Keywords: calibration, time, frequency, uncertainty, quality system

Abstract

In this paper, a process of preparing and reviewing calibration and measurement capabilities of European time and frequency laboratories is described. Detailed review procedures are described. All major events are given which determined both the timing and content of this international project.

1 Introduction

At a Comité International des Poids et Mesures (CIPM) meeting held in Paris on 14 October 1999, the directors of the national metrology institutes (NMIs) of thirty-eight Member States of the Metre Convention and representatives of two international organizations signed a Mutual Recognition Arrangement (MRA) for national measurement standards and for calibration and measurement certificates issued by NMIs [1]. The MRA was signed to establish the degree of equivalence of national measurement standards, to provide for mutual recognition of calibration and measurement certificates issued by NMIs and to provide governments and other parties with a secure technical foundation for wider commercial agreements.

2 Calibration and measurement capabilities

Implementation of the MRA and thus recognition of national standards and certificates comprises 3 interconnected processes taking place at the NMIs, RMOS and at global level:

- Key Comparisons (KC’s) (currently 408) of national standards serve to test capabilities of NMIs (to determine their degree of equivalence) in various metrological areas
- NMI Calibration and Measurement Capabilities (CMC) are thoroughly reviewed by RMO experts including the coverage by a Quality System based on ISO 17025 standard.
- NMI Quality Systems need to be in place and successfully reviewed by RMO's.

Outcome of this process are statements of CMCs of each NMI quoted in the BIPM key comparison and calibration database (KCDB), which is maintained by BIPM and is available to the public on the BIPM website (www.bipm.fr). Key comparisons and CMCs are grouped under the following fields:

- Acoustics, ultrasound and vibrations,
- Electricity and magnetism,
- Flow,
- Length,
- Mass,
- Metrology in chemistry,
- Photometry and radiometry,
- Ionizing radiation,
- Thermometry and
- Time and frequency.

3 CMCs in the field of time and frequency

In the field of time and frequency, no CMC tables were prepared before year 2001 because there was no key...
<table>
<thead>
<tr>
<th>Units</th>
<th>Time Scale diff.</th>
<th>Rate difference</th>
<th>Frequency diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hz</td>
<td>ns/d, s/s, 10^{-15}</td>
<td>ns/d, 10^{-15}</td>
<td>Hz/Hz, 10^{-15}</td>
</tr>
</tbody>
</table>

Figure 2. From the time scale TAI calculated by BIPM, the Key Reference Value UTC is derived and also UTC – UTC(NMI) which is the result of the Key Comparison for time, CCTF-K2001.UTC (for 2001)

Comparison (KC) defined in this field. However, at the 14th Consultative Committee for Time and Frequency (CCTF) meeting (April 1999) the Working Group (WG) on the consequences of the global MRA was created to examine and report on this matter to the next CCTF. A first report of this WG MRA was presented at the 15th CCTF (June 2001). This report and the consequent proposals were discussed at the CCTF meeting as reported under section 11 of the Report of the 15th Meeting of CCTF. It was decided that the Key Comparison for time and frequency is the outcome of the computation of UTC – UTC(k), its designation is CCTF-K2001.UTC (for the year 2001) and the Key Comparison Reference Value is UTC as computed by the BIPM Time Section.

EUROMET and APMP RMOs have then prepared CMC tables for their NMIs. However, the format of the CMC tables was not yet harmonized by the WGMRA so this process, already in the stage of inter-RMO review, was stopped in 2002.

For that reason, WGMRA met during the PTTI Meeting in December 2002. On this occasion the final list of the three main t&f quantities (time scale difference, frequency and time interval) was discussed and adopted. It was published as WGMRA Guideline 1, Rev. 20021209 [2]. Two more Guidelines, related to the first, were also adopted then, namely:

- WGMRA Guideline 2 (Rev. 20021205) clarifies the estimation of the uncertainty to be taken for the Best Measurement Capability (BMC);
- WGMRA Guideline 3 (Rev. 20021210) clarifies how to extrapolate the uncertainty from the KC results for averaging times shorter than the 5 days interval of the BIPM circular T data.

