

APPENDIX E.2
REPORT OF THE 13TH MEETING OF THE
CCEM WORKING GROUP ON LOW FREQUENCY QUANTITIES (WGLF)
(11 March 2015)
TO THE CONSULTATIVE COMMITTEE FOR ELECTRICITY AND MAGNETISM

**List of Members of the CCEM Working Group on Low Frequency Quantities as of
11 March 2015**

Chairman

Dr J.M. Williams, National Physical Laboratory [NPL], Teddington

Members

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

Federal Institute of Metrology METAS [METAS], Bern-Wabern

Instituto Nacional de Metrologia, Qualidade e Tecnologia [INMETRO], Rio de Janeiro

International Bureau of Weights and Measures [BIPM], Sèvres

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

National Measurement Institute, Australia [NMIA], Lindfield

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

National Physical Laboratory [NPL], Teddington

National Research Council of Canada [NRC], Ottawa

Physikalisch-Technische Bundesanstalt [PTB], Braunschweig

SP Technical Research Institute of Sweden [SP], Borås

VSL [VSL], Delft

The Working Group on Low Frequency Quantities (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) held its thirteenth meeting on 11 March 2015 at the Bureau International des Poids et Mesures, Pavillon de Breteuil, Sèvres, France.

The following delegates from member laboratories were present:

Dr Ilya Budovsky (NMIA), Dr Luca Callegaro (INRIM), Mr Nick Fletcher (BIPM), Dr Pierre Gournay (BIPM), Dr Gleb Gubler (VNIIM), Dr Barry Inglis (NMIA, CIPM President, outgoing President of the CCEM), Dr Daniela Istrate (LNE), Dr Beat Jeckelmann (METAS), Dr Nobuhisa Kaneko (NMIJ/AIST), Dr No-Weon Kang (KRISS), Dr Alexander Katkov (VNIIM), Dr Jürgen Melcher (PTB), Dr Thomas Nelson (NIST), Dr Jim Olthoff (NIST), Dr Po Gyu Park (KRISS), Dr François Piquemal (LNE), Dr Jon Pratt (NIST), Dr Gert Rietveld (VSL, incoming President of the CCEM), Mr Karl-Erik Rydler (SP), Dr Carlos Sanchez (NRC), Dr Bernd Schumacher (PTB), Dr Yozo Shimada (NMIJ/AIST), Dr Uwe Siegner (PTB), Dr Stéphane Solve (BIPM), Dr Michael Stock (BIPM, Executive Secretary of the CCEM), Dr Yi-Hua Tang (NIST), Dr Jonathan Williams (NPL).

Guests:

Dr Hala AbdElMegeed (NIS), Dr David Aviles (CENAM), Dr Mustafa Cetintas (UME), Dr Murray Early (MSL), Dr Israel Garcia (CENAM), Dr Eugène Golovins (NMISA), Mr Dennis Lee (SCL), Mr Lucas di Lillo (INTI), Dr Helge Malmbeek (JV), Dr Antti Manninen (MIKES), Mr Miguel Neira (CEM), Dr Susanne Picard (BIPM), Mr Jiri Streit (CMI), Dr Jing Tao (A*STAR), Dr Jiangtao Zhang (NIM).

Dr Hällström (MIKES) joined the meeting temporarily via a remote connection.

1. MINUTES AND ACTIONS OF THE LAST MEETING, APPROVAL OF THE AGENDA

The 13th meeting of the CCEM Working Group on Low Frequency Quantities (WGLF) was held on 11 March 2015 at 14:00, with Dr Williams as the chair.

The Chairman welcomed the participants to the meeting. All participants briefly introduced themselves. Dr Callegaro was appointed rapporteur.

The agenda was published as working document CCEM-WGLF/15-01. The draft agenda was adopted without changes.

