CCEM

Electricity and Magnetism Supplementary Guide for the Submission of CMCs

Version 6.2 (October 2022)

1. Scope

This Supplementary Guide reports information on how to formulate Calibration and Measurement Capabilities (CMCs) in the field of Electricity and Magnetism (EM) for publication in the KCDB 2.0. The Guide is intended to be used worldwide, but makes provision for specific requirements of each Regional Metrology Organization (RMO), particularly concerning the way the information supporting CMCs is gathered and the detailed CMC intra-regional review process.

For general information related to the CMC review process, acceptance criteria, support by key and supplementary comparisons etc. the reader is addressed to CIPM MRA-G13 and the complete set of CIPM documents, downloadable from the web at: https://www.bipm.org/en/cipm-mra/cipm-mra-documents .

This Guide is addressed to both the NMIs that have not yet submitted any CMCs and the NMIs that would like to add CMCs to their set or modify CMCs already published.

Suggestions about presentation of specific quantities in CMC entries are given in Appendix 1. A list of questions and answers and of pending problems is given in Appendix 2.

2. Closely related documents

The following documents are cited in this Supplementary Guide and must be used with it. They can all be found on the BIPM web site:

a) CIPM MRA-G-13, *CMCs in the context of the CIPM MRA: Guidelines for their review, acceptance and maintenance*
b) Classification of services in electricity and magnetism
c) Getting Started with the KCDB restricted web portal

3. Modification of CMCs already in the KCDB

Following the document CIPM MRA-G-13 *CMCs in the context of the CIPM MRA*, modified CMCs fall into four categories:

a) CMCs corrected for material or editorial errors or for improving the explanatory text; these CMCs do not require a new review, but changes need to be confirmed by the local RMO TC/WG Chair.

b) CMCs modified to increase the uncertainty or to reduce the scope; also these CMCs do not require a new review. Also in this case, changes need to be confirmed by the local RMO TC/WG Chair.

c) In case that the change was originated by a comparison result, the TC chairperson should verify that the reduction in scope or the increase of the uncertainty is

sufficient to assure the equivalence of the measurements. It is desirable in this case that the relevant RMO (or the BIPM) informs the other RMOs of the changes and their motivation.

d) CMCs modified to change the method of measurement or to reduce the uncertainty or to increase the scope; these CMCs require a full new review as if they were new CMCs. The update can be done by "clicking" in the right column in "Institute CMCs".

For CMCs of categories a), b) and c), modifications must be made on the KCDB 2.0 website. After logging in with his/her username and password, the writer can update (modify) the CMCs. By clicking in the column far right, the update function can be triggered. The CMC form will open; the update can be made. When saving the updated CMC it will be marked as modified, "**M**", in the CMC table. When updating a CMC, the items that have been updated should be indicated in "Comments for review".

4. Submission of new CMCs

New CMCs should be uploaded into the KCDB site. Each NMI´s writer has to log in into the KCDB site, go to "CMCs", "My CMCs" and then "Create CMC". A menu will be deployed and the writer has to choose the Metrology area and fill in the form. More information can be found in Getting_started_KCDB_platform.pdf .

If an NMI declares CMCs for the first time, it has to fill in the form that can be found in the KCDB 2.0 website.

Another option is to download an Excel template, fill in this file and then upload all the information to the KCDB. KCDB staff encourage writers not to use this tool.

5. Intra-RMO review process

The intra-RMO review has been designed to mirror the JCRB (also known as inter-RMO) review. The CMC may be revised an unlimited number of times. Set date limits are not programmed and are hence, in respect to the software, not fixed. A CMC is drafted by the Writer and submitted to the TC Chair for intra-RMO review. The TC Chair may accept, or not accept, the CMC, or ask the writer for a revision. The TC Chair may also consult reviewers within the same RMO.

Writer, Reviewer and TC Chair may add comments to each CMC during the intra-RMO review process. When the CMC has been accepted by the RMO, it can be submitted for the JCRB review. The TC Chair has the possibility to add additional documents for the submission, such as the mandatory QMS support documentation. A flow diagram of the intra-regional review process is available in Appendix B of CIPM MRA-G-13.