### 4 Structure and contents of the t&f CMC files

CMC files have the following main titles with corresponding subtitles:

- Calibration or Measurement Service
  - Quantity
  - Instrument or Artifact
  - Instrument Type or Method
- Measurand Level or Range
  - Minimum value
  - Maximum value
  - Units
- Measurement Conditions / Independent Variable
  - Parameter
  - Specifications
- Expanded Uncertainty
  - Value
  - Units
  - Coverage Factor
  - Level of Confidence
  - Is the expanded uncertainty a relative one?
- Reference Standard used in calibration
  - Standard
  - Source of Traceability
- List of Comparisons supporting this measurement / calibration service
  - NMI Time and Frequency Services Administration
    - NMI Service Identification
    - Service Category
    - NMI
    - Internal Comment
- Comment for the user
The WGMRA Guideline 1 is specifying only Quantity and Instrument or Artifact under the Calibration and Measurement Service as well as Service Category under the Time and Frequency Services Administration. These entries should strictly follow the WGMRA Guideline 1.

5 Work of EUROMET Technical Committee (TC)

EUROMET has prepared a detailed procedure for reviewing CMC files in the EUROMET Directory [3]. Overview scheme is shown on Figure 3 for both CMC and QS reviews. The same procedures apply for self-declared and third party assessed quality systems covering the NMI services providing the declared CMCs. Work of the EUROMET TC was divided into three logical steps: preparation of CMC files, regional review of those files and inter-regional review of other RMOs CMC files. Although the work started in year 2000, not much progress was done due to nonexistent KC for time and frequency field. In the followings only the work carried out after the adoption of WGMRA Guideline 1 is presented.

5.1 Preparation of CMC files

In order to prepare CMC files, some more detailed rules were established prior starting the work. EUROMET t&f TC took WGMRA Guideline 1 as a reference for preparing CMC files. Based on this document, a more detailed list for each classification was prepared in which all the details, starting from those reported in chapter 4, and necessary to the preparation of the CMC files have been defined.

5.1.1 Time scale difference

The following service categories were defined for time scale quantity:

<table>
<thead>
<tr>
<th>Calibration or Measurement Service</th>
<th>Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Instrument or Artifact</td>
</tr>
<tr>
<td>Time scale difference</td>
<td>Local clock vs. UTC (NMI)</td>
</tr>
<tr>
<td>Time scale difference</td>
<td>Local clock vs. UTC</td>
</tr>
<tr>
<td>Time scale difference</td>
<td>Remote clock vs. UTC (NMI)</td>
</tr>
<tr>
<td>Time scale difference</td>
<td>Remote clock vs. UTC</td>
</tr>
</tbody>
</table>

Table 1. Time scale difference calibration services

Measurement methods used are:

- for Local clock vs. UTC(NMI) or UTC:
  - Time interval measurement
- for Remote clock vs. UTC(NMI) or UTC:
  - GPS common view
  - Two-way satellite time and frequency transfer (TWSTFT)
  - standard signal emission
  - telephone time signal, etc.

Measurand level or range is typically specified from –1 s to +1 s. Parameter under measurement conditions is typically prediction time for results related to UTC and averaging time for remote calibrations. Expanded uncertainty is specified as an absolute uncertainty in ns, with coverage factor of 2, which gives 95% level of confidence. The reference is typically a
cesium beam clock and list of comparisons supporting this measurement calibration service is CCTF-K2001.UTC. In the comment for the user, it is noted that the result of a calibration is fractional part of modulo 1 second difference, but additionally an integer part can be provided also.

5.1.2 Frequency

For frequency calibrations, the following services have been defined:

<table>
<thead>
<tr>
<th>Calibration or Measurement Service</th>
<th>Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Instrument or Artifact</td>
</tr>
<tr>
<td>Frequency</td>
<td>Local frequency standard</td>
</tr>
<tr>
<td>Frequency</td>
<td>Remote frequency standard</td>
</tr>
<tr>
<td>Frequency</td>
<td>General frequency source</td>
</tr>
<tr>
<td>Frequency</td>
<td>Frequency counter</td>
</tr>
<tr>
<td>Frequency</td>
<td>Frequency meter</td>
</tr>
</tbody>
</table>

Table 2. Frequency calibration services

Measurement methods used are:
• for Local frequency standard:
  o phase / time measurement
  o frequency difference multiplication
• for Local generic frequency source:
  o direct frequency measurement using electronic counter
• for Remote frequency standard:
  o GPS common view
  o TWSTFT
  o standard signal emission
  o telephone time signal, etc.