The previous (12th) formal meeting of the WGLF was held at the BIPM in 2013. The Chairman proposed a change in the wording of the CCEM-K13 (power harmonics) description, since the NPL had been inadvertently omitted from the participants. There were no further comments on the minutes. The minutes prepared by Dr Sze Wey Chua for the 12th meeting (see CCEM-WGLF/15-02) were adopted.

2. REVIEW OF CURRENT AND RECENTLY COMPLETED CCEM COMPARISONS

Four ongoing CCEM comparisons were discussed at the meeting.

a. CCEM-K2: DC resistance, 10 M Ω and 1 G Ω , pilot NRC, Canada

Dr Sanchez (NRC, pilot laboratory) reported on the present status of the CCEM-K2 comparison. The comparison is on schedule and the travelling standards are currently being transported from South Africa to New Zealand. The standards seem to have recovered well from the step change which occurred at the end of the SIM loop, since a linear drift model describes the present standards' behaviour quite well. The standard circulation should be completed during summer 2015. The draft A report is expected for autumn 2015.

b. CCEM-K3.1: Inductance, 10 mH, pilot PTB, Germany

Dr Melcher (PTB, pilot laboratory) reported that the travelling standard was returned to Australia in a defective state. For further work, a new and very expensive travelling standard would be required. The activity is considered to have stopped and the comparison has had to be cancelled. Dr Budovsky suggested that the measurements performed should be considered as part of the results of a future key comparison.

c. CCEM-K5: primary power, pilot CENAM, PTB, VSL

Dr Rietveld (VSL, pilot laboratory) reported on the comparison (see also the working document WGLF/15-10). The comparison pilot activity is shared between three NMIs (CENAM, organization; PTB, providing part of the travelling standard (1 RD22-22-332S instrument, see below) and multiple measurements during circulation; VSL, data processing and reporting).

The travelling standard is a set of two Radian Research RD22-22-332S instruments, and a datalogger for the recording of environmental parameters. Software for data readout of the travelling standards will be provided. The instrument firmware has been modified to achieve a significant deviation of the actual quantities to be measured with respect to the nominal value. Connection instructions are provided. The standards are currently being characterized.

The measurements are to be performed at voltage levels of 120 V and 240 V, current 5 A, phase angles of 0°, $\pm 60^\circ$, $\pm 90^\circ$. The expected uncertainty level is below 20 $\mu\text{W}/\text{VA}$.

The comparison will involve 11 participants and the expected circulation time is 18 months. A further 6 months will be required for data analysis and reporting.

Dr Rietveld commented on the circulation strategy. A double loop (two standard sets circulating at the same time) would shorten the circulation time but the comparison outcome is more prone to failures of the standard. He would prefer a single loop.

NMIs will receive a call to nominate contact persons.

Dr Budovsky asked about the number of instruments included in each set of travelling standards. Dr Rietveld replied that the travelling standard includes two items. Dr Budovsky asked about the possibility of embedding the data acquisition software in the acquisition program of the participant laboratory. Dr Rietveld replied that this would be possible. The Chairman asked about possible

inconsistencies in the use of either the pulse output or the digital communication bus output. Dr Rietveld prefers the exclusive use of digital output. Dr Nelson commented that NIST has seen a very small, but detectable difference between the two outputs. A decision will be made after a consultation with the participants. The comparison is expected to start in late 2015.

d. CCEM-K13: harmonics of voltage and current, pilot NIM, NRC, SP, NPL

The Chairman described the comparison. Seven participants and a circulation duration of two years are expected. The support group includes NIST, NRC, SP, NPL, and NIM. NIM will provide the travelling standard and a 6-month characterization; SP will draw up the measurement protocol and the circulation schedule. A suggestion is that NRC/NIST will contribute to monitoring the stability of the travelling standard and will undertake pilot measurements. The NPL will collate the data and deliver the final report.

