATE DATE OF THE NEXT MEETING**

A proposal was made to schedule the next meeting for the second week of March 2009.

The president thanked all participants for their contributions and attention and adjourned the meeting.

H. Slinde, Rapporteur

June 2007

**RECOMMANDATION DU  
COMITÉ CONSULTATIF D'ÉLECTRICITÉ ET MAGNÉTISME  
PRÉSENTÉE AU COMITÉ INTERNATIONAL DES POIDS ET MESURES**

**RECOMMANDATION E 1 (2007) :**

**Proposition de modifications à apporter au Système international d'unités (SI)**

Le Comité consultatif d'électricité et magnétisme (CCEM),

**ayant examiné** différentes options possibles à propos de modifications à apporter au Système international d'unités (SI) et les mérites associés de chacune d'entre elles, en consultation avec les métrologistes du domaine de l'électricité, avec les utilisateurs de l'industrie et d'autres groupes de la communauté de la métrologie,

**considérant**

- que définir des unités à partir de constantes fondamentales, en particulier la charge élémentaire,  $e$ , et la constante de Planck,  $h$ , assurent leur stabilité à long terme et leur cohérence,
- que certaines combinaisons de la charge élémentaire,  $e$ , et de la constante de Planck,  $h$ , fournissent des grandeurs fondamentales pour les phénomènes quantiques dans les domaines de l'électricité et du magnétisme,
- qu'il existe des effets quantiques macroscopiques qui lient les constantes fondamentales  $e$  et  $h$  à des grandeurs macroscopiques observables,
- que la représentation du volt, fondée sur l'effet Josephson et la valeur conventionnelle de la constante de Josephson,  $K_{J-90}$ , et la représentation de l'ohm, fondée sur l'effet Hall quantique et la valeur conventionnelle de la constante de von Klitzing,  $R_{K-90}$ , fournissent au monde entier depuis 1990 des références pratiques, accessibles, reproductibles, à faible bruit et extrêmement linéaires,
- que les représentations du volt et de l'ohm adoptées en 1990, bien qu'utilisées quotidiennement dans le monde entier, ne sont pas des unités du SI et que les modifications à apporter au SI recommandées ci-dessous permettront des réalisations directes des unités de tension et de résistance dans le SI, par l'utilisation de l'effet Josephson et de l'effet Hall quantique, et assureront ainsi la stabilité à long terme et l'exactitude des unités électriques,
- que la théorie, la reproductibilité et l'indépendance des réalisations expérimentales des effets Josephson et von Klitzing sont bien établies,
- que les effets Josephson et von Klitzing sont liés directement à des constantes fondamentales et que ces relations sont étayées par d'autres mesures de haute précision, si bien que rien ne peut suggérer que les expressions usuelles décrivant ces effets sont incorrectes,
- que la cohérence des mesures électriques a été grandement améliorée depuis l'introduction des représentations du volt et de l'ohm, fondées sur les effets Josephson et von Klitzing,
- que l'on continuera à utiliser ces étalons quantiques dans un avenir prévisible,

- que les améliorations des techniques associées à l'effet Josephson et à l'effet Hall quantique, ainsi qu'au transport de charge quantifié, se poursuivent, rendant ces références encore plus exactes, plus faciles à mettre en œuvre et plus polyvalentes,

**reconnaisant** que l'adoption de valeurs fixées de  $e$  et de  $h$  risque d'introduire une petite discontinuité, acceptable, dans les résultats des mesures électriques,

**recommande**

- de modifier le SI par l'adoption de valeurs fixées de la charge élémentaire,  $e$ , et de la constante de Planck,  $h$ , et que cette décision soit prise dans un proche avenir, par exemple en 2011, à condition que l'on soit parvenu à un accord convenable entre les résultats d'expériences indépendantes,
- que les laboratoires nationaux de métrologie soient fortement encouragés à soutenir toutes les activités de recherche visant à mettre en œuvre les modifications recommandées ici et à améliorer notre connaissance de la science concernée, fournissant et maintenant ainsi la meilleure cohérence possible au SI,
- que les valeurs de la charge élémentaire,  $e$ , et de la constante de Planck,  $h$ , soient fixées comme étant les valeurs les plus récentes publiées par CODATA, avant l'adoption de ces modifications au SI, en utilisant des valeurs arrondies sans incertitude associée,
- que les définitions des unités électriques et leurs mises en pratique soient révisées pour refléter ce changement, et que le CCEM soit impliqué dans ce processus,
- si l'on retient le concept d'unités de base, que l'ampère reste une unité de base pour des raisons de continuité historique et pour l'analyse dimensionnelle du SI, bien qu'il n'y ait pas d'ordre hiérarchique préféré parmi les unités électriques pour la traçabilité,
- que l'ampère soit défini, par exemple, de la manière suivante :  
« L'ampère est l'intensité d'un courant électrique équivalent exactement à un flux de  $1/1,602\ 176\ 53 \times 10^{-19}$  charges élémentaires par seconde. » (Il s'ensuit que cette définition fixe la charge élémentaire comme étant égale exactement à  $1,602\ 176\ 53 \times 10^{-19}$  A s),
- que l'on fasse la publicité et la promotion active de ce changement au SI, afin d'assurer son introduction en douceur auprès de la communauté de la métrologie ; il faudra au moins un an pour y préparer le grand public.

**RECOMMENDATION OF  
THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM  
SUBMITTED TO THE INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES**

**RECOMMENDATION E 1 (2007):**

**Proposed changes to the International System of Units (SI)**

The Consultative Committee for Electricity and Magnetism (CCEM),

**having reviewed** different possible changes to the SI and having considered the associated merits of each by consulting with electrical metrologists, industrial users and others in the metrology community,

**considering**

- that defining units in terms of the fundamental constants, specifically the elementary charge,  $e$ , and the Planck constant,  $h$ , ensures their long-term stability and consistency,
- that combinations of the elementary charge  $e$  and the Planck constant  $h$  are fundamental quantities in quantum phenomena in electricity and magnetism,
- that macroscopic quantum effects exist which link the fundamental constants  $e$  and  $h$  to macroscopic observables,
- that the representation of the volt using the Josephson effect and the conventional value of the Josephson constant,  $K_{J-90}$ , and the representation of the ohm using the quantum Hall effect and the conventional value of the von Klitzing constant,  $R_{K-90}$ , have provided practical, accessible, reproducible, low noise and highly linear references world-wide since 1990,
- that the 1990 representations of the volt and the ohm, while in daily use world-wide, are not SI units and that by implementing the changes in the SI recommended below, the use of the Josephson effect and quantum Hall effect would allow direct SI realizations of voltage and resistance and thus provide long term stability and accuracy to the electrical units within the SI,
- that the theory, reproducibility, and independence of experimental realizations of the Josephson and quantum Hall effects are well established,
- that the Josephson and quantum Hall effects are directly related to fundamental constants as evidenced by coherence with other high precision measurements and that this coherence is such that there is no evidence to suggest that the usual expressions describing these effects are incorrect,
- that consistency among electrical measurements has been greatly improved since the introduction of the representations of the volt and the ohm by the Josephson effect and the quantum Hall effect,
- that the use of these quantum-based standards will continue for the foreseeable future,
- that improvements in the technology associated with the Josephson and quantum Hall effects, as well as quantized charge transport, are continuing, making these references even more accurate, easier to operate and more versatile,

**recognizing** that adoption of fixed values of  $e$  and  $h$  may introduce a small, but acceptable, single discontinuity in the results of electrical measurements at the time that the redefinition is implemented,

**recommends**

- that the SI be changed by adopting fixed values of the elementary charge  $e$  and Planck constant  $h$ , and that this decision be taken in the near future, for example in 2011, provided that adequate agreement is achieved among independent experiments,
- that the National Metrology Institutes be strongly encouraged to support relevant research in order to implement the changes recommended here and to improve our knowledge of the relevant science thereby providing and maintaining the most consistent SI possible,
- that the values of the elementary charge  $e$  and the Planck constant  $h$ , be fixed at the values most recently published by CODATA preceding the adoption of these changes to the SI, but rounded and given without associated uncertainties,
- that the definitions of the electrical units and their *mises en pratique* be revised to reflect this change, and that the CCEM be involved in this process,
- that if the concept of base units is retained then the ampere be kept as a base unit for the purposes of historical continuity and SI dimensional analysis although there is no preferential order of traceability within the electrical units,
- that the ampere be defined, for example, as follows:  
“The ampere is the electrical current equivalent to the flow of exactly  $1/(1.602\ 176\ 53 \times 10^{-19})$  elementary charges per second.” (It follows that this definition fixes the elementary charge as exactly  $1.602\ 176\ 53 \times 10^{-19}$  A s),
- that this change in the SI be actively publicized and promoted to ensure its smooth introduction into the measurement community and that one year is the minimum time needed to prepare the general public for such a change in the SI.



## APPENDIX E 1.

### Working documents submitted to the CCEM at its 25th meeting

Open working documents of the CCEM can be obtained from the BIPM in their original version, or can be accessed on the BIPM website:

<http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CCEM>.