6. JCRB review

The general interregional review process is described in CIPM MRA-G-13.

The following describes the principles of the process followed by the CCEM in addition to the general process. The steps involved in the review process are described in the following section.

- RMOs are required by the CIPM MRA to cooperate in reviewing submitted CMCs. It is not necessary that all RMOs review the same CMC set. RMOs (through the chair of CCEM WGRMO and TC-Chairs) may communicate with each other to divide responsibility or to decide who will participate in the JCRB review. However, it is important that the process works in a way that ensures the confidence in the approved CMCs.
- In 2015 the CCEM agreed to further improve the efficiency of the CMC review through selective sampling of the entries to be reviewed. A proposal for the scope of the inter-RMO review is made by the chair of WGRMO, based on the magnitude of change, history of previous reviews, coverage by on-site technical review, rotation and high-level technical judgement. However, the final decision on the scope of the review lies within the RMOs.
- The review should be restricted to new and improved services, with either reduced uncertainty or wider scope.
- Technical peer review reports should be included in the CMC submission, when available, and the information be used by the reviewers.
- A new CMC set should only be submitted by an RMO if the JCRB review process for the previously submitted batch is completed.
- The CCEM uses shorter deadlines as the standard JCRB procedure. The enforcement of these shorter deadlines needs to be made by the chair of WGRMO, because the KCDB 2.0 sends reminders after the - longer - deadlines specified in the document CIPM MRA-G-13.

The different steps involved in the JCRB review process are the following (*in italics: specific CCEM rules*, in roman: general JCRB rules)

- The RMO TCEM Chair submits the CMC set for JCRB review.
- Automatic e-mails informing about the submission are sent to relevant persons: RMO representatives, RMO TCEM chairs.
- *A proposal for the scope of the JCRB review, based on selective sampling, is made by the chair of WGRMO to the RMO TCEM Chairs, based on the magnitude of change, history of previous reviews, coverage by on-site technical review, rotation and high-level technical judgement.*
  The WGRMO Chair makes a recommendation about which RMO should make the review of each of the CMCs selected for review. This is ONLY a recommendation and the final decision on the scope of the review lies within the RMOs. This recommendation can be seen in the KCDB website and each RMO can show its interest by accepting to make the review.

- The TC Chairs should first indicate the intention to review, or not to review a CMC. The TC Chairs shall then indicate the date for review. The TC Chairs may approve the CMC or ask the writer for revision. The TC Chairs may also consult reviewers within their own RMO. The reviewer and TC Chair may add comments to each CMC during the JCRB review process. If the CMC is approved by all reviewing RMOs, it is automatically transmitted to the KCDB Office for publication and will not be submitted to a vote. If at least one of the reviewing RMOs asks for a revision, the CMC is made available to the Writer for revision, as soon as all reviewing RMOs

have indicated their standpoint, or at latest when the time limit for review has passed. The revised CMC is returned to the TC Chair of the originating RMO who will submit the CMC for vote. Unanimous approval will enable the KCDB Office to publish the CMC.

- If a TC/WG Chair needs to change the date specified for sending their first comments he/she should make the change through the KCDB website before the original deadline has expired. Note, however, the JCRB Executive Secretary constantly monitors the review status and repeated or unduly long extensions may cause some questions and need discussion with the originating RMO.
- *If a reviewer requires additional information to make a decision on the submitted CMC, he/she should contact the submitting NMI within three weeks after the start of the review or write his/her request in the "Add comments" section at the end of the CMC.*
- *A maximum of three weeks is allowed for the first response of the submitting NMI to the request of the reviewer.*
- Following the re-submission of the revised CMCs by the submitting RMO TC-Chair, the RMOs TC/WG Chairs now have three weeks for considering the final vote. Two weeks after the final submission, a reminder e-mail will be sent and after one further week the RMO loses its right to vote and is considered an abstention. The final approval is done on a consensus basis. All the RMOs should approve or abstain to vote, but a single vote against is enough for not approving the CMCs. A flow diagram of the JCRB review process is available in Appendix C of CIPM MRA-G-13

7. General guidance on the formulation of CMCs

7.1 Each CMC must correspond to only one classified service category and to only one measurand: for example electrical power and energy, even if in the same category, are different measurands and should be reported in different CMC declarations .