The comparison will call for the measurement of 4-5 sets of waveforms (sine waves, field-recorded waves, waves with single harmonics) at the nominal voltage of 120 V and nominal current of 5 A, with a frequency of the fundamental harmonic of 50 Hz. Measurands will be the magnitude and phase of the voltage and current for the different harmonics.

The circulation will start in the last quarter of 2015.

Mr Rydler suggested limiting the number of waveform sets to four. Dr Budovsky commented that the calculation of the reference values, given the large dataset to be provided by each participant, will be a difficult task.

3. NEW CCEM COMPARISONS

a. Update on plans for CCEM-K4: Capacitance, 10 pF

Dr Gournay reported on the comparison plan; see also the working document WGLF/15-09.

The comparison is open to all NMIs or DIs which maintain a realization of the farad based on the calculable capacitor or a representation based on the quantum Hall effect. The comparison will be organized as a set of bilateral comparisons (circulation NMI-BIPM-NMI) occurring simultaneously.

Each NMI has to provide its own travelling standard. The nominal value of 10 pF has been chosen for the travelling standard as the most commonly used nominal value for national maintained standards, 100 pF is possible as additional optional nominal value. Two capacitors for each nominal value are expected. Capacitance standard models acceptable are Andeen-Hagerling AH11A (in the AH1100 frame); General Radio mod. 1408; custom standards defined as two terminal-pair impedance standards.

The nominal measurement voltage is 100 V for 10 pF and 10 V for 100 pF, measurement frequency 1592 Hz. The circulation will start after the end of the EURAMET.EM-S31 comparison, when the cause of the unexplained data inconsistencies that occurred in this comparison has been found.

Dr Jeckelmann inquired about the differences between this comparison and BIPM.EM-K14.a and BIPM.EM-K14.b. Dr Stock, the Chairman and Mr Fletcher explained that:

- the set of bilateral comparisons will be performed in the same period;
- a single report will be delivered;

- the key comparison reference value for CCEM-K4 will not be the BIPM value (as in the BIPM.EM K14 comparisons) but evaluated from the results of *all* participants.

Dr Piquemal enquired whether it would be possible to provide two reference values, one related to measurements traceable to the calculable capacitor and the other to the quantum Hall effect. It is commented that this is an option and it is up to the participating laboratories to decide which reference value(s) they report.

The Chairman asked about additional measurement frequencies, e.g. 800 Hz or 1 kHz. Dr Budovsky insisted on distinguishing between mandatory and optional measurement frequencies; 1 kHz could be an optional frequency.

The Chairman concluded the discussion by proposing that an invitation be sent to the NMIs. The task force to organize the comparison will include the BIPM, LNE (O. Thévenot), and NIST (Yicheng Wang).

b. Update on plans for CCEM-K6.a and -K9: AC-DC transfer

The Chairman introduced the comparisons and noted that little progress has been made since the last meeting.

Mr. Rydler reported on the technical specifications of the two comparisons:

In CCEM-K6.a the nominal voltage is 2 V in the frequency range 1 kHz to 1 MHz, and in CCEM-K9 nominal voltages are 200 V, 500 V and 1 kV, in the frequency range 1 kHz to 100 kHz.

Mr Rydler proposed:

- to share the pilot duties among different NMIs;
- to extend the frequency range down to 10 Hz;
- to limit CCEM-K9 to a single nominal voltage value.
- that the minimal number of travelling standards needed are one converter for CCEM-K6.a, and one converter with a range resistor for CCEM-K9.

Dr Budovsky:

- noted that the CCEM-K6.a nominal voltage can be anywhere between 1 V and 4 V;
- proposed to limit CCEM-K9 to a nominal value of 500 V because of the severe limitation in acquiring a commercial amplifier capable of supplying 1 kV 100 kHz, and considering that 500 V is sufficiently representative for high-voltage AC/DC measurements.

Dr Katkov proposed the inclusion of a measurement voltage of 700 V (approx. 1 kV peak).

The Chairman enquired about the support group and participants.