Document  
CCEM/

- 07-00 Draft agenda for the 25th meeting of the CCEM, 1 p. (restricted access)
- 07-01 BIPM, CCEM. — Report of the 24th meeting of the CCEM, 51 pp. (restricted access)
- 07-02 BIPM. — Technical work programme of the BIPM Electricity section through 2012, 4 pp. (restricted access)
- 07-03 BIPM. — The BIPM watt balance and calculable capacitor projects, M. Stock, 3 pp. (restricted access)
- 07-04 CCEM WGSP. — Report of the CCEM Working Group on Strategic Planning (WGSP) on BIPM work programme, 1 p. (restricted access)
- 07-05 CCEM WGS1. — Draft Recommendation EM 1 (2007): Proposed changes to the SI, 2 pp. (restricted access)
- 07-06 CCEM WG on RMO Coordination. — Electricity and magnetism supplement guide to the JCRB instructions for Appendix C of MRA, 18 pp. (restricted access)
- 07-07 INRIM (Italy). — Electricity and magnetism calibration services form, G. Marullo Reedtz, 1 p. (restricted access)
- 07-08 NMIA (Australia). — Report on research and development activities in electricity and magnetism, B. Ricketts, 3 pp. (restricted access)
- 07-09 NMIA (Australia). — Progress reports on CCEM or RMO comparisons CCEM-K12; APMP.EM-S7; APMP.EM-K4.1 and APMP.EM-K6.a, B. Ricketts, 4 pp. (restricted access)
- 07-11 NIST (United States). — Status report to CCEM of electrical metrology developments at NIST, W.E. Anderson, 6 pp. (restricted access)
- 07-12 INMETRO (Brazil). — Report of the research activities of INMETRO Electrical Metrology Division, E. Afonso and G. Kyriasis, 7 pp. (restricted access)
- 07-13 METAS (Switzerland). — Progress report on electrical metrology at METAS 2005 to 2007, A. Eicheberger *et al.*, 5 pp. (restricted access)
- 07-14 SP (Sweden). — Report from SP Technical Research Institute of Sweden, electrical metrology, K.-E. Rydler, 3 pp. (restricted access)
- 07-15 PTB (Germany). — Progress report on electrical metrology at the PTB between 2005 and 2007, 8 pp. (restricted access)
- 07-16 CEM (Spain). — Activities 2005-2007 from CEM Electricity Division, M. Neira, 3 pp. (restricted access)
- 07-17 KRISS (Rep. of Korea). — APMP.EM.RF-K3.F: Horn antenna gain bilateral comparison – Declaration and protocol revised, J.S. Kang, 6 pp. (restricted access)
- 07-18 NMi VSL (Netherlands). — Draft B report EUROMET project 818: Calibration factor of thermistor mounts, J.P.M. de Vreede, 20 pp. (restricted access)

Document  
CCEM/

- 07-19 CCEM GT-RF. — Proposal to approve CCEM.RF-K3.F for full equivalence, J. Randa, 1 p. (restricted access)
- 07-20 CCEM GT-RF. — Spreadsheets CCEM.RF-K3.F, 9 pp. (restricted access)
- 07-21 CCEM GT-RF, PTB (Germany). — EUROMET.EM.RF-K10.CL EUROMET comparison 525 (GT-RF/99-2): Power in the coaxial PC 3,5 mm line system – Draft B report, D. Janik, 47 pp. (restricted access)
- 07-22 NPLI (India). — Activities of Electrical and Electronic Standards Division of the National Physical Laboratory of India (NPLI), 5 pp. (restricted access)
- 07-23 MIKES (Finland). — Progress report on electrical metrology at MIKES between 2005 and 2007, 4 pp. (restricted access)
- 07-24 KRISS (Rep. of Korea). — Progress report of KRISS Electromagnetic Metrology, K.-T. Kim, T.-W. Kang and Y.S. Song, 5 pp. (restricted access)
- 07-25 NIM (P.R. of China). — New activities in NIM since 2005, Z.L. Lu, Z.H. Zhang and Q.L. Gao, 4 pp. (restricted access)
- 07-26 NIM (P.R. of China). — The influence on parasitic capacitance on ac QHR, Z.H. Zhang, Z.K. Li and J.T. Zhao, 3 pp. (restricted access)
- 07-27 CCEM GT-RF. — CCEM RF key comparison: Noise in waveguide between 18 GHz and 26.5 GHz, 2 pp. (restricted access)
- 07-28 INRIM (Italy). — Progress report of INRIM in electricity and magnetism, G. Marullo Reedtz, 6 pp. (restricted access)
- 07-29 NMIJ (Japan). — Laboratory report of the National Metrology Institute of Japan (NMIJ) in the field of electricity and magnetism, K. Komiyama and Y. Nakamura, 7 pp. (restricted access)
- 07-30 LNE (France) . — News from LNE and progress report on electrical metrology since 2005, 6 pp. (restricted access)
- 07-31 INRIM (Italy). — Comments to the Draft Recommendation EM 1 (2007): Proposed changes to the SI, F. Cabiati, 3 pp. (restricted access)
- 07-32 MSL (New Zealand). — Report on electromagnetic metrology activities at MSL, New Zealand, L. Christian, 4 pp. (restricted access)
- 07-33 CSIR NML (South Africa). — Report by the CSIR National Metrology Laboratory South Africa (for the period 2005-04 to 2007-02), S. Singh, 3 pp. (restricted access)
- 07-34 CCEM WGKG. — Report on the meeting of the CCEM Working Group on Electrical Methods to Monitor the Stability of the Kilogram (WGKG), July 2006, I. Robinson, 6 pp. (restricted access)
- 07-35 NMi VSL (Netherlands). — News from NMi Van Swinden Laboratorium (2005-2006), J. de Vreede and G. Rietveld, 3 pp. (restricted access)
- 07-36 JV (Norway). — Progress in the field of electrical quantities at Justervesenet, 3 pp. (restricted access)
- 07-37 DFM (Denmark). — Status for fundamental electrical metrology in Denmark, H.D. Jensen, 1 p. (restricted access)
- 07-38 NPL (United Kingdom). — A report on progress in electrical metrology at NPL for the 25th meeting of the CCEM, J. Williams, 6 pp. (restricted access)

Document  
CCEM/

- 07-39 CCEM WGSJ. — Report of the first meeting of the CCEM Working Group on Proposed Modifications of the SI (WGSJ), B. Jeckelmann, 5 pp. (restricted access)
- 07-40 BIPM. — CPEM'06 round table discussion "Proposed changes to the SI", M. Stock and T.J. Witt, 5 pp. (*Metrologia*, 2006, **43**, 583-587) (restricted access)
- 07-41 Considerations on future redefinitions of the kilogram, the mole and other units, P. Becker *et al.*, 14 pp. (*Metrologia*, 2007, **44**, 1-14) (restricted access)
- 07-42 CCEM WGLF. — Report to the CCEM on the 9th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF), H. Bachmair, 6 pp. (restricted access)
- 07-43 BIPM. — BIPM Electricity section staff resources, 1 p. (restricted access)
- [07-44](#) CCEM. — Recommendation E 1 (2007): Proposed changes to the International System of Units, 2 pp. (SI)
- [07-45](#) CCEM. — Recommandation E 1 (2007) : Proposition de modifications à apporter au Système international d'unités, 2 pp. (SI)



**APPENDIX E 2.**  
**REPORT OF THE 9TH MEETING OF THE**  
**CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES**  
(13 and 14 March 2007)  
**TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM**

**1 OPENING OF THE MEETING;**  
**APPOINTMENT OF A RAPPORTEUR;**  
**APPROVAL OF THE AGENDA**

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its ninth meeting on 13 and 14 March 2007 at the International Bureau of Weights and Measures, Pavillon de Breteuil, at Sèvres.

The following were present: H. Bachmair (Chairman WGLF, PTB), A. Bounouh (LNE), J.P.M. de Vreede (NMi VSL), B.D. Inglis (NMIA, President of the CCEM), D. Inglis (NRC-INMS), T.W. Kang (KRISS), A.S. Katkov (VNIIM), K.-T. Kim (KRISS), K. Komiyama (NMIJ/AIST), G. Marullo Reedtz (INRIM), J. Melcher (PTB), Y. Nakamura (NMIJ/AIST), J.K. Olthoff (NIST), F. Piquemal (LNE), J. Randa (NIST), B. Ricketts (NMIA), G. Rietveld (NMi VSL), I.A. Robinson (NPL), K.-E. Rydler (SP), Yu. P. Semenov (VNIIM), Y.S. Song (KRISS), J. Williams (NPL).

Guests: E. Afonso (INMETRO), L. Christian (MSL), S.W. Chua (SPRING), E. Dressler (CSIR-NML), B. Jeckelmann (METAS), G. Kyriazis (INMETRO), Z. Lu (NIM), A. Manninen (MIKES), A.K. Saxena (NPLI), S. Singh (CSIR-NML\*), H. Slinde (JV), J. Streit (CMI), Z.H. Zhang (NIM).

Also present: N. Fletcher, R. Goebel, S. Solve, M. Stock and T.J. Witt (Executive Secretary of the CCEM) (BIPM).

Sent regrets: H. Laiz (INTI), M. Neira (CEM).

The 9th meeting of the WGLF opened on 13 March at 14:03, with Hans Bachmair in the chair.

He opened the meeting and welcomed the participants to the 9th meeting of the CCEM Working Group on Low Frequency Quantities.

Fifteen documents submitted for consideration are listed on the restricted website as documents WGLF/07-00 to 15.

D. Inglis was appointed rapporteur for the meeting.

The agenda as published was adopted (WGLF/07-00), with a change in the order of items to better fit with the travel arrangements of some delegates.

The Minutes of the meeting on 14 March 2005 were approved.

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\* Renamed NMISA.

## Informal notes of the WGLF meeting in July 2006 in Turin (WGLF/07-04)

Notes were circulated on 9 October 2006 with a deadline 15 November for comments. Four comments were received:

- a) Regarding the question of the participation of INMETRO in [CCEM-K13.CL](#): INMETRO is now ready to participate.
- b) Regarding the organisation of a comparison of ac voltage using sampling techniques: INMETRO has asked to postpone this comparison.
- c) Regarding comparison identifiers: the BIPM Key Comparison Database manager does not consider the identifier too important, as long as the RMO, the subfield (EM) and the type of comparison (key or supplementary) is mentioned.

Proposal: Use the CCEM and BIPM identifier scheme to minimise possible confusion, especially among our customers.

- d) [COOMET.EM-S1](#): Measurements are completed.

The revised meeting notes will be placed on the restricted website.

## Summary of actions following the meeting of 9 July 2006

1. Proposed comparison on ac shunts:

- a) CCEM WGLF Chair to clear the use of the JEMIC artefact.

Approval was obtained immediately after the meeting. JEMIC generously agreed to place a shunt at the pilot laboratories disposal, even if JEMIC cannot participate in this comparison.