7.2 Whenever possible, CMCs corresponding to different values of the same quantity shall be grouped together in a matrix. If the uncertainty depends on two variables (like the range of the measurand and the range of the parameter) matrices shall also be used (see section 12).

7.3 Each CMC declaration should be self- consistent, without reference to other services , because each CMC will be usually displayed alone by the database.

NOTE 1. For some quantities (power and energy, AC-DC transfer, voltage and current ratios, RF calibration factor, RF reflection coefficient and RF scattering parameters) recommendations for a uniform presentation are reported in Appendix 1.

8. Language and Symbols

The following rules complement those in CIPM MRA-G-13:

- as units for angle use the symbols °,','' or rad; do not use: deg, min, sec, nor degree, minute, second, nor arc-second;

- use accepted SI prefixes for decimal multiples and sub-multiples; they must be written close to the symbol of the unit of measurement, in the appropriate columns, and not close to the numerical values;
- when reporting a list of items in the same cell use the comma (,) as the separation character [e.g.: DC voltmeter, multimeter, multifunction transfer standard];
- use a colon (:) to introduce a specification of a previous text-item of information [e.g.: reflection coefficient on coaxial: phase]

9. Electricity and Magnetism Classification scheme

9.1 The *Classification of Electricity and Magnetism CMCs*, approved by the CCEM, provides the NMIs with uniform and world-wide agreed terminology for the classification of their services. These are divided in major headings, sub-headings and categories. For each category, characterized by a 3-number classification, a list of instruments/artefacts is given.

9.2 CMCs can only be submitted for services listed on the approved classification of EM services.

9.3 The most recent approved classification of EM services is available from the BIPM web site.

10. Creation of a CMC

The procedure to create CMC can be found at https://www.bipm.org/en/cipm-mra/kcdb-help .

11. Use of Matrices

Where possible, the use of matrices is mandatory. If the quantity has different values, the matrix has only one dimension, corresponding to the range of values. When the quantity depends on two variables, (usually the range and a parameter), it should be presented in a two-dimensional matrix. This technique will reduce the number of lines in the table and will improve presentation.

Matrices should be used, for example when for one service category, several values can be included. For example, service category 5.1 “AC/DC voltage transfer (for frequencies higher than 1 MHz see 11.7.1)” is split in three sub-sub-categories:

a) AC/DC transfer difference at low voltages (typically below or equal to 0.5 V):
b) AC/DC transfer difference at medium voltages (typically above 0.5 V to 5 V)
c) AC/DC transfer difference at higher voltages (typically above 5 V)

When this happens, instead of having three different lines for each sub-category, a matrix with all the AC/DC values (in voltage and frequency) has to be used. Figure 1 shows how these values should be reported.

Voltage	10 Hz to 30 Hz	> 30 Hz to 50 kHz	> 50 kHz to 100 kHz	> 100 kHz to 300 kHz	> 300 kHz to 1 MHz
1 mV to 10 mV	30	25	35	50	100
> 10 mV to 60 mV	12	12	25	40	75
> 60 mV to 300 mV	4	2	4	5	10
> 300 mV to 20 V	2	1	4	5	9
> 20 V to 100 V	4	5	8	-	-
> 100 V to 1000 V	5	6	12	-	-

Figure 1: AC/DC uncertainty matrix. The expended uncertainties given in this table are expressed in µV/V.

It is recommended to use ranges for the measurand and the parameter instead of fixed values to avoid ambiguities for values in-between the tabulated fixed values. It is also recommended to avoid overlapping ranges by using the '<' or '>' signs, as in the example above.