Preliminary composition proposed for the support group: SP, INTI, PTB, NMIA, NRC. Preliminary list of participants: NRC, JV, NMIJ, NIM, LNE, NMISA.

Dr Abdelmegeed expressed an interest in the NIS joining the follow-up regional comparison.

c. Outlook on future comparisons in the context of the CCEM strategy

The Chairman presented a time chart of the finished, ongoing and planned CCEM comparisons. Any proposal for future comparisons (to occur after 2017) has to be submitted to the CCEM for approval.

With respect to the key quantity DC voltage, the regional equivalence is well maintained by the BIPM.EM-K10.a, and BIPM.EM-K10.b ongoing comparisons (1.018 V and 10 V). There is no need for a new key comparison for this quantity.

The Chairman commented about the possible need for new key comparisons on DC resistance, considering also the lower number of comparisons performed within BIPM.EM-K12 with respect to BIPM.EM-K10.a and BIPM.EM-K10.b.

The Chairman pointed out that no comparison has been performed on DC current or AC resistance in the last 20 years, whereas AC voltage, AC current and AC power are well covered by present ongoing or planned comparisons.

The Chairman proposed the initiation of a new comparison of inductance standards. Dr Melcher suggested for the travelling standard a nominal value of 100 mH, which despite not being the key value allows the achievement of a lower uncertainty; a key measurement frequency is 1 kHz. Dr Kaneko reminded the attendees of the difficulties which had occurred during the customs clearance of such travelling standards within the APMP. Dr Callegaro commented that there are possible problems with instabilities of General Radio-like toroidal inductance standards in high-humidity environments. Delegates from the PTB, NIST, NPL, VSL, NMIA, NRC, UME and NMISA expressed an interest in participating in the comparison. The Chairman proposed that the start of the circulation of the travelling standard should be scheduled for 2018.

4. REVIEW OF ONGOING BIPM COMPARISONS (M. STOCK)

Dr Stock presented working document WGLF/15-12, slides detailing the ongoing comparisons involving the BIPM; summarized as follows:

BIPM.EM-K10.b	10 V Josephson comparison; about two per year. Planned for 2015: DMDM, NIMT.
BIPM.EM-K10.a	1.018 V Josephson comparison.
BIPM.EM-K11	1.018, 10 V bilateral comparison with Zeners as transfer standards; 2-3 per year. Considered also as a preparation for a Josephson comparison. Ongoing and planned for 2015: NIS, SMD, NIMT, JV, NSAI.
BIPM.EM-K13.a/b	(1 ohm, 10 kohm): about two per year. Planned for 2015: NIMT, CMI.
BIPM.EM-K12	quantum Hall resistance comparison. 15 new comparisons are expected (Planned for 2015: VSL, INMETRO). For the 1 ohm resistor used in this comparison, a frequency dependence at very low frequency (down to 3 mHz) has been observed.
BIPM-K14.a/b	10 pF and 100 pF bilateral. Planned for 2015: NMISA.
EURAMET-S31	10 pF and 100 pF. First circulation (2010-2011) showed lack of consistency in the comparison results among the participants. Circulation of ac-dc resistors

eliminated this as a possible cause of errors. A second circulation has started with NMIA as a new participant with a calculable capacitor.

Dr Stock continued the presentation by showing slides on the number of calibrations performed by the BIPM: about 2 per year for solid-state Zener dc voltage standards, about 25-30 per year for dc resistance standards and capacitance standards. In 2015, the BIPM will undergo an external audit of the CMC claims for dc voltage, dc resistance, and capacitance.

Dr Stock summarized the BIPM 2016-2019 work programme, highlighting the new activities in preparation for future on-site Josephson ac voltage comparisons, on-site quantum Hall resistance comparisons, and the organization of the incoming CCEM-K4.201X comparison on capacitance.

Dr Rietveld noted that the usefulness of resistance comparisons at 1 Ω level as part of BIPM.EM-K12, given the relatively poor performance of travelling standard, is of little interest and might be considered obsolete.