- b) CCEM chair to ask NMIJ to resolve the question of Designated Institutes (DI) in Japan.

As of now, JEMIC is not nominated as a DI.

- c) NRC (pilot) to proceed when all is cleared.

See topic 2, this meeting, below "Proposals for new comparisons".

2. The linking of [SIM.EM-K1](#) to a CCEM or BIPM comparison:

See topic 2, this meeting, below "Proposals for new comparisons".

3. Proposal for changes in the classification scheme:

See topic 4, this meeting, below "Possible revision of the classification scheme".

4. Procedure for the participation of attendees who are not delegates to the WGLF:

A general discussion took place regarding attendance at and participation in CCEM WG meetings. The following are the main points raised:

- Delegates' laboratories are convoked through the Director of the BIPM, as for the CCEM, though the individual appointment of the delegate is by the member laboratory.
- Other attendees are at the request of, or at least at the approval of, the Chairperson (CP) of the WG. Those not delegated by their laboratory in response to the convocation, and not invited by the CP should request permission to attend from the CP.

- The CIPM has no general rule on the issue of meeting attendance. It was agreed that the Chair would take forward a proposal that the above rules be applied to future CCEM WG meetings.

## 2 REPORTS ON BIPM AND CCEM COMPARISONS

The Minutes present only those comparisons which involved discussion or action by this meeting. The full list of BIPM, CCEM and RMO comparisons considered at the meeting is shown in the Appendix to the Minutes.

### 2.1 Ongoing BIPM key comparisons

[BIPM.EM-K10.a](#) and [BIPM.EM-K10.b](#): dc voltage, Josephson standards.

1 V: No bilateral comparisons

10 V: INMETRO (BR) in April 2006 ( $x_i = 19 \text{ nV}$ ,  $u_i = 16 \text{ nV}$ )

NMIA (AU) in May 2006 ( $x_i = 0.9 \text{ nV}$ ,  $u_i = 1.7 \text{ nV}$ )

NMi VSL in October 2006 ( $x_i = -1.5 \text{ nV}$ ,  $u_i = 1.8 \text{ nV}$ )

In 2004 a new variant B of this bilateral comparison was introduced, in which a stable reference voltage produced across the BIPM Josephson array is measured using the laboratory's Josephson array voltage standard and detector. As a consequence of this simplified comparison scheme, of 36 laboratories polled, 32 expressed a wish to participate in a BIPM comparison.

A total of 9 comparisons have been completed since 2004. With staff retirements, BIPM proposes to do no more than 3 per year from now on.

Typically these comparisons are done over one week. After setting up the measurement and connecting the systems, preliminary measurements are made. It is then often possible to improve the agreement and the uncertainties, after which the uncertainty budget is discussed. Typically one of three cases arises:

1. No major problems.
2. Some problems – differences up to three orders of magnitude larger than usual (typically around 1 part in  $10^{10}$  at 10 V). The problems are identified and corrected in the first week. The last series of measurements are then the only reported data.
3. Disagreement, but the problems are not identified. The only option open to the laboratory is to either publish the disagreement, or withdraw.

In some cases, the deviation of the reference value is larger than  $1 \sigma$  (eg INMETRO above). Also, the first results achieved during a bilateral comparison are often improved on when adjustments and or corrections to the procedures have been made. It was suggested by Stéphane Solve that when a significant improvement is obtained during the comparison both the initial and final values be added to the KCDB with a note, but that only the final result should appear on the

graph of results. If it is difficult to reach agreement, then the problems should be discussed with the support group.

Considerable discussion ensued, the main (often contradictory) points raised being:

- This is really only a problem in the case of bilateral comparisons.
- Improvement during a sequence of measurements is not unusual, and the best (usually the final) results should stand, alone.
- It is not reasonable to ignore that the fact that considerable improvement was achieved over the period of the measurement. Both starting and finishing results should be reported, with comment.
- It is not useful to report more than one value in the KCDB, as this will lead to confusion in the minds of clients.
- A support group should be assembled to refine this proposal. This group could also be called on in the future to mediate disagreements.
- The same issue might arise with other CCs (for example, gravimetry measurements for watt balance experiments can show similar behaviour). Should we aim for a coordinated solution across all CCs?

It was agreed that:

- where such situations arise in BIPM bilateral comparisons then both the early and final results will be given in the KCDB, with a comment; and only the final agreed result will be given on the graph;
- for the JJA VS comparisons, a support group will be formed from Barry Wood (NRC), Blaise Jeanneret (METAS), Laurie Christian (MSL), and Yi-hua Tang (NIST); and
- Barry Inglis will address this issue at the upcoming CIPM meeting.

## 2.2 Completed CCEM key comparisons

[CCEM.K11](#) and [CCEM.K11.1](#): ac/dc transfer at low voltages, pilot SP (SE) (WGLF/07-09).

Draft B report was received 9 February, and put on the restricted website on 13 February. Delegates had been asked to look at this report in advance of the meeting. Karl-Erik Rydler gave a short report on the comparison.

**Vote** (this meeting): Comparison approved for submission to the CCEM for inclusion in the KCDB.

## 2.3 Ongoing CCEM key comparisons

[CCEM-K7](#): ac voltage ratio, pilot NPL (UK).

Measurements are completed. Following circulation of Draft A of the report a discussion arose over how to determine the KCRV.

Report from Ian Robinson (Pilot laboratory):

This comparison includes 17 institutes measuring 40 ratios, leading to 80 results per institute, and consequently 180 pages of tables and graphs.



There has been much discussion around the use of a weighted mean to determine the KCRV, because one laboratory with especially small uncertainties heavily influences the value of the KCRV.

There is also an issue of what to do with “outliers”, especially since some are only outliers when the KCRV is driven by a weighted mean.

The overall analysis is complicated by the non-uniform style of uncertainty budgets.

Ian Robinson will:

- not change the present analysis without additional resources;
- discuss with Maurice Cox a way out of the problem of the KCRV being determined essentially by one laboratory;
- include a plot showing the stability of the travelling standard;
- not change the formatting of the results graph; and
- try to minimise the size of the report.

The discussion centred on the following:

- Can the laboratory with the very small uncertainties justify them adequately? (Ian Robinson – yes).
- The use of a weighted mean for the KCRV leads to other laboratories with relatively small uncertainties becoming outliers. This seems unjust, and possibly misleading.
- Regardless of how the KCRV is determined, if two laboratories quote small uncertainties and disagree in value, then they in fact disagree, and we should not “cheat” on this issue. And moving the KCRV will not solve the problem.
- Is it possible to solve the problem by applying a “cut-off” uncertainty or a “maximum weight limit” to the weighed mean calculation?
- It has been suggested in the past that a Monte Carlo approach would work in these circumstances. (Ian Robinson - this has not been tried for lack of time).

It was agreed to leave this issue to the pilot laboratory to come to agreement with the participants, with help from the support group as necessary.

[CCEM-K13.CL](#): ac power with non-sinusoidal waveforms, pilot NRC (CA).

As of the informal Turin meeting, the WGLF had understood the pilot study to be successfully completed. The pilot laboratory was then to determine interest in participation and to submit a proposal with protocol for approval of the CCEM.

It has since transpired that:

- Practically all potential participants have requested to be **last** in the measurement sequence.
- Most potential participants would like first to do a preliminary evaluation of their measurement system, before doing the actual KC.
- Among the three laboratories involved with the original pilot measurements there are still unresolved issues.

Eddy So has proposed that this KC be postponed for at least 2 years. In the mean time, the pilot project should continue, and opportunities should be provided to interested NMIs to do an

informal bilateral comparison with one of the three main laboratories in the pilot project or with SP (Sweden), which has already done a bilateral comparison with NRC.

The discussion centred around whether it was better to postpone the KC, which means that under present rules no other power comparisons can be done for some time; or to eliminate it for present. It was agreed that the Chair would contact Eddy So and request a more detailed report on the pilot study before this decision could be taken.

### 3 PROPOSALS FOR NEW CCEM KEY COMPARISONS

Proposals for further comparisons put forward at the informal WGLF meeting in Turin:

#### 3.1 Comparison of magnetic flux density up to 2 T

This comparison was proposed by NMI VSL. As no pilot laboratory has come forward, this comparison is postponed.

#### 3.2 Comparison of current and voltage ratios using instrument transformers

Six NMIs were interested in such a comparison, but as with -K13, no-one is ready. It is now postponed until [CCEM-K7](#) is finished, and until after -K13 is started.

#### 3.3 Characterisation of ac shunts with respect to modulus and phase or time constant

Eight NMIs were interested in such a comparison. Presently a pilot study is under way between NRC, NIST and JEMIC. Depending on its outcome, a decision about proposing a KC on ac shunts will be made.

#### 3.4 Repetition of comparisons (proposal in 2002)

Key quantities:

**dc voltage:** Are [BIPM.EM-K10](#) and [BIPM.EM-K11](#) sufficient?

**dc resistance:** Are [BIPM.EM-K12](#) and [BIPM.EM-K13](#) sufficient?

These are the BIPM comparisons linked in with other RMOs where possible. A problem has arisen with linking [SIM.EM-K1](#) (1  $\Omega$  resistance) to the KCDB, since none of the participants has taken part in an “Approved for equivalence” comparison, or one of the above. To solve this SIM linking problem, NIST volunteered to do a bilateral comparison to link with the [BIPM.K13.a](#) comparison.

It was generally agreed that a systematic study of travelling standards would be useful before trying to compare resistance measurements systems, since experience shows that the travelling artefacts used are generally less stable and less predictable than is useful when comparing quantum Hall based primary measurement systems.

**Impedance:** Is [BIPM.EM-K14](#) sufficient?

With the changeover of duties following staff retirement, BIPM would like to do a bilateral comparison of capacitance with a laboratory that traces its capacitance chain to the QHR. They require an uncertainty of  $<1 \times 10^{-7}$ , ideally as low as  $4 \times 10^{-8}$ , for both 10 pF and 100 pF. NIST volunteered after the meeting.