Another example is category 7.1.1 "ac power and energy at single phase (frequencies below or equal to 400 Hz)". In this case there are several parameters to take into account like voltage, current and power factor. Figure 2 shows how these values should be reported.

Voltage	Current	cos φ	Uncertainty/ (µW/(V A))
60 V to 120 V	0.1 A to 0.5 A	0.1 ≤ cos φ ≤1	75
120 V to 240 V	0.1 A to 0.5 A	0.1 ≤ cos φ ≤1	90
60 V to 240 V	0.5 A to 10 A	0.1 ≤ cos φ < 1	32
60 V to 240 V	0.5 A to 10 A	cos φ =1	25
60 V to 240 V	0.5 A to 10 A	0.1 ≤ cos φ < 1	32
60 V to 240 V	10 A to 50 A	0.1 ≤ cos φ ≤1	100
60 V to 120 V	50 A to 100 A	0.1 ≤ cos φ ≤1	75
120 V to 240 V	50 A to 100 A	0.1 ≤ cos φ ≤1	130

Figure 2: Single phase power and energy matrix. This example could be improved by avoiding the common endpoints of the voltage ranges by using the '<' or '>' signs as in figure 1.

In the case of several parameters, one of them can also be displayed on the horizontal axis. Figure 3 shows as an example table with S-parameters where the connector type and the measurand are the two leasing columns and the frequency is displayed in the horizontal direction.

Connector	abs(Syx)	9 kHz to 3 GHz	3 GHz to 12 GHz	12 GHz to 18 GHz	18 GHz to 20 GHz	20 GHz t
BNC 50 Ohm	0 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-3 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-6 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-10 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-20 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-30 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-40 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-50 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-60 dB	0.03 dB to 0.05 dB	-	-	-	
BNC 50 Ohm	-70 dB	0.04 dB to 0.06 dB	-	-	-	
BNC 50 Ohm	-80 dB	0.10 dB	-	-	-	
Type-N 75 Ohm	0 dB	0.01 dB	0.01 dB to 0.02 dB	0.02 dB	-	
Type-N 75 Ohm	-3 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-6 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-10 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-20 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-30 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-40 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	
Type-N 75 Ohm	-50 dB	0.02 dB	0.02 dB	0.02 dB to 0.03 dB	-	

Figure 3: CMCs for S-parameters. The connector type and the measurand are shown in the two first columns the parameter frequency is displayed horizontally.

Appendix 1
Presentation of some CMCs in Electricity and Magnetism

In the following some suggestions are given in order to harmonise the presentation of CMCs concerning particular quantities.

a) DC and AC Divider Ratios. Divider ratios will be presented as output/input, so that ratio values will usually be lower than 1.

b) LF Electrical Power and Energy. The following points should be considered:

- the unit of measurement must be in agreement with the type of power (W for active, var for reactive, VA for apparent), which suggests to have one separate entry for each type;
- the relative uncertainty is usually referred to the apparent power so that units like mW/VA (for active power) should be used;
- in the parameter, the ranges for voltage, current, active or reactive power factor (with indication if inductive or capacitive) and frequency must be reported;
- for energy, the minimum and maximum measuring times must be reported;
- for three-phase power, it is usual to report the range values per phase: for clarity the information that the given range is "per phase" is to be specified in the user comment .

c) AC-DC (voltage or current) transfer difference. In range, voltage or current values must be reported and not values for the transfer difference. This approach is suggested also for HF AC-DC transfer difference. The uncertainty is generally given as relative to the voltage or current values.

d) AC-DC voltage transfer category boundaries
It is suggested to use 0.5 V and 5 V as the boundaries for the low, medium and higher voltage categories.

e) AC high voltage and current transformers

For these CMCs it is proposed to always report the ratio error for the real part (or modulus) of the ratio and the phase displacement (in rad or better in mrad) for the argument. The primary and the secondary voltage or current should be reported as parameters. This format is in accordance with the corresponding IEC standards for instrument transformers.

