**GT-RF notes**

Chairman: Markus Zeier, METAS, Switzerland
Rapporteur: Christopher Eio, NPL, UK

Present at the meeting:

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| Djamel Allal | LNE | France |
| Michael Stock | BIPM | France |
| Mustafa Cetintas | UME | Turkey |
| Ghislain Granger | NRC | Canada |
| Paul Hale | NIST | USA |
| Carlos Sanchez | NRC | Canada |
| Hala Abdel Megeed | NIS | Egypt |
| Yozo Shimada | NMIJ | Japan |
| Nobu-hisa Kaneko | NMIJ | Japan |
| No Weon Kang | KRISS | Korea |
| Murray Early | MSL | New Zealand |
| Jonathan Williams | NPL | UK |
| Israel Garcia | CENAM | Mexico |
| Po Gyu Park | KRISS | Korea |
| Gao Qiu Lai | NIM | China |
| Eugene Golovins | NMISA | South Africa |
| Ilya Budovsky | NMIA | Australia |
| Luca Callegaro | INRIM | Italy |
| Rolf Judaschke | PTB | Germany |
| Tom Crowley | NIST | USA |
| Ivan Malay | VNIIFTRI | Russia |
| Sergei Kolotygin | VNIIFTRI | Russia |
| Igor Chirkov | VNIIFTRI | Russia |
| Jing Tao | A*STAR | Singapore |
| Faisal Mubarak | VSL | Netherlands |
| Dennis Lee | SCL | Hong Kong |

The meeting took place at the Bureau International des Poids et Mesures, commencing at 13:00 CET on 10 March 2015.

No new items were added to the agenda before commencing the meeting.

**Agenda item 2: Chairman's report on developments since the last official meeting (March, 2013).**

The chairman reported the following items:

- The minutes of the 22nd meeting of the GT-RF in 2013 have been approved and are available on the BIPM website.
- An unofficial GT-RF meeting was held during CPEM 2014 in Rio de Janeiro
- The terms of reference of the GT-RF have been approved by the CCEM and are on the website
- The CCEM strategic plan has been finalized and was published on the CCEM website in March 2014
- UME (Turkey) is a new member of the CCEM

- A reduction of the CMC entries within EURAMET has taken place (see note [1])
- Two key comparisons have been completed with the results now publicly available:
    - CCEM.RF-K24.F: Field strength 1 to 18 GHz piloted by NPL [Metrologia, 2013, 50, Tech. Suppl 01007]
    - CCEM.RF-K25.W: Power in waveguide 33 to 50 GHz piloted by PTB [Metrologia, 2015, 52, Tech. Suppl. 01001]
- A new key comparison has been approved:
    - CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz and 90 dB piloted by NMIJ

[1] The reduction has been achieved through the use of matrices to represent the CMCs. The proposal was discussed by the WGRMO and the CCEM. The use of matrices has been recommended but not declared as mandatory.

**Agenda item 3: Reports on current GT-RF Key Comparisons (KCs)**
The chairman reported information relating to each comparison reported at the last meetings and the pilots provided updates.

CCEM.RF-K5c.CL: S-parameter PC-3.5 mm piloted by NMIJ

Status prior to meeting:

- March 2013: Delay at NIST reported
- CPEM 2014: Apparently on schedule

NMIJ reported that the comparison is now delayed approximately 3 months due to transportation issues in non-EU loop. The EU loop is delayed by about 1 month. NMIJ, doing the stability checks for both loops, will re-schedule the remaining parts of the loops to make sure that both sets of standards can be at the same time at NMIJ for the stability checks.

NMIJ requests participants to ship “door-to-door”. Christopher Eio (NPL) suggested that perhaps shipping terms could be included in protocols in the future.

CCEM.RF-K22.W: Noise in waveguide 18 to 26.5 GHz piloted by LNE

Status prior to meeting:

- Measurements completed
- March 2013: Draft A announced for May 2013
- CPEM 2014: Draft A promised for end of 2014

LNE reported that the Draft A was sent to participants at the start of March 2015.

CCEM.RF-K23.F: Antenna gain 12 to 18 GHz piloted by NIST

Status prior to meeting:

- March 2013: Draft A report announced for April 2013
- Results published elsewhere prematurely
- CPEM 2014: Draft A was announced to come out soon

NIST reported that the Draft A would be ready by now but it is not. No specific date could be given as to when it will be sent to participants. The chairman asked if a deadline could be set but Tom Crowley (NIST) was unable to commit to one.

**ACTION:** Tom Crowley will contact Perry Wilson at NIST to agree a deadline for distributing the Draft A report to the participants. If nothing happens the chairman will follow up on this.