**ac power:** [CCEM-K13.CL](#) is still being planned.

**Magnetic quantities:** There still is interest in magnetic flux density up to 2 T, but no volunteer to be the pilot laboratory.

**ac ratio:** [CCEM-K7](#) and eventually plans will be made for a comparison of ac current and voltage ratios using instrument transformers.

**ac/dc transfer:** [CCEM-K12](#), Repetition of [CCEM-K6.a](#)?

At the informal EUROMET LF experts meeting on ac/dc transfer in Turin, 2006, it was agreed to propose the next ac/dc comparison to be a repeat of [CCEM-K6.a](#), which will begin in one or two years time, and will cover the frequency range of 1 kHz to 1 MHz.

There were no further proposals for new CCEM key comparisons.

## 4 REPORTS ON RMO COMPARISONS

### 4.1 APMP comparisons

The report was submitted by Yang Sup Song.

[APMP.EM-K6.a](#): ac/dc voltage transfer, pilot: NMIA (AU).

Measurements completed, Draft B report being prepared.

The declaration form and protocol has not yet been circulated within the WGLF. This will be done together with the Draft B report, because the comparison was already started when APMP asked for registration in the KCDB.

### 4.2 COOMET comparisons

The report was presented by Alexander Katkov. In addition, he described the travelling JJA VS comparisons that have been run successfully for some years, and have been described in *Metrologia*.

[COOMET.EM-K4](#): Capacitance at 10 pF, pilot: UkrCSM (UA).

Status: In progress.

[COOMET.EM-S1](#): ac/dc voltage transfer, pilot: VNIIM (RU).

Status: Measurements completed.

[COOMET.EM-S4](#): Capacitance at 100 pF, pilot: UkrCSM (UA).

Status: In progress.

The above three comparisons are delayed as a consequence of customs problems. It is proposed to link [COOMET.EM-K4](#) above with the [CCEM-K4](#) comparison.

Yury Semenov proposed a comparison of capacitance values from 1 nF to 10  $\mu$ F, at 1 kHz and 50 V. Four laboratories indicated interest, but no pilot volunteer came forward. VNIIM will prepare standards, but will not pilot the comparison.

It was agreed that those laboratories interested in such a comparison should contact Yury Semenov to make arrangements.

#### 4.3 EUROMET comparisons

Presently EUROMET has quite a large number of bilateral comparisons, because the new EU members are interested in having their CMC claims supported by the corresponding comparisons.

[EUROMET.EM.BIPM-K11.6](#): dc voltage (Project 846), pilot: BEV (AT).

This is a bilateral supplement to -K11. Measurements are completed, the Draft A report was agreed, and the Draft B report has been circulated. The comments suggested require changes to the report. These changes are not accepted by one of the participating laboratories.

The WGLF Chair suggests that to solve this problem Gert Rietveld, Beat Jeckelmann and Tom Witt meet to discuss a new solution.

#### 4.4 SADC MET comparisons

Report from Erik Dressler, CSIR-NML.

The CSIR-NML is planning a SADC MET comparison of dc voltage at 10 V using a Fluke Zener. They are presently at the stage of characterising the travelling behaviour of the Zener.

The Chair reminded the meeting that details of the protocol and the proposed link to an existing comparison in the KCDB must be approved before commencement of any KC to allow entry of the results in the KCDB, and that participating laboratories must be signatories of the CIPM MRA or designated institutes for their results to be placed in the database.

#### 4.5 SIM comparisons

The full report was presented by Harold Sanchez.

There is a proposal for a bilateral comparison between NIST and NIS (Egypt) in a broad range of ac/dc quantities. NIST is to decide on the proposed links to the KCDB before submitting a protocol for approval.

## 5 POSSIBLE REVISION OF THE CLASSIFICATION SCHEME

At the informal meeting of the WGLF in Turin, a few small changes in the classification scheme were discussed. The Chairman of the WGLF was asked to prepare a document with the proposed wording and to submit it in advance to this meeting (WGLF/07-05 and -06).

It was agreed that an item should be added to the classification scheme as 2.3, and that it should be written as:

**“2.3 dc resistance ratios-----Resistance ratio devices-----dc resistance ratios”**

where “ratio device” was understood to include various methods including dc ratio bridges and Hamon resistors.

It was then further agreed that similar wording should be used to add a similar new classification for ac resistance ratios under **4.1.5**, to include measurements made using ac ratio bridges or inductive voltage dividers.

It was also agreed to modify 5.2, 5.3, 6.3, 8.3, 8.3.4, 8.6 and 8.6.3 so that it becomes more obvious to clients which type of ac voltage or current ratio measurements are included under which headings. At the same time the “<” symbols in the tables are to be replaced by “≤”.

The Chair is to propose all these changes to the CCEM.

## 6 POSSIBLE REVISION OF THE CCEM GUIDELINES FOR COMPARISONS

### 6.1 Comparison identifiers

Discussion arose at the WGRMO meeting in Turin regarding the harmonisation of comparison identifiers. This issue had also been discussed at the WGLF and GT-RF meetings in Turin, and it was recommended to adopt the CCEM KC identifier scheme for the RMO KCs. For clarification it is suggested to add a paragraph 2.4 to the guidelines which it is thought will help the RMOs to choose the correct comparison identifiers.

It is recommended to adopt this scheme for all types of comparisons, i.e., CCEM and BIPM KCs and RMO KCs and SCs. The use of this scheme will minimise possible confusion, particularly for the customers of the KCDB. An RMO comparison cannot just be a KC on its own – it must be linked to a CCEM or BIPM KC. It is recommended that RMOs make early contact with the KCDB manager when developing key comparisons to check whether or not a link to a CCEM or

BIPM KC can be made. Otherwise, a comparison should be organised as an RMO SC. A KC is not required to justify a CMCs listing.

The Chair led this discussion with a presentation.

The principle structure of a comparison identifier must be as follows:

**Institution<sup>1)</sup>. Subject-field<sup>2)</sup>. Subfield<sup>3)</sup> - Type<sup>4)</sup>. Consecutive number<sup>5)</sup>  
Subordinate number<sup>6)</sup>. RF identifier<sup>7)</sup>**

1. As institution choose *CCEM*, *BIPM* or an *RMO* (*APMP*, *COOMET*, *EUROMET*, *SADCMET*, *SIM*). For a *CCEM* comparison, the subfield will be cancelled.
2. As only electricity and magnetism is dealt with, the subject-field is *EM*.
3. The subfield will be cancelled for ordinary dc and low frequency comparisons. For comparisons in the high-frequency field use *RF* as subfield, for magnetic quantities *M*.
4. The type of a comparison is a key *K* or a supplementary *S* comparison. Note that supplementary comparisons are only organised by the RMOs.
5. The consecutive number will be given by the KCDB manager.
6. The subordinate number is only necessary for supplements to already existing key comparisons.
7. The RF identifier describes the medium of propagation of the electromagnetic wave. *CL* stands for coaxial line, *F* for field and *W* for waveguide.

It is proposed to add Chapter 2.4 to the CC Comparison Guidelines to help participants understand the naming scheme. The main details from the discussion were:

- This is compatible with the nomenclature used by other CCs.
- The *EM* at 2. above is not required for *CCEM* comparisons.
- 7. above is already agreed by the GTRF.
- When establishing a comparison, the reference number (based on the above) should be agreed with the database manager.
- BIPM numbers do not correlate well with the regional numbers or the CCEM numbers. This is thought to be mainly historic, but it cannot be changed at this point.
- When the protocol is written the linking laboratory(ies) should be specified, so that it is clear immediately whether or not the proposed link is justifiable.

It was agreed that the Chair propose to the CCEM that we proceed with these changes.

## 6.2 The impact of KC results on CMCs

There has already been a long lasting discussion on the impact of the results of comparisons on the CMC claims of the participating laboratories. At the informal meeting of the WGRMO in Turin this topic was discussed, and the Chairman of the WGRMO was asked to draft a discussion paper for the next WGRMO meeting. Giancarlo Marullo Reedtz gave a brief introduction to this topic, which was followed by a discussion of possible changes to the Guidelines.

Giancarlo summarised the present situation as follows:

- Discussions started in 2005 with the suggestion that a statement on support for CMCs be included with the results of each KC. However, concern was expressed at the Turin meeting that we should not be releasing potentially damaging information to the public.
- It is now proposed to set up a formal procedure with each KC. The procedure is only to be carried out by experts in the field, preferably the participants in the comparison: and it should start when Draft A is released. After discussion amongst the participants the coordinator would prepare an executive report.
- This Executive Report would include basic information, plus the varying points of view if a difference of opinion exists. It should also include a list of unsupported CMC claims, and any withdrawals.
- The Executive Report would be finalised when Draft B is approved, and would be confidential to the participants, to the EM regional chairpersons and to the CCEM WGRMO.
- The CCEM WGRMO will agree on procedure to be implemented, will be informed and will promote discussion.

The main points of the lengthy discussion that followed are summarised:

- The GTRF Chair, Jim Randa, reported that the issue had also been discussed at the GTRF of March 2007, where it was proposed that the function could be passed to the pilot laboratory, who would be required to get a letter from each participant stating that their CMCs are supported, or that they are not. In the latter case a suitable corrective action should be specified by the participant. It was pointed out that in the GTRF model, the Executive Summary would contain participant testaments but would not contain judgements. The GTRF had felt that it is not the role of laboratories to judge other participants. In the case of a disagreement a laboratory would contact the RMO directly.
- The RMO is the responsible body overall since they are the initial approvers of CMCs, and so they should be the arbiter in cases where a change may be required.
- It should be a self-regulatory process. As soon as the Draft A report is circulated, laboratories should take appropriate action on their own results. Where the action is insufficient, the issue should be raised by other participants.
- Concern was expressed that in requesting that the pilot laboratory Draft the executive report political responsibility is being put on to the pilot laboratory. It is really important that the report be objective, and that the content comes from the participants themselves and not from the pilot laboratory.
- It was also suggested that the statement from the participant should state clearly which CMCs are supported by the comparison, and that there be a time limit on the discussion. If a laboratory wants to withdraw or increase their CMC uncertainty this can be done now reasonably rapidly through the RMO.
- If a participant does not submit a statement regarding CMC support, that should be mentioned in the report. Then the TC of the RMO should get involved. The RMO Chair has the final decision on what to do, and can withdraw the CMCs of a member. The time deadline for the statement from the laboratory should be after Draft B is completed.
- It was alternatively suggested to take the pilot laboratory out of this loop by requiring that the statements of compliance be sent directly to the RMO, possibly to the chair of the appropriate TC.