5. REVIEW OF CURRENT AND RECENTLY COMPLETED RMO COMPARISONS – SUMMARY OF IMPORTANT ASPECTS AND CONCLUSIONS (RMO TCEM CHAIRS)

EURAMET

Dr Piquemal gave a presentation on the comparisons performed within EURAMET. See working document WGLF-15/04; a short summary is given here:

- Completed comparisons: No key comparisons, four supplementary comparisons (S24, S27, S32, S39);
- Ongoing comparisons: two key comparisons (K12, K10b), ten supplementary comparisons (S31, S33, S34, S35, S36, S37, S38, S40, S41, MS2);
- New comparisons: three (K5, lightning impulse, S parameters in 1.85 mm coax)

Dr Piquemal announced the TC-EM SC-Power and Energy experts meeting to be held at SP, Borås, Sweden, 19-20 May 2015; the subsequent TC-EM SC-Low Frequency experts meeting at SP, Borås, Sweden, 21-22 May 2015; and the TC-EM DC and Quantum Metrology experts meeting at METAS, Bern, Switzerland, 27-29 May 2015.

APMP

Dr Kaneko presented working document WGLF/15-06, which gave details of the comparisons performed within APMP. A short summary is given here:

- Completed comparisons (report published or accepted for publication): two key comparisons (APMP.EM.BIPM-K11.4, K3.F), three supplementary comparisons (S9, S13, S14);
- Comparisons with completed circulation of the standards, report in preparation: five key comparisons (APMP.EM.BIPM-K11.3, APMP.EM.BIPM-K11.5, K2, RF-K8.CL, K5.1), one supplementary comparison (S21.F)

- Comparisons with measurements ongoing: one key comparison (K12), four supplementary comparisons (S8, RF-S5.CL, S12, S6.CL)
- Approved comparisons (protocol and schedule in preparation): S15, K3/S10
- Comparisons being planned: three key comparisons and one supplementary comparison (K1.1, K8, K1.a, S15)
- One pilot study on 100 ohm resistance standards.

Dr Kaneko informed the meeting about the last APMP TCEM Meeting held in the Republic of Korea in September 2014 and the APMP training activity: PTB-APMP-APLMF training project in 2014, the APMP-TCEM DEC training workshop. A list of planned meetings was given.

Dr Kaneko informed the meeting about the ongoing activity to reduce the number of CMC entries by using more matrices, by which a reduction percentage of 58 % was achieved in the latest APMP CMC update.

The new APMP TCEM Chairman is Dr Murray Early, MSL.

COOMET

Dr Katkov presented working document WGLF/15-07, which highlighted the comparisons performed within COOMET. A short summary is given here:

The total number of comparisons is 33:

- Eleven proposed, of which one key comparison (K6.a) and 10 supplementary comparisons (S15, S13, S16, S10, S9, RF-S1 + four not yet labelled);
- Five agreed, all supplementary comparisons (S8, S7, S6 + two not yet labelled);
- One planned, supplementary (S14);
- Four completed in 2012-2014 (BIPM-K11, EM-S11 + two not labelled);
- Three under reporting, of which one key comparison (BIPM-K10.b) and two supplementary (S2, S4).

SIM

Dr Di Lillo presented working document WGLF-15/08, detailing the comparisons performed within SIM. A short summary is given here:

- Four completed key comparisons (K4, K6.1, K9.1, K5);
- Five completed supplementary comparisons (S3, S4, S5, S9.b, S10);
- Four ongoing key comparisons (K12, K5b.CL, K3, K4.1);
- Three ongoing supplementary comparisons (S4.1, S7, S8);
- Three new supplementary comparisons (S11, S12, + one not yet labelled);
- One new key comparison (K13).

Dr Di Lillo reported on the SIM technical meetings and the training and development events that occurred in 2013 and 2014, and the CMC review process within SIM.