CCEM.RF-K26: Attenuation in PC-2.4 mm, up to 40 GHz ad 90 dB piloted by NMIJ

Status prior to meeting:

- The KCDB status is “planned”
- Oct 2014: the technical protocol was approved by the CCEM

NMIJ reported that the comparison commenced in February 2015. Two NMIs have finished their measurements and the standards are currently on the way to NPL. The measurements are expected to be complete by August 2016. Ilya Budovsky (NMIA) stated that NMIA will withdraw from the comparison.

As this is a long comparison with a large number of participants, the chairman requested that, if a participant encounters problems or delays during their scheduled slot, the standards be shipped onwards as scheduled and the participant re-schedule their measurements for the end of the comparison to avoid inconvenience to other participants.

APMP.EM.RF-K8.CL: Power Type-N 10 MHz to 18 GHz piloted by NMIJ

Status prior to meeting:

- KCDB status is “in progress”
- March 2013: first loop to be finished in March 2013
- CPEM 2014: measurements completed by December 2013, Draft A in preparation

NMIJ reported that two participants requested to re-measure the standards and this was allowed as the results had not be distributed amongst participants. The pilot is still waiting for the reports from two of the participants and the Draft A will be distributed once these have been received. These two participants are:

- KRISS: No Weon Kang reported that they are building a new calorimeter system and wish to link this with their comparison results before submitting the report
- NMIA: Ilya Budovsky stated that the RF lab has closed down since participation in the comparison and they will probably withdraw the result

APMP.EM.RF-S5.CL: Characteristic impedance of air lines piloted by NMIJ

This is a supplementary comparison. NMIJ reported that there is a 4 month delay due to shipping. It was scheduled originally to finish in January 2016 and now needs to be re-scheduled. The standards are currently at NMC/A*STAR.

SIM.EM.RF-K5b.CL: S-Parameters, Type-N, 2 to 18 GHz piloted by INTI

Status prior to meeting:

- KCDB status is “in progress”
- March 2013: Final measurements announced for April 2013

Nobody was present from INTI to give an update.

**ACTION:** The chairman will contact INTI to find out the current status of this comparison.

Pilot study: EM properties of material piloted by NMIJ

Status prior to meeting:

- March 2013: Circulation of measurement protocol announced for June 2013
- CPEM 2014: NMIJ replaced NIST as pilot

NMIJ reported that they have chosen from the sample geometries proposed by NIST and have proposed four sample types. They will draft the measurement protocol and distribute it to participants for review by June 2015, finalize the measurement protocol based on feedback from the participants by August 2015 and prepare two types of low-loss dielectric materials and complete sample machining by October 2015.

**Agenda item 4: New comparisons**

At CPEM 2014, NPL proposed antenna comparison of tilt angle and axial ratio. Christopher Eio clarified that this should be an antenna gain comparison with secondary parameters being measured. Other labs expressed interest in joining an antenna gain comparison: NIST, NMIJ, LNE, KRISS (K band), UME, NIM.

Christopher Eio also stated that NPL is interested in a noise comparison above 33 GHz. Tom Crowley said that NIST would be interested in a comparison using WR-10. No Weon Kang, KRISS would also be interested in a WR-10 comparison. Gao Qiu Lai, NIM expressed interested in a WR-15 comparison.

Christopher Eio said that NPL would only be prepared to pilot one of these comparisons, not both.

**ACTION:** Christopher Eio to discuss with colleagues the details of these comparisons and e-mail participants to gauge interest. Based on the interest, NPL will choose which to pilot.

Tom Crowley (NIST) reported a bilateral power comparison in WR-15 piloted by NIM. This is an informal activity not registered at the BIPM or at one of the RMOs. If successful, NIM will propose a WR-15 CCEM comparison. Tom Crowley also was unaware of the 19 GHz antenna gain comparison proposed by NIST at CPEM 2014. Christopher Eio said that this could probably be combined with the comparison proposed by NPL.

**ACTION:** Tom Crowley to contact Ron Ginley about the plans for a 19 GHz antenna gain comparison.

There were no other suggestions for future comparisons.

**Agenda item 5: CMCs**

The chairman gave a presentation entitled “Format of S-parameter entries in CMC database” as a representative of METAS asking whether S-parameters should be listed in real/imaginary or magnitude/phase format in the CMC database.

Of those NMIs with S-parameter CMCs, 10 use magnitude/phase format, 8 use real/imaginary and 4 use a mix of the two or it is undefined. Real/imaginary representation tends to be used by European NMIs, and magnitude/phase representation across the rest of world. METAS moved back from real/imaginary representation to magnitude/phase representation during the last CMC review.