- The consequences for outliers with small uncertainties can be time-consuming. The pilot laboratory already has too much work, and should be relieved of the ethical or political issues, especially since there is no mathematical method to absolutely identify a non-compliant CMC.
- The last point was dealt with by saying if there is a KCRV then one can certainly make a clear statement regarding the overlap of one's own  $2\sigma$  error bars. And in fact there will be situations where the results support the CMC even though they "fail" the KC test – for example where the uncertainties presented in the KC are much smaller than those in the relevant CMC.
- Conversely, where there is only one value it is relatively easy to see if the result of a comparison supports a CMC. In many cases there is a multiplicity of results across a series of ranges of different parameters. And in these cases it is much more difficult to see whether the results support the CMCs or not.
- It was pointed out also that one should NOT reverse the process, so that in a case where one obtains good agreement in a KC with the KCRV, with small uncertainties, one then subsequently reduces the CMC uncertainties to fit.

It was agreed at this point that there should be an Executive Report, which could be a "cut and paste" of participant statements of support.

In summary, it was agreed that the Chair recommend to the CCEM to change paragraph Section 6.6 and 7 of Annex 4 of the CCEM Guidelines to read that for each KC an Executive Report be produced outlining the extent to which a KC support's the participants CMCs. But it is up to the participants to each submit their own part of this report, and not to the pilot laboratory to make a judgement. This Executive Report would then be for limited distribution to a restricted group.

It was further agreed that the report would go to the Chair of the relevant TC and to the participants. If there were no agreement on the report at the RMO level, then it would be referred to the appropriate CCWG for consideration. Any withdrawals should be noted in the main body of the report, and not in the executive report, as is presently required.

It was stressed that it is the responsibility of the RMO TC Chair, or of the RMO review committee, to check the report against the KC results and the CMCs, and it is not the responsibility of the pilot laboratory to do this. A time deadline should be included, such that the RMO would be alerted were the reporting requirements not met in a timely manner.

Finally, the report is a confidential supplement to Draft B, and is not published with Draft B.

## 7 RECENT DEVELOPMENTS IN THE NMIS

Because of the time constraints, only one laboratory report was presented to the meeting. This was the report from KRISS. The laboratory reports can be found on the working documents section of the CCEM 2007 page of the BIPM website.



## 8 ANY OTHER BUSINESS, DATE AND PLACE OF THE NEXT MEETING

The Chair requested some thought be given to his replacement since he will be retiring at the beginning of next year. He proposes to continue to chair the group until the next official meeting of the WGLF.

The next meeting of the WGLF will be held in 2008, in conjunction with CPEM 2008 in Boulder, Colorado. This will be an informal meeting.

The next formal meeting will be held at the time of the next CCEM meeting, probably in 2009, but that is a date to be fixed by the CCEM.

The meeting closed on 14 March at 11:30.

D. Inglis, Rapporteur  
June 2007

## 9TH MEETING OF THE CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES APPENDIX TO THE MINUTES

This Appendix contains a full listing of all the comparisons considered during the meeting. In cases where there was significant discussion, the comparison and the discussion are also included in the main body of the Minutes.

### 1 REPORTS ON BIPM AND CCEM COMPARISONS

#### 1.1 Ongoing BIPM key comparisons

[BIPM.EM-K10.a](#) and [BIPM.EM-K10.b](#): dc voltage, Josephson standards.

1 V: No bilateral comparisons

10 V: INMETRO (BR) in April 2006 ( $x_i = 19 \text{ nV}$ ,  $u_i = 16 \text{ nV}$ )

NMIA (AU) in May 2006 ( $x_i = 0.9 \text{ nV}$ ,  $u_i = 1.7 \text{ nV}$ )

NMi VSL in October 2006 ( $x_i = -1.5 \text{ nV}$ ,  $u_i = 1.8 \text{ nV}$ )

The discussion generated by the result of the INMETRO comparison is reported in the minutes.

[BIPM.EM-K11.a](#) and [BIPM.EM-K11.b](#): dc voltage, Zener diode.

1 V: NCM (BG) in May 2006 ( $x_i = -1.39 \text{ } \mu\text{V}$ ;  $u_i = 1.00 \text{ } \mu\text{V}$ )

10 V: NCM (BG) in May 2006 ( $x_i = -0.99 \text{ } \mu\text{V}$ ;  $u_i = 4.00 \text{ } \mu\text{V}$ )

[BIPM.EM-K13.a](#) and [BIPM.EM-K13.b](#): Comparison of resistance standards.

1  $\Omega$ : NML (IE) in April 2006 ( $x_i = 0.0 \times 10^{-8}$ ;  $u_i = 19.0 \times 10^{-8}$ )

INM (RO) in May 2006 ( $x_i = 7.0 \times 10^{-8}$ ;  $u_i = 13.0 \times 10^{-8}$ )

10 k $\Omega$ : NML (IE) in April 2006 ( $x_i = 28.0 \times 10^{-8}$ ;  $u_i = 46.0 \times 10^{-8}$ )

INM (RO) in May 2006 ( $x_i = -9.0 \times 10^{-8}$ ;  $u_i = 9.0 \times 10^{-8}$ )

#### 1.2 Completed CCEM key comparisons

[CCEM-K10](#): Resistance 100  $\Omega$ , pilot PTB (DE) (WGLF/07-07).

The Draft B report of CCEM-K10 was circulated by email on 24 April with 19 May as a deadline for response. Six responses were received which were mostly in favour of the Draft B report with a few comments from 3 laboratories. These were taken into consideration by the pilot laboratory together with the remarks being made at the meeting in Turin. A revised Draft B report was circulated on 16 January with a deadline 15 February. The revised report was

approved by the WGLF and the CCEM, comments from one laboratory were taken into account. The final report can be found on the restricted website.

The results have been published in the KCDB.

[CCEM-K11/CCEM-K11.1](#): ac/dc transfer at low voltages, pilot SP (SE) (WGLF/07-09).

Draft B report was received 9 February and put on the restricted website on 13 February. Delegates had been asked to look at this report in advance of the meeting. Karl-Erik Rydler gave a short report on the comparison.

Vote (this meeting): Comparison approved for submission to the CCEM for inclusion in the KCDB.

### 1.3 Ongoing CCEM key comparisons

[CCEM-K7](#): ac voltage ratio, pilot NPL (UK).

Measurements completed. Comments on Draft A were circulated by email. A controversial discussion arose on how to determine the KCRV. The discussion is reported in the minutes.

It is referred to the pilot laboratory, the support group and the participants to come to agreement.

[CCEM-K12](#): ac/dc current transfer, pilot NMIA (AU) (WGLF/07-01).

Comparison started in April 2005. Measurements are ongoing, and were running to schedule until recently. Measurements should complete in May if the present Customs problem clears OK.

[CCEM-K13.CL](#): ac power with non-sinusoidal waveforms, pilot NRC (CA).

The pilot laboratory has requested that the start of this comparison be delayed for 2 years. The discussion is reported in the minutes.

## 2 REPORTS ON RMO COMPARISONS

### 2.1 APMP comparisons

[APMP.EM.BIPM-K11.2](#): dc voltage, pilot: KIM-LIPI (ID).

Status: Measurements completed, Draft B report prepared and reviewed within APMP.

[APMP.EM-K4.1](#): Capacitance (10 pF), pilot: NMIA (AU).

Status: In progress.

[APMP.EM-K6.a](#): ac/dc voltage transfer, pilot: NMIA (AU).

Status: Measurements completed, Draft B report being prepared. See additional comments in minutes.

[APMP.EM-K9](#): ac/dc voltage transfer, pilot: CMS ITRI (TW).

Status: Measurements completed, Draft B report being prepared.

[APMP.EM.RF-S4](#): ac/dc voltage transfer, pilot: NMIA (AU).

Bilateral comparison, participants NMIA and NPL India, start in May 2003, protocol and declaration form available. Ongoing.

[APMP.EM-S7](#): Capacitance (100 pF), pilot: NMIA (AU).

Status: In progress.

[APMP.EM.RF-S3](#): Reflection coefficient in coaxial line, pilot: NPLI (IN).

Status: In progress.

## 2.2 COOMET comparisons

[COOMET.EM-K4](#): Capacitance at 10 pF, pilot: UkrCSM (UA).

Status: In progress.

[COOMET.EM-S1](#): ac/dc voltage transfer, pilot: VNIIM (RU).

Status: Measurements completed.

[COOMET.EM-S4](#): Capacitance at 100 pF, pilot: UkrCSM (UA).

Status: In progress.

See note in the minutes re: delays to these three comparisons.

## 2.3 EUROMET comparisons

[EUROMET.EM.BIPM-K11.6](#): dc voltage (Project 846), pilot: BEV (AT).

This is a bilateral supplement to -K11. Measurements completed. The Draft A report was agreed, and the Draft B report was circulated.

See additional notes on this comparison in the minutes.

[EUROMET.EM-K2](#): High ohmic resistors (Project 851), pilot: METAS (CH).

Protocol approved by WGLF and CCEM. Two parallel loops, 24 laboratories,  $3 \times 10 \text{ M}\Omega$  and  $3 \times 1 \text{ G}\Omega$  resistors per loop. Measurements are completed, and Draft A is in preparation.

[EUROMET.EM-K3](#): Inductance at 10 mH (Project 889), pilot: PTB (DE).

Trilateral supplement to [CCEM-K3](#) with INM (RO), NCM (BU) and PTB (Pilot). PTB provides the link to [CCEM-K3](#). Protocol approved by WGLF and CCEM. Measurements completed, Draft A in preparation.

