CCEM WGLF Meeting (hybrid) 8th March 2023

Murray Early, WGLF Chair

3. Progress on CCEM Key Comparisons

Reports regarding:

a. CCEM-K5.2017: primary power (Gert)

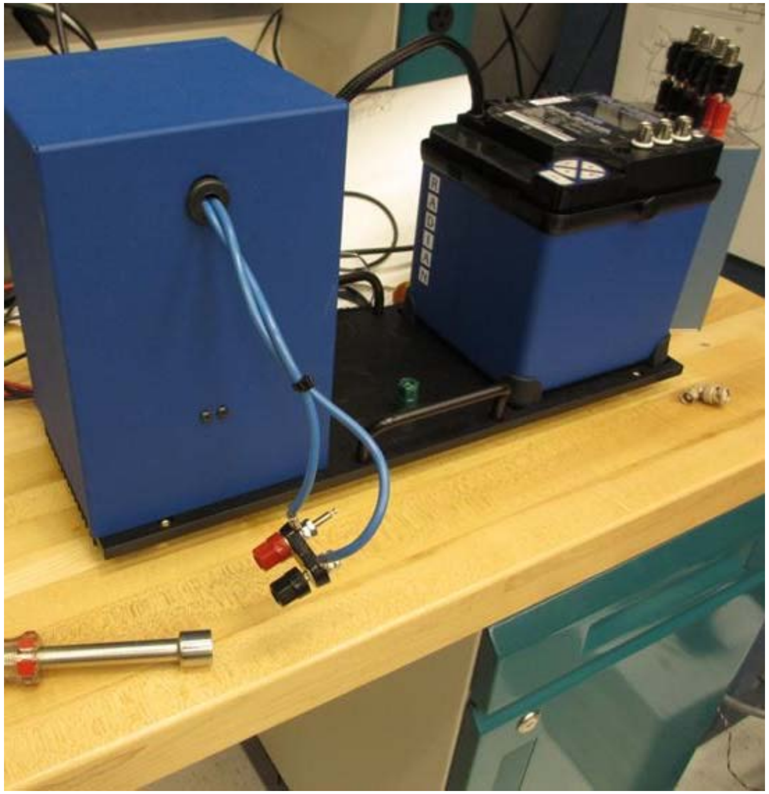
b. CCEM-K6a (3 V to 1 MHz) and -K9 (500 V to 100 kHz): AC-DC transfer (Karl-Erik)

c. CCEM-K6c (3 V to 100 MHz): RF-DC transfer (Karl-Erik)

d. CCEM-K13: harmonics of voltage and current (Karl-Erik)

CCEM-K5.2017

- Measurand: Primary power at 120 & 240 V, 5 A, 53 Hz; phase 0°, ± 60°, ± 90°,
- Artefact: two Radian travelling standards (thanks to NIST)
- Support group: **PTB** (pilot measurements), **CENAM** (logistics) and **VSL** (analysis and reporting)
- Other participants: **NIST, INMETRO, LNE, SP, NIM, NMIA, VNIIM, NMISA**
- Aimed uncertainty level < 20 µW/VA
- Worst drift ~1.6 ppm/yr (PF = 1)
- All reports completed by Oct 2022 (significantly affected by COVID)
- No significant outliers
- Draft A report: spring 2023



CCEM-K6.a/K9

- Measurand: ac/dc voltage transfer:
- K6.a: 3 V, 10 Hz - 1 MHz
- K9: 500 V and 1000 V, 10 Hz – 100 kHz
- Artefacts: NIST PMJTC + Fluke Range Resistor
- Support group: RISE (logistics), INTI (reporting), NIST (pilot measurements), PTB and NMIA
- Other participants: RISE, INTI, PTB, NMIA, NIST, NRC, JV, NMIJ, NIM, LNE, NMISA, INMETRO, VNIIM
- Running in parallel with K6c
- Started end of 2018, affected by several device failures and COVID delays
- 3rd loop restarted with new schedule - NMIJ measured 3 V MJTC Sep 2022 NMISA, NMC A*STAR and INTI remaining
- End of circulation scheduled to Dec 2023

