

## Consultative Committee for Electricity and Magnetism (CCEM)

President: Dr.ir Gerrit Rietveld

Executive Secretary: Dr Michael Stock

### 1. Executive summary

The [Consultative Committee for Electricity and Magnetism](#) covers a very broad field of metrology which is based on a large number of measurement standards, realizing many derived units and ratios over a wide frequency range. Since the 25<sup>th</sup> CGPM, significant steps have been taken to increase the impact and the efficiency of the CIPM MRA in the EM area, most notably via more strategic planning of comparisons, full implementation of matrices in the presentation of CMCs, and the introduction of a more efficient CMC review process. The BIPM has provided continued support to the worldwide comparability of EM measurements amongst others via its ongoing key comparison programme.

Based on the outcomes of the 2017 CCEM workshop on [“Future Challenges in Electrical Metrology”](#), a first discussion was held on revision of the existing CCEM strategy, setting new priorities for the future. At the next CCEM meeting in March 2019 a new CCEM strategy, based on the workshop outcomes, will be discussed.

Major scientific efforts in the past four years were devoted to progressing electrical methods to realize the kilogram, in preparation of the proposed revision of the SI. A draft [mise en pratique](#) has been developed for the base SI electrical unit, the ampere, and for derived electrical units in the revised SI. Since the introduction of the revised SI will introduce a small step change in voltage and resistance measurements and related derived quantities, [CCEM Guidelines for Implementation of the ‘Revised SI’](#) have been prepared to support the electrical stakeholder community in handling this step change.

### 2. Scope of the CCEM

The CCEM is responsible for advising the International Committee for Weights and Measures (CIPM) on all matters related to measurement standards for electricity and magnetism, including the EM work programme activities of the BIPM Physical Metrology Department.

The application of electricity is ubiquitous in daily life and electrical metrology covers a broad field involving many quantities and requiring many derived standards. Typical examples are voltage, current, resistance, capacitance, inductance, power, transformer ratio, ac-dc transfer, electrical field strength, magnetic field strength, antenna factors and radiofrequency scattering parameters. In many cases, the quantities span both a very wide range of values (for example nanovolts to megavolts) and frequencies (ranging from dc far into the radiofrequency range), with different techniques required for different ranges.

Due to the vastly different technologies required in the low frequency and the radiofrequency ranges, the detailed technical work of the CCEM is undertaken by two CCEM Working Groups: the low-frequency and the radiofrequency working groups (WGLF and GT-RF respectively).

### 3. Strategy

The present [CCEM strategy document](#) was developed in 2013 and focuses on two main components: future technical challenges in electromagnetism and the need for future key comparisons. As start of the CCEM strategy review, a workshop was held on 23 March 2017 on “Future Challenges in Electrical Metrology”. The workshop covered the following major themes and challenges (some [presentations](#) available on the CCEM web pages):

- Quantum technology;
- NMI on a chip;
- Nanomagnetism and spintronics;
- Electrical measurements for micro / nanoelectronic devices;
- High-frequency electromagnetic metrology (RF to terahertz);
- Electrical power and smart grids.

Following the workshop, the [CCEM strategy summary](#) has been updated to reflect the workshop outcomes. An important part of the CCEM strategy is to further improve the efficiency and effectiveness of the CIPM MRA via strategic planning of KCs, by optimising CMC reviews, and implementing further recommendations of the CIPM MRA review work group. The full CC strategy is presently under review and will be discussed during the next CCEM meeting on 28-29 March 2019.

### 4. Activities and achievements since the last meeting of the CGPM

#### 4.1. Main activities / services / projects

Two CCEM meetings were held during the period 2015-2018, one on 12-13 March 2015 and one on 22-24 March 2017. The [meeting reports](#) and the majority of the [presentations/working documents](#) are publicly available on the CCEM webpages.

At the 2015 and 2017 CCEM meetings, major attention was paid to matters related to fundamental constants and the revision of the SI. The CCEM WG on “electrical methods to monitor the stability of the kilogram” presented the worldwide state-of-the-art in watt balances and their measurement results for the Planck constant  $h$ . This WG furthermore organized regular meetings of scientists working on watt balance experiments, to which representatives of the Avogadro community are invited, for in-depth discussions of technical matters between the scientists working on these experiments. The CCEM strongly supported the proposed renaming of ‘watt balances’ to ‘Kibble balances’, in honour of the late dr Brian Kibble for his invention of this crucial instrument in coming towards a revision of the SI.