[EUROMET.EM-K5.1](#): ac power (Project 687), pilot: UME (TR).

Follow-up of [EUROMET.EM-K5](#). 9 participants. Transfer standard supplied by PTB. Protocol following [EUROMET.EM-K5](#) and approved by WGLF and CCEM. Measurements ongoing. Link to [EUROMET.EM-K5](#) through 5 laboratories (MIKES, NMi VSL, OMH, PTB, UME).

[EUROMET.EM-K6.a](#): ac/dc transfer at 3 V (Project 889), pilot: PTB (DE).

Bilateral supplement to [CCEM-K6.a](#) with NCM (BG) and PTB. Protocol approved by WGLF and CCEM, measurements completed. Draft A in preparation.

[EUROMET.EM-K10](#): dc resistance 100  $\Omega$  (Project 636), pilot: PTB (DE).

Protocol approved. Comparison is performed in three loops. Measurements completed. Draft A report agreed, Draft B report in preparation. Link to CCEM-K10 by four laboratories (BIPM, METAS, MIKES, PTB).

[EUROMET.EM-K11](#): ac/dc mV transfer (Project 464), pilot: SP (SE).

Protocol approved by WGLF and CCEM. NPLI will be included in this comparison. Comparison is ongoing.

Most of the EUROMET laboratories have measured, and the standard is presently in CSIR.

[EUROMET.EM.RF-K8.1.CL](#): Calculation factor of thermistor mounts (Project 818), pilot: NMi VSL (NL).

Follow-up of [EUROMET.EM.RF-K8.CL](#). Protocol agreed. Measurements completed. Draft B approved by the GT-RF. Final approval at the CCEM meeting.

Discussed at the GT-RF meeting, March 2007.

[EUROMET.EM.RF-K10.CL](#): RF power, 3.5 mm coaxial (Project 525), pilot: PTB (DE).

Measurements completed. Draft A report agreed, Draft B report submitted to the GT-RF for approval. Three linking laboratories to CCEM.EM.RF-K10.CL (SIQ, NPL, PTB).

Discussed at the GT-RF meeting, March 2007.

[EUROMET.EM-S7](#): ac conductivity (Project 427), pilot: NPL.

Comparison was organized in connection with an EU project on electrical conductivity. Protocol approved. Measurements completed. Draft A agreed, Draft B report in preparation. The results from Boeing are still missing.

[EUROMET.EM-S11](#): Current transformers (Projects 473 and 612), pilot: NPL (UK).

Draft A report circulated and agreed. Draft B report for both projects shortly before completion.

[EUROMET.EM-S19](#): Current transformers (Project 688), pilot: UME (TR).

Measurements completed. Draft A report in preparation.

[EUROMET.EM-S22](#): Low-ohmic resistors (Project 835), pilot: NMi VSL (NL).

Measurements completed. A larger comparison can be organised, if there is interest.

[EUROMET.EM-S23](#): Alternating voltage ratio (Project 815), pilot: INM (RO).

Measurements completed, Draft A agreed, Draft B in preparation.

[EUROMET.EM-S24](#): Ultra-low dc current sources (Project 830), pilot: PTB (DE).

Measurements ongoing.

[EUROMET.EM-S25](#): ac/dc transfer at high voltage (Project 889), pilot: PTB (DE).

Measurements completed, Draft A in preparation.

[EUROMET.EM-S26](#): Inductance (100 mH) (Project 816), pilot: INM (RO).

Measurements ongoing.

[EUROMET.EM-S28](#): dc voltage, Josephson standards (Project 928), pPilot: PTB (DE).

Protocol complete, comparison will start in April 2007.

[EUROMET.EM.RF-S25](#): Field strength above 1 GHz (Project 819), pilot: CMI (CZ).

Preliminary tests have been completed. Measurements will start in the beginning of 2007.

[EUROMET.EM.RF-S26.CL](#): Effective efficiency (Project 874), pilot: LNE (FR).

Measurements completed, Draft A in preparation.

## 2.4 SIM comparisons

The full report was presented by Harold Sanchez.

[SIM.EM.BIPM-K11.b](#): dc voltage (10 V), pilot: NIST (US).

Protocol complete.

[SIM.EM-K1](#): Resistance (1  $\Omega$ ), pilot: NIST (US).

Protocol complete.

[SIM.EM-K2](#): High ohmic resistances (1 G $\Omega$ ), pilot: NIST (US).

Protocol complete.

[SIM.EM-K3](#): Inductance (10 mH), pilot: INMETRO (Brazil).

Protocol in progress.

[SIM.EM-K4](#): Capacitance (10 pF), pilot: NIST (US).

Ongoing.

[SIM.EM-K6.a](#): ac/dc voltage transfer, pilot: CENAM (MX).

Measurements completed.

[SIM.EM-K9](#): ac/dc voltage transfer, pilot: CENAM (MX).

Measurements completed.

[SIM.EM-K11](#): ac/dc voltage transfer, pilot: CENAM (MX).

Measurements completed.

**SIM.EM-K12**: ac/dc current transfer, proposed in SIM.

[SIM.EM-S2](#): ac energy, pilot: NIST (US).

Ongoing.

[SIM.EM-S3](#): Capacitance (1000 pF), pilot: NIST (US).

Ongoing.

[SIM.EM-S4](#): Capacitance (100 pF), pilot: NIST (US).

Ongoing.

[SIM.EM-S5](#): dc and ac voltage and current, dc resistance, pilot: NIST (US).

Protocol complete, measurements started in 2005, repetition of SIM.EM-S1.

[SIM.EM-S6](#): Resistance (1 M $\Omega$ ), pilot: NIST (US).

Ongoing.





**APPENDIX E 3.**  
**REPORT OF THE 19th MEETING OF THE**  
**CCEM WORKING GROUP ON RADIOFREQUENCY QUANTITIES**  
 (12 and 13 March 2007)  
**TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM**

**1 OPENING OF THE MEETING;  
 APPOINTMENT OF A RAPPORTEUR;  
 APPROVAL OF THE AGENDA**

Report of the meeting of the CCEM Working Group on Radiofrequency Quantities (GT-RF) which took place on Monday 12 March afternoon and Tuesday 13 March 2007, in the Pavillon du Mail of the BIPM, Sèvres.

The following were present: D. Allal (LNE), H. Bachmair (PTB), L. Brunetti (INRIM), H.A. Chua (SPRING Singapore), R. Clarke (NPL), J.P.M. de Vreede (NMI VSL), Q. Gao (NIM), B.D. Inglis (NMIA, President of the CCEM), R. Judaschke (PTB), T.W. Kang (KRISS), K.-T. Kim (KRISS), K. Komiyama (NMIJ/AIST), G. Marullo Reedtz (INRIM), A. Michaud (NRC-INMS), J. Randa (Chairman, NIST), B. Ricketts (NMIA), Y.S. Song (KRISS), J. Williams (NPL), M. Zeier (METAS).

Invited: E. Afonso (INMETRO), E. Dressler (CSIR-NML\*), G. Kyriazis (INMETRO), H. Sánchez (ICE, San José), S. Singh (CSIR-NML).

Also present: S. Solve, M. Stock, T.J. Witt (Executive Secretary of the CCEM) (BIPM).

The Chairman, Jim Randa, opened the meeting at 14:00 and asked the attendees to introduce themselves.

Brian Ricketts was appointed rapporteur for the meeting.

The Chairman sought approval for the minutes of the 18th meeting the GT-RF which was held on the 15 March 2005. No matters being raised, the minutes were approved by the meeting.

The Chairman sought approval for the proposed agenda for the meeting. The agenda was approved by the meeting.

**2 DEVELOPMENTS SINCE THE 18th MEETING OF THE GT-RF**

A new CCEM working group called the CCEM Working Group on Coordination of the Regional Metrology Organizations (WGRMO) was formed. The members of this working group

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\* Renamed NMISA.

comprise: the chairpersons of the electricity and magnetism technical committees of the RMOs, the chairpersons of the WGLF and the GT-RF, the executive secretaries of the CCEM and the JCRB and the coordinator of the KCDB. Past and future chairpersons of the electricity and magnetism technical committees of the RMOs may also be members of the WGRMO. One of the main functions of this group is to foster uniformity among the RMOs on the ways in which CMC spreadsheets are prepared and reviewed.

When a member of a comparison support group is not a participant in the comparison that person should not have access to the results of the comparison until the Draft A report of the comparison has been approved by the participants.

### 3 COMPLETED COMPARISONS

#### 3.1 Comparisons approved by the 18th meeting of the GT-RF and now approved by the CCEM

[CCEM.RF-K8.CL](#): Power, 10 MHz – 18 GHz, NMi VSL (J. de Vreede).

[CCEM.RF-K10.CL](#): Power, 50 MHz – 26 GHz, PTB (D. Janik).

The results of these comparisons are available on the KCDB.

#### 3.2 Comparisons approved by the GT-RF and CCEM since the 18th meeting of the GT-RF

[CCEM.RF-K9](#): Noise, 12.4 GHz – 18 GHz, LNE (D. Allal).

[CCEM.RF-K18.CL](#): Noise, up to 1 GHz, NPL (C. Eiø).

In this comparison one participant was traceable to another participant. The method of dealing with this situation led to a scientific paper (*Metrologia*, 2006, **43**, S268-S275).

[CCEM.RF-K20.CL](#): E-field strength, 10 MHz – 1 GHz, METAS (F. Pythoud).

[CCEM.RF-K21.F](#): Antenna factor, 300 MHz and 900 MHz, NPL (D. Knight).

The results of these comparisons are available on the KCDB.

#### 3.3 Comparisons approved since last GT-RF and CCEM meetings

[CCEM.RF-S1.CL](#): Power, 50 MHz – 50 GHz, NIST (T. Crowley).

[CCEM.RF-S21.F](#): Antenna factor, attached to [CCEM-RF-K21.F](#), NPL (D. Knight).

[EUROMET.EM.RF-K8.CL](#): Power, 10 MHz – 18 GHz, NMi VSL (J. de Vreede)

The results of these comparisons are available on the KCDB.