CCEM-K6.c

- Measurand: ac/dc voltage transfer:
- K6.c: 3 V, 500 kHz - 100 MHz
- Artefact: NIST PMJTC
- Support group: RISE (protocol), NIST (pilot measurements), PTB
- Other participants: NRC, NIM, LNE, VNIIM, A*STAR
- Running in parallel with K6a/K9
- Started at the end of 2018, affected by several device failures and COVID delays
- 3rd loop restarted with new schedule - NMIJ measured 3 V MJTC Sep 2022 NMISA, NMC A*STAR and INTI remaining
- End of circulation scheduled to Dec 2023

CCEM-K13

- Measurand: power harmonics with 3 waveforms:
- Sine wave at 120 V, 5 A, unity power factor
- IEC62053-21 signals: voltage 10%, current 40%, 5th harmonic
- Field-recorded waveform
- Artefact: Fluke 6105
- Support group NIST (technical support), NRC, RISE (logistics), NPL (analysis and report), NIM (pilot measurements)
- Other participants: PTB, VNIIM, NMIA
- Started end of 2018, affected by device failures and COVID delays
- Jun 2021, problems in definition of phase of the current harmonics compared to the technical protocol (TP), and issues related to resolution
- circulation stopped, and travelling standard returned to NIM for correction of the implementation, TP updated
- new circulation schedule Sep 2022 to Mar 2024
- Oct 2022 measured by RISE and NPL, VNIIM withdraws
- Feb 2023. Travelling standard is now at PTB

4d: Forward Look on Comparisons

Reminder of previously established principles (<2015?)

- 10 key quantities, 1 - 4 values in each quantity
- Discipline of NOT increasing the number of quantities without a strong case
- Review the values within a quantity
- Interval between comparisons typically 10 years, based on evolution in laboratories, some quantities longer or even no future comparison scheduled
  - Suggest 'start to start' should be 15 to 20 years?
- Choices also strongly influenced by the activities in the RMOs

4: New Comparisons

2021: Following survey of WGLF members and some discussion… a plan was proposed:

CCEM Key Comparisons	Repeat	Next	RMO
K14: high ac voltage	15	2023	?
K12: ac-dc current, 10mA/5A	15	2023	Y
K8: dc voltage ratio?	20	2023	?
K11: low ac-dc voltage, 10mV/100mV	15	2025	Y
K2: high dc resistance, 10MΩ, 1GΩ and 1TΩ?	15	2025	Y
K7: ac voltage ratio, 1kHz	20	2027	?
K5: single phase ac power, 50/60Hz	15	2029	Y
K6.a: mid ac-dc voltage, 3V to 1MHz	15	2031	Y
K6.c: RF-dc voltage, 3V to 100MHz	15	2031	Y
K4: capacitance, 10pF/100pF	20	2035	Y
K9: high ac-dc voltage, 500V/1000V (was K6.b)	15	2031	Y
K3: inductance, 10mH	20	2041	Y
K10: dc resistance, 100Ω	-	-	-
K13: power harmonics	-	-	-

4. New Comparisons

Reports regarding:

a. Update on preparation for CCEM-K3.X, 10 mH inductance [Leigh J, online]

b. Update on preparation for High Voltage comparison (K14?)
   (VTT, NMIA, RISE, INTI, VNIIMS) [Jari H, online]

c. Update on preparation for AC-DC Current comparison (K12.X?)
   - strong interest – 13 labs
   - NRC willing to co-ordinate

CCEM-K3 Inductance (10 mH at 1 kHz) (Leigh J)

Organisation:

- PTB – characterisation of standards, pilot laboratory measurements
- NIM – logistics, scheduling, transportation and participant report submission
- NMIA – comparison protocol, KCDB registration, analysis and reporting

13 Laboratories:

• AFRIMETS	NMISA
• APMP	NIM, NMIA, KRISS
• COOMET	VNIIM
• EURAMET	INRIM, LNE, PTB, VTT
• GULFMET	EMI
• SIM	INMETRO, NIST, NRC

Transportation stability of standards

Standards:

- Two GR 1482-H inductance standards
- Enclosed in individual temperature-controlled enclosures at 30.0 °C
- Requires 12 V DC
- Recovery time for unpowered transport ~ 1 day / °C

Transportation options investigated:

- Powered transportation
    - Suitable for ground transport (eg within EURAMET)
    - Not available for air transport
- Temperature-controlled shipping containers
    - Expensive, not very stable, not hot enough, no power

CCEM-K3 Proposal

Loop 1: EURAMET

- Land transport - GR inductors in powered enclosures
- Target uncertainty <10 µH/H

Loops 2-4:

- Air transport - GR inductors in unpowered enclosures
- Target uncertainty <30 µH/H ?