f) RF calibration factor

NMIs should report in *measurand level and range* the maximum and minimum power levels. g)

RF categories 11.2 (reflection coefficient and attenuation) and 11.3 (scattering parameters)

The first distinction between categories 11.2 and 11.3 is the type of measuring equipment used. If it only measures the magnitude of the quantity involved (and does not give any phase information) then the CMC line belongs under category 11.2, otherwise under 11.3.
For category 11.3.1 and 11.3.2, reflection coefficient is usually reported in linear terms. For categories 11.3.3 and 11.3.4, transmission/attenuation, values are often reported in dB, which is familiar to the customer. But from a physical point of view, a presentation as a complex value in linear terms should be preferred. The Euromet HF experts have agreed to use the latter format: the exact format is not yet fixed. In case of a linear presentation, information about the dB-range concerned may be given in column U (comments for the user).

h) Presentation of related quantities (complex quantities).

Real and imaginary parts of complex quantities belong to the same classification category.

Appendix 2
Answers to question and problems

Problem. If an NMI can offer the calibration of certain instruments and standards at two different levels of uncertainty, for example using a more refined (but time consuming) and a more straightforward method, can both services be submitted as two different CMCs?
Comment. In principle a CMC should correspond to the best capability of the NMI, but some CMC users, for example the secondary laboratories, would like to have all the NMI services they use listed in the database. Then the answer could be: propose as CMCs also lower level services if they employ different methods of measurement and are used to transfer traceability to secondary laboratories.

Problem. What is the meaning of "Source of traceability"?
Comment. In general it is the laboratory performing the first step of the traceability chain that ends at the corresponding standard reported in column N. But for complex traceability chains it is often the laboratory performing the last part of the chain. An example is the case of resistance scaling, where laboratories that obtain traceability from the BIPM in the range 1 Ω to 10 kΩ, report traceability to themselves for higher resistance ranges, where they use their own measurement procedures to extend the traceability given by the BIPM.

Problem. Is it possible for the same reported standard to report, as sources of traceability two different NMIs?
Comment. The only case when this can be accepted is when a CMC covers a wide range of values and traceability is different in different parts of this range. Otherwise traceability must be to only one laboratory. Of course, if this is metrologically correct, it does not take into account that, for example, commercial reasons could lead to change the NMI providing traceability. On the other side it is believed that the choice of an NMI as traceability provider is a medium or long term decision: for example, within EURAMET it is usual to register traceability agreements as EURAMET projects

Problem. It may happen that an NMI asks to reduce its uncertainty during the review process.
Answer. This situation does not give any problem, if the reviewer has enough supporting evidence for the new
uncertainty. When the review process is finished, the CMC uncertainties should not be reduced any more, if not as a consequence of a new review (see CIPM MRA-D-04 on how to modify existing CMCs).

Problem. Is it possible to present an uncertainty dependent only on one variable (e.g. the range of the quantity) with a matrix?
Answer. Yes, this is possible and can be used when it is difficult to express the dependence of the uncertainty on the variables by an variable by an equation.

Problem. Is it possible to use an uncertainty matrix when one of the two variables on which the uncertainty depends is not a physical quantity but, for example, the type of connector, as in some HF measurements?
Answer. Yes. This has indeed been done by an NMI for RF-DC transfer difference.

Problem. Is it possible to use a range declaration for the uncertainty in a cell of an uncertainty matrix?
Answer. No! The cells of an uncertainty matrix should contain only numbers. If mathematical expressions are used in the matrix to obtain the uncertainty values, after calculation these expressions must be substituted by numbers having the right number of significant digits.

Problem. When the uncertainty is given as a range (u_1 to u_2) sometimes it is not clear if it varies linearly with the range of the quantity or with the range of a parameter, or if the variation is not linear at all and the limits are just the extreme values of the uncertainty.
Answer. The general rule says that in case of a range declaration the uncertainty should vary linearly from the lowest to the highest value of the independent variable. Of course this is not relevant if the uncertainty declaration is supported by an uncertainty matrix, where the functional dependence is clearly visible. If there is no matrix, it is suggested to follow
§ 8.4: the dependence on the quantity or on a parameter or on both can be specified with a short text in the same column I; the non linear variation can be explained in column U, comment for the user. But if the dependence is not linear, as there is no way to evaluate the uncertainty in the middle of the range, the total variation of the uncertainty must be limited, or the CMC will become useless.