Measurand level or range specifies the applicable frequency range of the service. Measurement conditions are specified by averaging time corresponding to the gate time of the frequency counter used. Uncertainty is typically specified in relative form and is given in Hz/Hz. Other parameters, except comments for the user, are identical as for time scale difference.

5.1.3 Time interval

For time interval calibrations, the services envisaged are found in table 3.

Measurement methods used are:
• passive and active sources / meters:
  o Time interval measurement with electronic counter
• for chronometers:
  o stopwatch calibrator

Measurand level or range specifies minimum and maximum time interval applicable for the service. Under measurement conditions / independent variable a pulse amplitude and signal rise or fall time are specified. Uncertainty is specified as absolute uncertainty in ns with 95% level of confidence. Other parameters are equivalent to those specified for frequency service.

<table>
<thead>
<tr>
<th>Calibration or Measurement Service</th>
<th>Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Instrument or Artifact</td>
</tr>
<tr>
<td>Time interval</td>
<td>Period source</td>
</tr>
<tr>
<td>Time interval</td>
<td>Rise/fall time source</td>
</tr>
<tr>
<td>Time interval</td>
<td>Pulse width source</td>
</tr>
<tr>
<td>Time interval</td>
<td>Time difference source</td>
</tr>
<tr>
<td>Time interval</td>
<td>Delay source</td>
</tr>
<tr>
<td>Time interval</td>
<td>Period meter</td>
</tr>
<tr>
<td>Time interval</td>
<td>Rise/fall time meter</td>
</tr>
<tr>
<td>Time interval</td>
<td>Pulse width meter</td>
</tr>
<tr>
<td>Time interval</td>
<td>Time difference meter</td>
</tr>
<tr>
<td>Time interval</td>
<td>Delay meter</td>
</tr>
</tbody>
</table>

Table 3. Time interval calibration services

5.2 Regional review of CMC files

When the new classification was defined in April 2003 Contact Person Meeting in Ljubljana, a new Analysis Working Group (AWG) was elected from its members. It consists of six time and frequency experts from leading European time and frequency laboratories. A first task of AWG was the review of the new EUROMET CMCs files. A second task will be inter-regional review of other RMOs CMCs files.

When CMC files had been prepared and collected by TC Chairman, they were distributed among members of AWG to be reviewed. Additionally, with CMCs files an Appendix1 document was prepared by NMIs for each quantity included in the CMCs file. In this document, the laboratory had to specify details regarding the applied quality system, the publications relevant to the given CMCs, peer review or expert visit and other relevant information, and confirming laboratory abilities for specified CMCs. The review process consists of analyzing both technical abilities and quality system (Figure 1). Quality system verification within EUROMET is covered by QS Forum and therefore most of the review activities was focused on specifications given in CMC files. A direct communication between AWG member and the laboratory which CMCs were under the review process was established via e-mail. 16 CMCs files were thoroughly reviewed in three months. These CMCs files were then sent at the end of December 2003 to EUROMET Chairman, who started the process of inter-regional review.
5.3 Inter-regional review of CMCs files

The inter-regional review of EUROMET time and frequency CMCs files started in the beginning of 2004. Questions raised from other RMOs are answered directly by laboratories who prepared CMCs. When necessary, CMC files are corrected and updated. Communication is again established through e-mail and the TC Chairman is coordinating activities within EUROMET.

6 Current status of EUROMET t&f CMCs

Currently, there are 16 CMCs files for time and frequency covered by the EUROMET review process. These CMC files are now under the inter-regional review. Within these 16 CMCs files, there are 60 entries for time scale difference, 127 entries for frequency and 55 entries for time interval. Altogether, there are 242 CMCs entries for time and frequency in EUROMET CMCs files.

7 Future developments

One of the MRA goals is certainly a working calibration database (KCDB) in which all CMCs tables would be listed. Since no time and frequency CMCs tables are currently present in the KCDB, it is foreseen to conclude this process for EUROMET time and frequency CMCs tables, as well as for all other RMOs. The main workload is therefore expected in inter-RMOs review of CMCs tables. At the same time, the maintenance of CMC tables, when included in KCDB, will certainly present additional challenge.

Acknowledgements

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References