Additional measurements:

- NIM active simulated inductors (T network or electronic simulation)
- Target uncertainty <10 µH/H ?
- Artefacts expected to be completed June, but further study required
  Progress this development anyway!

High voltage key comparison? (Jari H)

Based on discussions with VSL, PTB, RISE, NMIA etc.:

- Quantity(ies)
  - AC voltage ratio and phase displacement
- Artefact
  - Oil filled (or dry?) instrument transformer
- Oil filled candidates
  - Australian option by J.S. Hansom (if they agree), max. 90 kV
  - Finnish option by TUNI: (very) old MWB, max. 76 kV
  - German option by PTB: max. 76 kV
  - Other options ??
- Pilot Group
  - PTB, 2 others?
- Coordinator ?
- CCEM or regional ? Probably CCEM

Australian

$$\frac{132\text{ kV}}{\sqrt{3}} \Big/ \frac{110}{\sqrt{3}}$$

Finnish

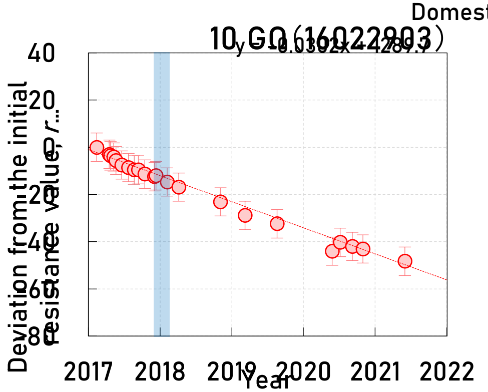
$$\frac{110\text{ kV}}{\sqrt{3}} \Big/ \frac{110}{\sqrt{3}}$$

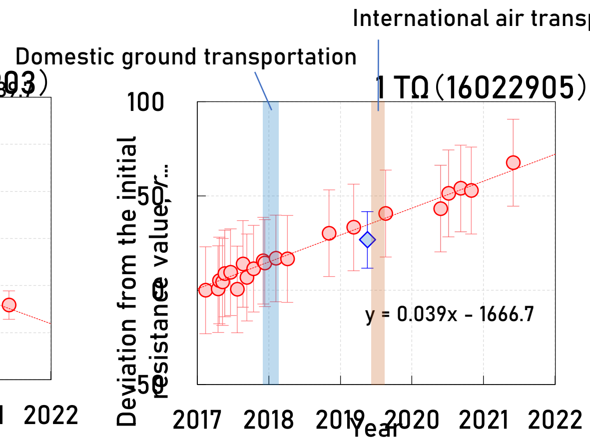
4d. Forward Look on Comparisons

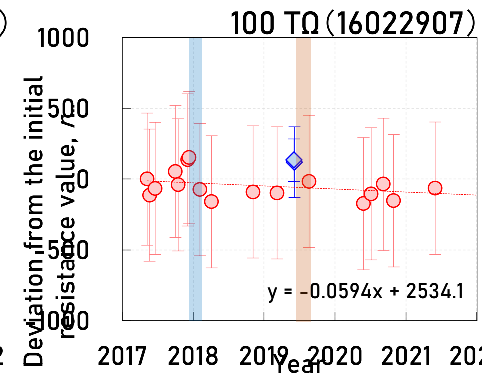
d. Forward look on comparisons
   i. K8: DCV to 1 kV feedback
      NB: how to support new RMO (GULFMET) K8?
   ii. Low AC-DC Voltage (CCEM-K11)
      NB: Does BIPM Onsite PJVS displace this?
   iii. Linearity feedback (discussed at WGRMO)
      No immediate comparison support required (can be extracted form uncertainty budget)
   iv. Future High Resistance (~TΩ, K2) or Small Current?
      Yes! – proceed with K2 (1 TΩ as an option?), consider pilot or supplementary for small current