Dr. J. Pratt, NIST, presented and demonstrated the [NIST Lego table top Kibble balance](#) to the CCEM community at the 2015 CCEM meeting. Following this presentation, many copies have been made by CCEM members for demonstrating the Kibble balance operation principle and the essence of the revised SI to the general public and wider CCEM stakeholder community.

The CCEM WG on “proposed modifications to the SI” drafted two important documents. First of all, a draft [mise en pratique](#) was developed for the base SI electrical unit, the ampere, and for derived electrical units in the revised SI. Secondly, since the introduction of the revised SI will introduce a small step change in voltage and resistance measurements and related derived

quantities, [CCEM Guidelines for Implementation of the 'Revised SI'](#) have been prepared to support the electrical stakeholder community in handling this step change. The documents were discussed at the CCEM meetings, and their final versions were approved by the CCEM members for publication.

Other CCEM meeting discussions on the revised SI concerned updates from the CCU work towards the revision of the SI, most notably updates of the 9<sup>th</sup> edition of the “[SI brochure](#)” (including the new definition of the ampere), and reports from the CODATA task group on fundamental constants.

Important further discussions of the CCEM meetings concerned progress updates of the three other CCEM working groups, reports of the work programme of the BIPM electricity laboratories, review of the CCEM strategy (see section 3), and improvement of the efficiency of the CIPM MRA.

In 2013, the CCEM had the largest number of CMC entries (about 7100) in the BIPM key comparison database (KCDB), reflecting the broad field covered by electromagnetic metrology. However, stimulated by the CCEM WGRMO, in the subsequent five years NMIs have consistently introduced matrices in the presentation of their CMCs, reducing the [number of CMC entries in the EM area](#) by almost 40 % to less than 4400 in November 2018. This has resulted to a significant decrease in the maintenance efforts of the CCEM CMCs, at the same time providing better CMC overviews to the users of the [KCDB](#) containing these CMCs.

In the same period, the CCEM WGRMO has optimised the CMC review process. Still, all EM CMCs are reviewed within the RMO (the intra-RMO review). The inter-RMO review, however, is significantly optimised: instead of having *all* other RMOs review the *complete* CMCs of a certain RMO, the review of these CMCs is now divided over the RMOs. Some relatively straightforward CMCs may even not be selected by the WGRMO chair for inter-RMO review. The rigidity of the inter-RMO review process is still guaranteed, as any RMO is free to review any CMC not assigned to them by the WGRMO chair for review.

Since the 25<sup>th</sup> CGPM, the CCEM has approved three CCEM key comparisons and 10 RMO key comparisons. It has reviewed 15 RMO supplementary comparisons. The BIPM Electricity Department has carried out 26 bilateral comparisons during this time.

The first round of key comparisons in electricity and magnetism is complete and a comparison plan for a second round has been carefully set up. In the field of low frequency measurements, the existing list of key comparisons is considered to be appropriate (with some minor modification of parameters) and it was decided that the comparisons should be repeated during the next ten years. In the field of radiofrequency measurements it is not generally possible to repeat all comparisons, since the resources are limited and the number of quantities is very large. A higher priority has been assigned to comparisons in frequency bands that have not yet been covered. For both fields, lists of future comparisons have been established, ranging until 2022. The first new comparisons have started.

One of these comparisons is CCEM-K4 on capacitance. Here, a new comparison scheme has been trialled, where all participating NMIs have sent their travelling standards to the BIPM for measurement. This ‘star scheme’ has resulted in a very effective performance of the comparison:

the total time from comparison start to the final agreed comparison report is less than two years – a record in the EM area. This result would not have been possible without the commitment made by the BIPM to carry out all the measurements as well as to coordinate the logistics.

The existing CCEM policy to maintain a strong science focus in its meetings has been strengthened: speakers were invited to make presentations on new developments in electrical metrology. Dr. F. Schopfer (LNE) presented ‘Advances in user-friendly quantum Hall resistance standards based on graphene’, dr. P. Hale (NIST) gave a presentation on ‘Waveform characterization’, and dr. W. Poirier gave insight in the LNE work on ‘Practical quantum realization of the ampere’. Furthermore a scientific workshop on “Future challenges in Electrical Metrology” with six invited speakers was held on 23 March 2017 (see chapter 3 of this report). It was decided to again have a similar scientific workshop at the next CCEM meeting in 2019.