Problem. For AC-DC transfer measurements, where the quantity is reported as a voltage or as a current (as agreed among the AC-DC experts), the uncertainty given as μV/V or as μA/A is relative or absolute?
Answer. It is relative, because it must be applied to the reported quantity, voltage or current.

Problem. There has been the proposal to report asymmetric limits for the uncertainty in certain cases. Examples are quantities that have physical limits (like a reflection or transmission coefficient, which is always limited between 0 and 1) or quantities given in non linear units.
Answer. Reporting asymmetric uncertainties is quite difficult and not easy to understand on the part of the user. If the approximation introduced by a symmetric declaration is considered not good enough, the range in the CMC line could be adequately reduced and the CMC line split.

Problem. For complex quantities, the form of presentation varies widely. For example, for AC voltage ratio, we have at least three different presentations for the imaginary component: same unit as the real component, as an angle in radian, or as an angle in degrees. For HF transmission and reflections coefficients, in some cases two lines are presented, one for real and one for imaginary, in other cases only one line for both is given. In the last case the two range-columns usually report only one value each (e.g.: -1; 1) but in other cases two values are reported in each column, with vector notation (e.g.: [-1,-1]; [1,1]).
Comment. This matter should be discussed by the LF and HF experts. When an agreement is reached, the solution suggested could be reported in Appendix 1. As it is obviously not possible to describe complex quantities in the different measurement fields in a unique way, the minimum which we should try to reach is to have only one description for one field. To give an example: for AC voltage ratios we should only use either the same description as it is used for the real component or an angle in rad or an angle in degrees. This would be much easier to understand for our customers.

Problem. Different forms of presentation are still given for AC power measurements. For example the range of the power factor is given as: "1 to 0 i/c", "0 ind./cap. to 1", "0 leading to 0 lagging", "0 to 1 inductive or capacitive".
Comment. This matter should be discussed by the LF experts. When an agreement is reached, the solution suggested could be reported in Appendix 1. We should try to agree on one format. This would be much easier to understand for our customers.

Problem. At present there are different ways to report the unit of measurement of the uncertainty in case of quantities without dimension or for relative uncertainty of quantities with dimension.
Comment. A way to unify this could be the following:
Absolute uncertainty for quantities without dimensions: no unit (there should be no unit also in column F).
Relative uncertainty for quantities without dimension: negative power of 10 or % Absolute uncertainty for quantities with dimensions: appropriate unit (Relative uncertainty for quantities with dimension: report the pertinent ratio of submultiples of the considered unit (for example μV/V); but if the unit is a combination of other units, it is better to use a negative power of 10 or %.

History of changes

Version number	Changes
4.2 (4 May 2009)	Note (f) on page 15: For the quantity rf calibration factor, the minimum and maximum power levels shall be stated in the column *measurand level and range* (instead of the calibration factor).
4.3 (6 August 2009)	Clarification in section 1 that changes of CMCs (additions, deletions, modifications) must be made in the Excel file of already existing CMCs.
4.4 (April 2011)	Insertion of chapter 0.6 on the inter-RMO review process, with deadlines and recommendations on how to accelerate the CMC review process. Modification of the answer to question 6 on page 17. It is now allowed to express the dependence of the uncertainty on one single variable by a 1 x n matrix.
5.0 (March 2017)	General update of the document for review by CCEM.
5.2 (April 2018)	New section 7 on interregional review process.
6.0 (February 2021)	for review by CCEM, not published: Bringing the document in line with the procedures of KCDB 2.0
6.2 (October 2022)	Replacement of Figures 1 and 2 with references to CIPM MRA-G-13. Clarification on the use of matrices in section 11