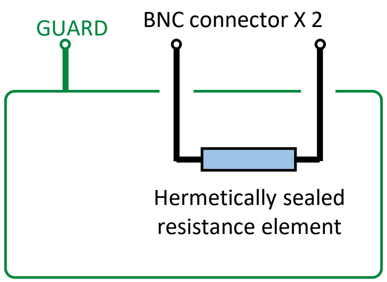
High resistance developments (Nobu K)

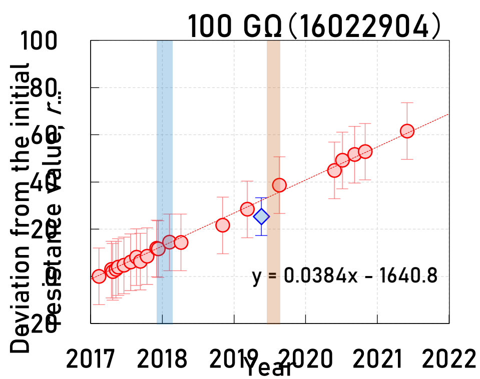
(W)120 mm × (D)80 mm × (H)70 mm, 0.6 kg

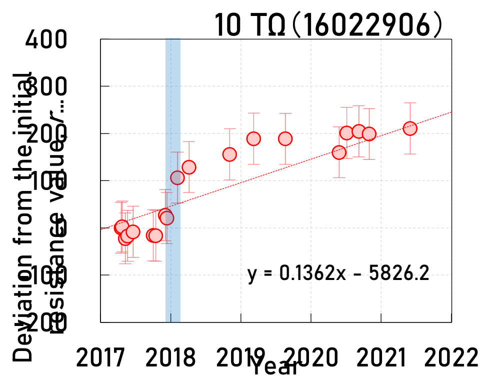








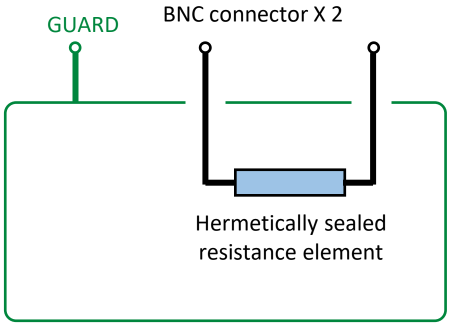




Resistor	Drift rate / year (μΩ/Ω)
10 GΩ (16022903)	-11.0
100 GΩ (16022904)	14.1
1 TΩ (16022905)	14.2
10 TΩ (16022906)	49.7
100 TΩ (16022907)	-21.7

High resistance developments - Summary

(W)120 mm × (D)80 mm × (H)70 mm, 0.6 kg



Resistor	Drift rate / year (μΩ/Ω)	Temperature coefficient (μΩ/Ω)/K	Humidity coefficient (μΩ/Ω)/%	Voltage coefficient (μΩ/Ω)/V
10 GΩ (16022903)	-11.0	+6.4	+0.1	-0.00
100 GΩ (16022904)	14.1	+0.8	-0.1	-0.00
1 TΩ (16022905)	14.2	-14.3	-0.0	-0.02
10 TΩ (16022906)	49.7	+8.2	-0.5	-1.96
100 TΩ (16022907)	-21.7	-1310	+1.0	-0.09

NMIJ kindly willing to provide artefact(s) to support K2 – thank you!

5. BIPM Comparisons

Review of ongoing BIPM comparisons

NB: APMP 1 Ω and 10 kΩ proposed key comparison will be linked to BIPM.EM-K12 through KRISS since no CCEM.EM-K1 - OK?

a. Status of on-site Josephson comparison of low frequency ac voltage [Stephane]

   Focus at ~ 1 V to 1 kHz, may go to 10 mV?

6a. WGLF Matters

Report on comparison support for magnetic quantities [Po Gyu Park]

Do we need consider better comparison support magnetic quantities?