With reference to [CCEM.RF-S1.CL](#) and [CCEM.RF-S21.F](#) there was some discussion about the principle that the CCEM does not normally run supplementary comparisons. The first of these two comparisons was started before this principle was well established. The second comparison, [CCEM.RF-S21.F](#), consists of measurements that were an extension of the ranges covered by [CCEM.RF-K21.F](#). The CCEM Guidelines now allow a report of a key comparison to have an attachment of additional measurements. The additional measurements attachment to a report may be used to support CMCs.

### 3.4 Comparisons proposed for full equivalence

[CCEM.RF-K3.F](#): Horn antenna gain at 26.5 GHz, 33 GHz and 40 GHz, NPL (D. Gentle). Participants: LNE, KRISS, NIST, NMi VSL, NPL.

This comparison was conducted in 1998-2000 and was approved for provisional equivalence. The APMP is proposing a similar comparison and it would be an advantage if the APMP comparison could be linked to [CCEM.RF-K3.F](#). This would only be possible if [CCEM.RF-K3.F](#) was approved for full equivalence. Claudine Thomas had suggested that this should be possible because the treatment of the results of the comparison followed the requirements for full equivalence and there should not be any extra work required by the pilot laboratory to have the comparison considered for full equivalence.

There was a general discussion about the linking of RMO comparisons to CCEM comparisons and Tom Witt stressed that the protocol of an RMO comparison should make specific mention of the proposed linking arrangement.

The representatives of the participating laboratories (KRISS, LNE, NIST and NMi VSL) raised no objections to [CCEM.RF-K3.F](#) being proposed for full equivalence and the meeting approved the proposal. Final approval of the proposal will be sought at the CCEM meeting later in the week.

### 3.5 Comparisons approved by the GT-RF by correspondence

[EUROMET.EM.RF-K8.1.CL](#): Power, 10 MHz – 18 GHz, NMi VSL (J. de Vreede). Bilateral with MIKES; follow-up to [EUROMET.EM.RF-K8.CL](#).

The report of this comparison was approved by the GT-RF by correspondence. Final approval of the report will be sought at the CCEM meeting later in the week.

### 3.6 Approval delayed

[EUROMET.EM.RF-K10.CL](#): Power, 50 MHz – 26 GHz, PTB (D. Janik). Draft B has been completed but NPL would like another 2 weeks to consider some details of the report. The Chairman said that 2-3 weeks after the meeting he would send the report to the GT-RF representatives for approval by correspondence.

## 4 CURRENT COMPARISONS

[CCEM.RF-K4.CL](#): Voltage, up to 1 GHz, NMi VSL (J. de Vreede). Draft A has been sent to participants.

[CCEM.RF-K5.b](#) S-parameters, 2 GHz – 18 GHz, NPL (C. Eiø). All measurements have been completed and the Draft A report is being written. The report of the measurements by KRISS has not been received by the pilot laboratory. Tae-Weon Kang from KRISS undertook to encourage relevant staff to forward their report. Bob Clarke expressed some concern about the number of participants in this comparison and in [CCEM.RF-K19.CL](#). He reported that the [CCEM.RF-K5.b](#) report was likely to be very large, due both to the number of participants and the number of quantities to be measured. It was suggested that the graphs could be sent as an electronic appendix to the report. One complication with the preparation of the Draft A report was presenting degrees of equivalence when the measurands are complex quantities. There was some discussion about the need to limit the size of CCEM comparisons.

[CCEM.RF-K9.1](#): Noise bilateral (PTB, VNIIFTRI). The LNE, the pilot laboratory of [CCEM.RF-K9](#) reported that the results had been received from PTB but there was no response from VNIIFTRI. The Chairman will contact VNIIFTRI.

[CCEM.RF-K19.CL](#): Attenuation, 60 MHz and 5 GHz (type N), NPL (J. Howes). Measurements are completed and the the pilot laboratory is waiting on the report from NMIA. Brian Ricketts undertook to encourage the relevant staff to forward their report as soon as possible.

## 5 NEW KEY COMPARISONS

### 5.1 Protocols submitted

[CCEM.RF-K22.W](#): Noise, 18 GHz – 26.5 GHz. A draft protocol for this comparison was presented. The pilot laboratory will be the LNE (D. Allal) with the other participants being KRISS, NIST, NMIJ and NPL. Since there are only five participants it was suggested that all five laboratories should contribute one member to the support group. It was pointed out that a list of personal names of the members of the support group would be required in the final version of the protocol. It was suggested that the protocol should give some indication of the expected uncertainties as a Guide to laboratories considering participation. Bob Clarke said that NPL would like more time to consider the protocol. It was decided to postpone approval of the protocol but it was noted that this comparison could proceed once the protocol had been approved since all other noise comparisons had been completed.

[APMP.EM.RF-K3.F](#) Horn antenna gain at 26.5 GHz, 33 GHz and 40 GHz. This bilateral comparison between KRISS and NMIJ is to be linked to [CCEM.RF-K3.F](#) with KRISS as the linking laboratory. There was some discussion about whether this comparison could be a CCEM rather than an APMP bilateral comparison. CCEM bilateral comparisons can occur when a

laboratory is not ready to join the main key comparison but subsequently links to the comparison by having a bilateral comparison with one of the participants in the original comparison. Since both participants in the proposed comparison are in APMP the meeting decided that it should remain as an APMP comparison. There was a discussion about the linking of this comparison to [CCEM.RF-K3.F](#). There was the issue of whether the time interval between the two comparisons was too great and the issue of whether the artefacts to be used in [APMP.EM.RF-K3.F](#) were able to measure the same quantities as in the original comparison. The meeting was satisfied that the proposed comparison was satisfactory on both these points and the declaration and the protocol were approved.

## 5.2 Proposals for new comparisons

### Antenna gain above 40 GHz

The KRISS has proposed a key comparison of antenna gain above 40 GHz. Two laboratories, the KRISS and the NIST expressed an interest in participation.

There was some discussion about whether a key comparison with a new parameter range should proceed with just two participants. There would be no reason in principle for not proceeding with a bilateral comparison of this type. It could however delay the commencement of another key comparison in antenna parameters. This led to a discussion on the possible level of interest in antenna measurements in other frequency ranges. In the range of 18 GHz to 40 GHz the following four laboratories expressed an interest; NPL, PTB, NIST and KRISS. The NPL offered to ask for interested laboratories.

Hans Bachmair suggested that KRISS and NIST (and any other interested laboratories) could take part in a pilot comparison for antenna gain above 40 GHz. This would not delay the commencement of a key comparison at lower frequencies.

The Chairman asked for other suggestions for new comparisons. He observed that the GT-RF does not have current or proposed comparisons in power or EM field strength. There were no expressions of interest in a power comparison but several laboratories (KRISS, LNE, METAS, NPL, NIST, PTB) expressed an interest in a comparison on EM field strength up to 18 GHz. The NPL offered to send emails to gauge the level of interest in other laboratories but could not commit to piloting such a comparison.

## 6 OTHER BUSINESS

### 6.1 Proposed changes to the CCEM Guidelines and the Supplement Guide

Hans Bachmair introduced the three following changes.

- 1) The first was a small change to Section 2.4 of the Guidelines which deals with comparison identifiers. The change is to make it clearer that the subfield of the identifier should be BIPM in the case of an RMO comparison which is linked to BIPM. Since BIPM does not take part in comparisons of magnetic quantities or RF quantities there is no conflict in using

the subfield to indicate that BIPM is the linking laboratory in an RMO comparison. It was stressed that RMO comparisons should adopt the same structure of comparison identifier to avoid confusion among the users of the KCDB. The proposed change was supported by the GT-RF.

- 2) Several changes were proposed to the classification scheme for CMCs. The changes relevant to the GT-RF involve categories 11.1.3 and 11.1.4. The classifications will remain the same but it is proposed to change note f) in the Supplement Guide. It is proposed that the note be changed to request that NMIs report the maximum and minimum power levels in the *Measurand level and range* column rather than calibration factor or effective efficiency. The proposed change was supported by the GT-RF.
- 3) Section 6.6 of Annex 4 of the CCEM Guidelines recommends that participants in a comparison report on the effect that the results of the comparison might have on some of their CMCs. This information was to be included in the comparison report. It was observed that this recommendation was rarely followed and it was thought possible that some NMIs would not wish to have information of this kind in the comparison report. It was proposed that the pilot laboratory should prepare an executive report which would consist mainly of a compilation of responses from the participants about the effect of the comparison on their CMCs. The executive report would also note if any participants did not respond to the request for this information. The executive report would only be circulated to participants and the members of the WGRMO. The point was strongly made by several representatives that the pilot laboratory should not have the responsibility of checking the validity of the participants' contributions to the executive report. On this basis the proposed change was supported by the GT-RF.

The meeting was adjourned at 18:00 and it was decided that the meeting would resume at 11:00 on the following day.

## **7 RECENT DEVELOPMENTS AT THE NMIS**

The Chairman asked if any representatives would like to highlight any new work at their laboratories. The METAS, NPL and PTB gave a brief review of the work detailed in documents submitted to this meeting. The KRISS and NIST gave a review of the relevant parts of the reports that their laboratories have submitted to the CCEM meeting.

## **8 GT-RF MEETING DOCUMENTS**

It was decided to make the following documents of this meeting available on the open access section of the CCEM website: [GT-RF/2007-00](#), [GT-RF/2007-07](#), [GT-RF/2007-08](#) and [GT-RF/2007-14](#). The remaining documents would remain with restricted access.

## 9 NEXT MEETING

It was decided that there should be an informal meeting of the GT-RF as a satellite meeting of CPEM 2008 in Boulder. The date and time of the meeting would be decided after consultation with the conference organizers.

The next official meeting of the GT-RF will be held in conjunction with the expected CCEM meeting in early 2009.

The meeting was closed at 12:02.