SCL (Hong Kong) and NIS (Egypt) became a CCEM Observer in 2015 and 2017 respectively, and CENAM (Mexico) became a CCEM Member in 2015.

#### 4.2. Challenges and difficulties

The CCEM needs to adequately respond to new metrology challenges in the EM area. To this end, the CCEM strategy will be revised and updated to identify these challenges. Furthermore, scientific workshops will be held to provide better insight in these challenges and to come to a joint effective approach in meeting them.

The efficient performance of key comparisons remains a challenge to the EM community. Following the success of the CCEM-K4 comparison, it will be examined whether a similar ‘star scheme’ can also be used for other comparisons. This will very much depend on the availability of suitable travelling standards, as well as a coordinator that is willing to be the central laboratory in the star scheme, performing the vast majority of the measurements.

The effective implementation of the CIPM MRA will continue to require attention in the coming years. Presently a review of the CMC categories in the high-voltage area is underway to match these better with the state-of-the-art in the field and present industry practice. The CMC review process has been significantly improved but may require further fine tuning. The implementation of the KCDB2.0 in the year following the 26<sup>th</sup> CGPM will be a major step forward for the CCEM, but will require significant attention as well ensuring a smooth transition from the ‘old’ to the ‘new’ KCDB.

#### 5. Outlook in the short and long term

The envisaged approval of the revised SI by the 26<sup>th</sup> CGPM is expected to give an impulse to the development of quantum standards as they now become the direct realisations of the SI units. The trend in these developments is for simple, table-top systems that are easy to use, also by industrial stakeholders. Additionally, the potential development of a true quantum current standard opens up exciting new possibilities for realization of the SI; the progress in this area has already been very significant in the past four years. The proliferation of quantum standards will further increase the relevance of the BIPM bilateral on-site comparisons of DC and AC Josephson voltage standards and quantum Hall resistance standards.

The revised SI will also lead to a need for the development of “routine operation” watt balances, requiring the development of more economical and reliable electrical standards with the lowest possible uncertainties. The need for precision electromagnetic measurements to realize mass, not only at kilogram level but also for smaller masses, will necessarily demand a continuing role for the CCEM.

Two rapidly evolving areas with EM measurement challenges already mentioned in the CCEM report to the 25<sup>th</sup> CGPM are (smart) electricity grids and the radiofrequency and microwave area. They both will require attention to assure an adequate response from the CCEM community. The scientific workshop next to the 31<sup>st</sup> CCEM meeting in 2019 will be devoted to the latter subject with industry and GT-RF experts providing an overview of the most recent developments in the field.

**Annex: CCEM Data**

**CCEM** set up in 1927 (as CCE)

President: G. Rietveld

**Membership:**

List of CCEM members and observers:

Executive Secretary: M. Stock

25 members and 3 observers

[http://www.bipm.org/en/committees/cc/ccem/members\\_cc.html](http://www.bipm.org/en/committees/cc/ccem/members_cc.html)

Meetings since the 25th CGPM meeting:

12-13 March 2015, 22-24 March 2017

Full reports of the CCEM meetings:

<http://www.bipm.org/en/committees/cc/ccem/publications-cc.html>

Five Working Groups:

RMO Coordination (WGRMO)

Low-Frequency Quantities (WGLF)

Radiofrequency Quantities (GT-RF)

Proposed Modification to the SI (WGSI)

Electrical Methods to Monitor the

Stability of the Kilogram (WGKG)

[http://www.bipm.org/en/committees/cc/ccem/working\\_groups.html](http://www.bipm.org/en/committees/cc/ccem/working_groups.html)

<b>CCEM Comparison activity</b>	<b>Completed</b>	<b>In progress</b>	<b>Planned</b>
CCEM key comparisons (and supplementary comparisons)	48 (incl. 18 approved for provisional equivalence, before 1999)	6	20
BIPM comparisons	1	9 (ongoing)	9 (ongoing)
CCEM pilot studies	0	1	2
CMCs	4374 CMCs in 194 service categories registered in the KCDB		