AFRIMETS

Dr Golovins presented document WGLF/15-05, which showed the comparisons planned within AFRIMETS. AFRIMETS has not yet completed or is running any comparisons; 3 supplementary comparisons are planned (S1, S2, S3).

Dr Golovins reported on the DC Volt and Resistance Workshop that was held in Addis Ababa, Ethiopia, on 16-17 June 2014.

6. CCEM STRATEGY

Dr Piquemal presented working document WGLF/15-11, entitled “*Metrology for nanoscale measurements*”. He remarked that a Proposed Research Topic (PRT) having the same title will be submitted to the European Metrology Programme for Research and Innovation. Dr Kaneko commented that the NMIJ is running a project about the measurement of contact resistance in microsystems.

7. DISCUSSION ON EURAMET PROPOSAL FOR CMCS IN CATEGORY 8 (HIGH VOLTAGE / HIGH CURRENT) AND CATEGORY 9.3 (CURRENT AND VOLTAGE WAVEFORM)

Dr Hällström (MIKES) joined the meeting temporarily via a remote connection.

The Chairman introduced the discussion by presenting the working document WGLF/15-03 (Excel file), which deals with the CMC classification for Categories 8 and 9. See also WGLF/15-03b, which includes some additional proposals from APMP, concerning service category 11.5, antenna properties. The Chairman described the connection between each numerical label and the corresponding search keys of the BIPM CMC database. The Chairman summarized the discussion within the WGRMO meeting in the morning.

Dr Rietveld noted that the present wording of the service descriptions in Cat. 8 is not aligned with the language employed by customers. He noted that 8.1 deals with “sources” that are not technically distinguishable from “meters” since a HV source always includes a meter acting on the source output with a servo loop. He also pointed out that the classification of Cat. 9.3 is not complete, since there is no equivalent of 9.3.1 for voltage harmonics. He further noted that the impact for a change in the classification can be quantified by the number of laboratories that have declared CMCs in the corresponding sub-categories affected by the change, indicated in column M of working document WGLF/15-03.

Dr Hällström commented that the new wording proposed is aligned with IEC standards.

Dr Thomas warned about the significant impact of any renumbering of the classification and strongly discouraged it if the goal of the change can also be achieved by keeping the present connection between numerical labels and sub-categories' content. In any case, some sub-categories can be suppressed but the numerical label should not be reemployed for new sub-categories.

Dr Budovsky summarized the WGRMO discussion outcome: for Cat. 8, to instate a working group to propose a new wording of the sub-categories, without changing the content (therefore, no direct involvement of the NMIs would be needed); for Cat 9, propose necessary changes, but since any change would have much more impact, leave them for a global revision of the classification in the future.

Dr Siegner proposed to limit the terms of reference of the task group to a simple rewording of the classification. Dr Rietveld proposed that the task group should be asked about a document on the impact of a change in the content of Cat. 9.

Dr Rietveld proposed a task group including as members Dr Hällström, Dr Bergman, Dr Yi Li (NMIA), Dr Istrate, and Dr Picard.

Dr Hällström asked whether the changes can be performed in the context of the next CMC review. Dr Budovsky noted that this is not possible because there can be only a single classification at a given time for the CMC set of all Regions.

8. ANY OTHER BUSINESS

There were no requests for further discussion topics from the delegates.

9. AVAILABILITY OF WGLF DOCUMENTS FOR PUBLIC RATHER THAN RESTRICTED VIEW

Dr Budovsky asked that the documents related to point 7 (High-voltage classification) should not be made public because a conclusion had not been reached.

10. DATE OF THE NEXT MEETING

An informal meeting of the working group will take place as a satellite meeting of the Conference on Precision Electromagnetic Measurements (CPEM) to be held in Ottawa, Canada, in July 2016.

The Chairman closed the meeting at 18:00 on 11 March 2015.