B. Ricketts, Rapporteur

June 2007

**List of actions**

Purpose	Person responsible	Action	Deadline
Approval for <a href="#">EUROMET.EM.RF-K10.CL</a>	Jim Randa	Will ask for approval by email	2-3 weeks after meeting
Laboratory report for <a href="#">CCEM.RF-K5.b.CL</a>	Tae-Weon Kang	Encourage submission of the comparison report from KRISS	As soon as possible
Response from VNIIFTRI on <a href="#">CCEM.RF-K9.1</a>	Jim Randa	Contact VNIIFTRI and enquire about report for CCEM.RF-K9.1	As soon as possible
Laboratory report for <a href="#">CCEM.RF-K19.CL</a>	Brian Ricketts	Encourage submission of the comparison report from NMIA	As soon as possible
Antenna parameters in the range 18 GHz to 40 GHz	Bob Clarke	Send an email to gauge interest	Meeting at CPEM 2008
EM Field Strength up to 18 GHz	Bob Clarke	Send an email to gauge interest	Meeting at CPEM 2008



**APPENDIX E 4.**  
**REPORT OF THE 2ND MEETING OF THE CCEM WORKING GROUP ON THE**  
**COORDINATION OF THE REGIONAL METROLOGY ORGANIZATIONS**  
 (14 March 2007)  
**TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM**

**1 OPENING OF THE MEETING;**  
**APPOINTMENT OF A RAPPORTEUR;**  
**APPROVAL OF THE AGENDA**

Report of the meeting of the CCEM Working Group on the Coordination of the Regional Metrology Organizations (WGRMO) which took place on Wednesday 14 March 2007 afternoon, in the Pavillon du Mail of the BIPM, Sèvres.

The following were present: H. Bachmair (EUROMET and Chairman CCEM WGLF), H.A. Chua (APMP), E. Dressler (SADCMET), Q. Gao (NIM), B.D. Inglis (NMIA, President of the CCEM), G. Kyriazis (SIM), J.K. Olthoff (SIM), J. Randa (SIM and Chairman CCEM GT-RF), B. Ricketts (APMP), H. Sánchez (SIM), S. Singh (SADCMET), Y.S. Song (APMP).

Sent regrets: T. Kolomiets (COOMET and Belgim), L. Marais (CSIR-NML) and G. Marullo Reedtz (Chairman, CCEM WGRMO).

Also present: P. Espina (Executive Secretary of the JCRB), M. Stock (future Executive Secretary of the CCEM), C. Thomas (Coordinator of the KCDB), T.J. Witt (Executive Secretary of the CCEM) (BIPM).

The meeting commenced at 15:00.

The acting Chairman welcomed participants and conveyed an apology from the WGRMO Chairman G. Marullo Reedtz who could not attend due to a personal obligation on the day of the meeting. The acting Chairman noted that COOMET was not represented.

The agenda for the meeting was displayed and approved by the meeting.

**2 MINUTES OF PREVIOUS MEETING AND MATTERS ARISING FROM IT**

*Item 5. Impact of comparison results on CMC.* It was noted that the issue of the possible conflict of the terms of reference of the WGRMO and the policy of the JCRB had been clarified by an email on 26 November 2006 from P. Espina. The CCEM could adopt a method of monitoring the effects of comparisons on CMCs provided that the chain of responsibilities outlined in the [JCRB-11/7\(a\)](#) was observed.

*Item 10. Traceability of an NMI's CMC to an instrument manufacturer.* P. Espina said that the JCRB ruling was that such traceability was not acceptable for an NMI. Although the instrument

manufacturer's laboratory may be accredited, the level of review and scrutiny of its calibration capabilities was not as comprehensive as the level of review and scrutiny applied to the CMCs of those NMIs which participate in the CIPM MRA. P. Espina was asked to write a letter to the WGRMO members and the RMO chairs to clarify this matter.

### 3 MATTERS RELATING TO CMCS

#### 3.1 Status of current inter RMO reviews

The following list of RMO reviews was discussed:

APMP.EM.5.2005: published 25 January 2007,

APMP.EM.6.2007: new intra RMO review started,

COOMET.EM.2.2006: revision in progress (final approval),

EUROMET.EM.2.2005: published 30 March 2006,

EUROMET.EM.3.2006: published 19 October 2006,

EUROMET.EM.4.2007: new intra RMO review started,

SIM.EM.1.2006: abandoned 14 March 2006,

SIM.EM.2.2006: revision in progress (final approval).

There was no action resulting from the discussion of these reviews.

C. Thomas made several points about the reviews:

- When an NMI wishes to modify its CMCs it should obtain the Excel version of its CMC table from the JCRB website (<http://www.bipm.org/JCRBCMCs/>). The username is tcgust and the password is tcontact. By choosing "Get Published CMCs" from the summary box and following the instructions it is possible to get the appropriate file. The NIST file, for example, will be named EM\_US.xls and when the file is modified and sent on for review the filename should be extended by adding, for example, the date.
- Before making any modifications, any entries in red font should be changed to black font. Any new entries or modified entries should use red font. Entries which already have a grey or a pink background will not appear in the KCDB but can be left in this file. If an entry is to be deleted it should be given a pink background and the words "to be deleted from the KCDB" should be entered in the NMI comments column. These instructions are included in document [JCRB-8/10\\_rev](#).
- A CMC must have only one category and one identifier.

The TCEM chairs were asked to ensure that their contact persons were well informed about these arrangements for modifying CMC tables.

### 3.2 Use of the JCRB inter-RMO review website

There was some discussion about whether greater use could be made of the JCRB website to track communications during the inter-RMO review of CMCs. It was decided that it would not be practical to implement this but rather to continue direct communication between NMIs with copies to the relevant TC chairs.

### 3.3 Report from the Executive Secretary of the JCRB

P. Espina gave a presentation on recent activities of the JCRB. The main items were:

- A list of meetings with JCRB involvement.
- A new policy for the review of quality management systems.
- New JCRB documents covering recommendations for on-site visits and selection criteria for visiting reviewers.
- Arrangements for the use of the CIPM MRA logo.
- The development of a more convenient system for access to the various documents related to the CIPM MRA.
- Seminars and workshops that are being held to promote the participation of more countries in the CIPM MRA.
- A direct comparison of documents [JCRB-11/6\(2\)](#) and [JCRB-11/7\(a\)](#) showing that the working groups on CMCs can take measures to monitor the effect of comparisons on CMCs as long as the procedures and their priorities outlined in [JCRB-11/7\(a\)](#) are observed. This point had already been discussed when reviewing actions arising from the last meeting.

### 3.4 Changes in the classification scheme

The proposed changes included a new category for resistance ratios, minor changes to the wording of categories concerned with instrument transformers and use of power levels rather than calibration factor or effective efficiency in RF power categories 11.1.3 and 11.1.4. These changes had been discussed in the earlier WGLF and the GT-RF meetings and no objections to the changes were made at this WGRMO meeting.

### 3.5 CMCs without comparison support

Some CMCs have uncertainties which cannot be directly supported by comparisons because artefacts that could provide a comparison at the claimed uncertainties are not available. P. Espina pointed out that [JCRB-14/06\(2a\)](#) lists five ways, other than comparisons, that can be used to support CMC claims. It was agreed that if doubt remained about a CMC claim the following sequence of measures should be followed: (i) direct communication with the laboratory, (ii) communication with the chairperson of the relevant RMO and (iii) appeal to the JCRB.

#### **4 IMPACT OF COMPARISON RESULTS ON CMCS**

This had already been discussed under items 3 and 4 but there was further discussion on the form of the proposed executive report. It was proposed that the executive report should be prepared by the pilot laboratory at the time of the preparation of the final report on the comparison. The executive report should consist of a compilation of short reports (requested in the comparison protocol) from the participants. The short report should list the CMCs that the participant should expect to be supported by the comparison and describe the measures that will be taken if any of these CMCs are not supported. If any participants do not provide such a report to the pilot laboratory, the pilot laboratory should include a statement in the executive report naming those participants. Unlike the main report of the comparison, the distribution of the executive report is to be limited to the participants, the TCEM chairs and the other members of the WGRMO.

The meeting approved the above arrangements for the executive report of a comparison and the CCEM will be asked for final approval.

#### **5 NEWS FROM THE RMOS**

Due to time constraints, no reports were presented to the meeting. The TCEM chairs were asked to submit their presentation for publication on the restricted website of the WGRMO.

#### **6 ROLE AND COMPETENCE OF THE WGRMO**

Due to time constraints there was no discussion of this topic.

#### **7 ELECTION OF NEW WGRMO CHAIRPERSON**

The term of the present chairman of the WGRMO ended with this meeting so the acting chairman asked for nominations for a new chairman. The acting chairman nominated Sze Wey Chua (APMP) who accepted the nomination. There were no further nominations so it was resolved to forward S.W. Chua's name to the CCEM for approval. (Approval was obtained on the following day).

The acting chairman and the meeting expressed their appreciation of the efforts that Giancarlo Marullo Reedtz has made as inaugural chairman of the WGRMO.

## 8 ANY OTHER BUSINESS AND NEXT MEETING

No other matters were raised.

It was decided that there should be an informal meeting of the WGRMO at CPEM in Boulder in June 2008. The date for this meeting will need to be decided in consultation with the organisers of CPEM. The next official meeting will be held in conjunction with the next CCEM meeting which is likely to be in early 2009.

The meeting was closed at 17:33.

B. Ricketts, Rapporteur

June 2007

### List of actions

Purpose	Person responsible	Action	Deadline
Traceability only to other NMIs (topic 3)	Pedro Espina	Write a letter to the WGRMO members and the RMO chairs to clarify the situation	As soon as possible
Review of CMCs (topic 4a)	TCEM chairpersons of the RMOs	Inform the contact persons of the RMO TCEMs, that the review of CMCs must always start from the Excel tables on the JCRB website and follow the other requirements mentioned in by C. Thomas in 4(a) above and in document JCRB-8/10_rev.	Next RMO TCEM meeting
Reports of the RMO TCEMs	TCEM chairpersons of the RMOs	Submit your report to T.J. Witt for publication on the restricted website of the WGRMO	As soon as possible