Support for Magnetic Quantities

Magnetic Flux(MF) and Magnetic Flux Density(MFD) Standards

Po Gyu Park(KRISS)

1. MF (Φ, Wb=V.s), Fluxmeter

1) Voltage and second: 1 Wb=1 V.s, Electric Integrator

2) MFD and winding area of pick-up coil: 1 Wb=1 T x 1 m^2, Faraday's law

Φ(Wb)=B(T) x S(m^2)

3) Windings area of the sensing coil (***S***, pick-up, search): S(m^2)=Φ(Wb)/B(T), Faraday's law

EUROMET.EM-S1(2002): Field coil (mWb/A), COOMET S26(2021): pick-up coil (m^2)

2. AC/DC MFD (*B*, T = Wb/m^2), KC required

1) ***B*** determined by measuring the NMR frequency of a spherical H_2o sample with the shielded proton gyromagnetic ratio(CODATA), $T_{90} \propto (h/\alpha^5)^{1/2}$, $\omega_p = \gamma_P' \cdot B$

2) CCEM.M.K1(2001): T/A, DC: Below 2 mT, AC: Below 20 kHz, Transfer std. coil (PTB:pilot, KRISS, VNIIM, NMIA, UME, NPL, IEN, NIM, CMI)

3) **DC 0.1 T ~ 1 T using NMR or Hall effect magnetometer**

4) **AC 20 kHz ~ 50 kHz using std. pick-up coil or AC magnetometer**

Support for Magnetic Quantities

CLASSIFICATION OF SERVICES IN ELECTRICITY AND MAGNETISM

Version No 9 (dated 04 June 2020)

10.2 Magnetic fields below 50 kHz

10.2.1 Magnetic flux(flux meter, flux etalon): KC of RMOs by Need(Green Color)

10.2.2 DC magnetic flux density: KC required in over 2 mT(CCEM. M.-K1, below 2 mT, 2001)

10.2.3 AC magnetic flux density: KC required in 20 kHz~ 50 kHz(CCEM. M.-K1, below 20 kHz, 2001)

10.2.4 DC shielding factor (ratio of DC magnetic flux density)

10.2.5 AC shielding factor (ratio of AC magnetic flux density)

10.2.6 Turn area (ratio of magnetic flux and magnetic flux density): pick up coil

10.2.7 Magnetic flux density or magnetic field strength per unit current: field coils

10.2.8 Magnetic field gradient: gradiometers

12. Measurements on materials(Test of magnetic materials, VSM, B-H Loop Tracer, etc)

12.3 Soft magnetic sheet and powder materials

12.4 Soft magnetic bulk material

12.5 Feebly magnetic, paramagnetic and diamagnetic material

12.6 Hard magnetic material

~~12.7 Magnetic data storage media~~(revised or deleted):

Floppy diskettes and audio tapes, Unable to test high-capacity storage media(Hard diskettes, RAM etc)

6b. WGLF Matters

Efficiency of comparison reviews

- New approach to comparison reviews since 2021: request a WGLF member (institute) to carry out the review
- Works well! Thanks to staff of the following institutes: PTB, INMETRO, NMIA, METAS, NMIJ, KRISS, NIST, RISE, NMISA, and INTI for providing competent reviews
- Still requires moderation by WGLF Chair…causing delays!!

6b. WGLF Matters

Efficiency of comparison reviews

- Waiting on response to reviews:
  - APMP.EM-K2
  - APMP.EM-K12
  - COOMET.EM-S6 (85%)
  - COOMET.EM-S26 (99%)
  - SIM.EM-S13
- Waiting on WGLF Chair:
  - APMP.EM-S8 (95%)
  - COOMET.EM-S7
  - COOMET.EM-S10 (reviewer required)
  - COOMET.EM-S18 (reviewer required)
  - COOMET.EM-S21 (90%)
  - COOMET.EM-S22
  - EURAMET.EM-S43
- NB: Reports that follow the guidelines are much easier/quicker to review!
- Suggest RMOs appoint their own third-party reviewer before submitting to WGLF?
- NB: RMO key comparisons must be linked – it is the linked results that are entered to the KCDB

8. WGLF Membership

Members

BIPM, CENAM, VNIIM, METAS

INMETRO. KRISS, LNE, INRIM

NIM, NIST, NMIA, NMC, A*STAR

NMIJ/AIST, NPL, NRC, PTB

RISE, VSL, VTT/MIKES

ToR: Membership

Membership of the WGLF is normally restricted to NMIs who are members of the CCEM and who have substantial programs and expertise in electromagnetic standards and measurements at low frequencies or at DC. Individual scientists from member NMIs can also be considered for membership. Members are appointed by the President of the CCEM, in consultation with the WGLF chairperson. In addition, the WGLF chairperson may invite guests on a one-off basis from other Member States or Associates.

Thank you…