Markus Zeier gave the following reasons for doing this:

- Real/imaginary uncertainties vary strongly as a point moves around the Argand plane. Because of this, quoting the smallest uncertainty is not very informative and an extra dimension would be required in the CMC matrix.
- Magnitude/phase uncertainties do not vary as much as a point moves around the Argand plane and this behaviour makes the magnitude/phase uncertainty more informative.

Rolf Judaschke (PTB) asked whether we should work towards a unique representation of the CMCs. The chairman stated that he has outlined reasons why we should change but it is not possible to force NMIs to use the magnitude/phase representation. With the NMIs at differing levels, not all may be able to provide exactly the same information.

Faisal Mubarak (VSL) commented that comparisons are usually performed using real/imaginary representation as it makes more sense to do so (although he prefers magnitude/phase himself). He stated that the information should be specified in such a way that comparisons can be made easily.

Luca Callegaro (INRIM) asked whether there should be some consideration for measurements close to a physical boundary and the uncertainty pushes it over this boundary. The chairman was unsure of the answer – unless a Monte Carlo simulation that respects these boundaries is used, then it will be a problem. An experienced user should be able to rely on own interpretation and maybe that’s good enough.

Mustafa Cetintas (UME) stated that for free-space users, magnitude and phase makes more sense.

Murray Early (MSL) stated that Blair Hall has just submitted a paper to Metrologia on this topic.

The discussion moved then away to CMCs in general.

Christopher Eio (NPL) commented on differences in quantity names and gave examples from CMCs relating to oscilloscope quantities. Michael Stock (BIPM) confirmed that this is a common problem. This might be addressed in the review of the CIPM MRA procedures and the KCDB, starting later this year.

Rolf Judaschke (PTB) asked which quantities should be included on the list. If all derived quantities are included, the list could get very long. There appear to be no fundamental rules on which are key quantities and which are derived.

Michael Stock (BIPM) responded stating that this is clear for key comparisons but not for CMCs. The answer depends on what is the purpose of CMCs? Do we need them for everything? This topic might also be brought up during the planned review of the CIPM MRA.

**Agenda item 6: Presentation**
Paul Hale (NIST) gave a guest presentation entitled “High-speed Waveform Metrology”.

**Agenda item 7: Other Business**
The chairman reported on the revision of EURAMET VNA guide cg-12 currently being undertaken as a European collaboration between METAS, LNE, NPL, PTB, SP and VSL. The existing guide is still in use by many labs and NMIs but is considered to be outdated and not applicable at higher frequencies:

- It is not GUM compliant
- Treatment of uncertainties is scalar and phase is neglected
- Many of the assumptions made are questionable (e.g., ideal air lines, connector reflections ignored, etc.)
- Limits of applicability are not defined
- It promotes “typical” values, some of which are unclear as to how they are derived
- Origins of the equations are not referenced

The guide is being revised as part of European Metrology Research Project “HF Circuits” and is scheduled for submission to EURAMET in mid-2016. It will be targeted mainly at calibration labs and some NMIs.

An outline content of new guide was presented:

- Introduction
- Traceability scheme
- Reference standards
- VNA calibration schemes
- Verification
- Uncertainty contributions
- VNA measurement model
- Uncertainty evaluation
- Practical advice
- Best measurement practice
- Appendices

Tom Crowley (NIST) asked if the drafts will be publicly available. The chairman said that the first drafts will probably be available to the consortium only and it may be possible to release the second draft to a wider audience depending on progress.

Following this presentation, there was a request from NMIJ in terms of service categories: they would like to make a small change to an existing service category in category 11. In cat 11.5 (sub categories 11.5.1, 11.5.2 and 11.5.3), they would like to extend the descriptions to include rod antenna, biconical antenna, log periodic antenna, horn antenna. There were no objections from the room.

The RMO working group needs to approve this change. The request has been forwarded to the chair of the working group already and this was confirmed by Michael Stock (BIPM).

**Agenda item 8: New policy on working documents**

There is a new policy at BIPM level. Working documents are principally public unless they contain sensitive information. By default, working documents relating to GT-RF will be public unless decided that they will not be. No objections from the room.

**Date of next meeting**
No date scheduled but will be in approximately two years' time. Members will be informed with appropriate notice.

The chairman asked if there should there be an unofficial meeting at CPEM in Ottawa? It was agreed amongst the participants that provisionally there will be one but it can be cancelled should attendance not be sufficient.

The chairman closed the meeting at 17:05.