CCEM WGLF Meeting (hybrid) 8th March 2023

Murray Early, WGLF Chair

3. Progress on CCEM Key Comparisons

Reports regarding:

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

3.2 CCEM-K6a (3 V to 1 MHz) and -K9 (500 V to 100 kHz): AC-DC voltage transfer (Karl-Erik)
[future star?]

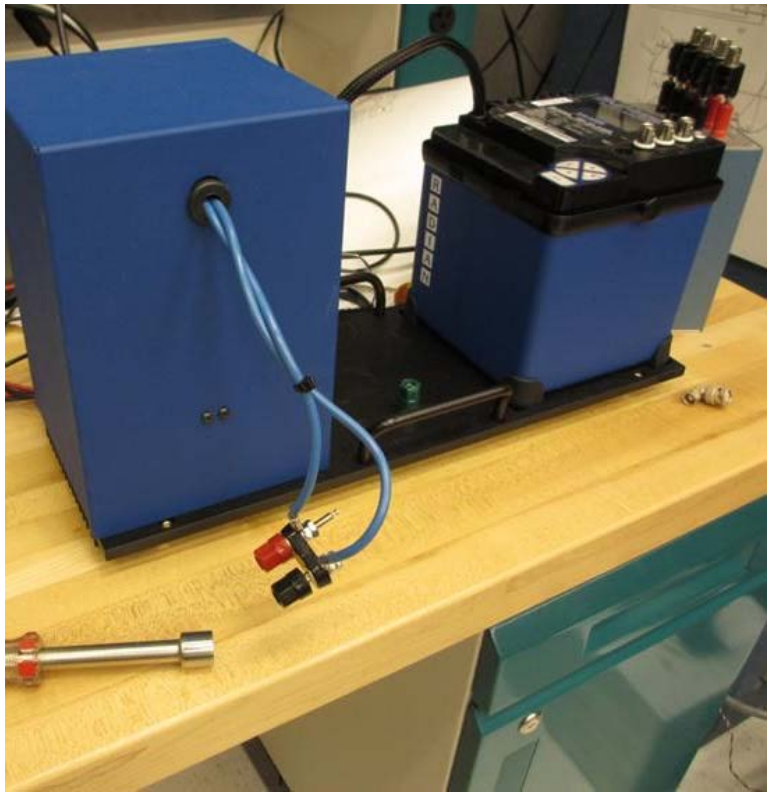
3.3 CCEM-K6c (3 V to 100 MHz): RF-DC transfer (Karl-Erik)
[future star?]

3,4 CCEM-K13: harmonics of voltage and current (Karl-Erik)

3.5 CCEM-K12.2025 (10 mA, 5A to 10 kHz) AC-DC current transfer (Ghislain)

CCEM-K5.2017 Power

- Measurand: Primary power at 120 & 240 V, 5 A, 53 Hz; phase 0°, ± 60°, ± 90°,
- Support group: **PTB** (pilot measurements), **CENAM** (logistics) and **VSL** (analysis and reporting)
- Other participants: **NIST, INMETRO, LNE, SP, NIM, NMIA, VNIIM, NMISA**
- Draft A report: Feb 2025, Draft B mid 2025?
- Good results but low uncertainty generates outliers (6/100)



CCEM-K6.a/K9 AC/DC Voltage

- K6.a: 3 V, 10 Hz - 1 MHz
- K9: 500 V and 1000 V, 10 Hz – 100 kHz
- 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
- Measurements complete June 2024, last reports received Dec 2024, results with INTI for analysis

CCEM-K6.c AC/DC Voltage

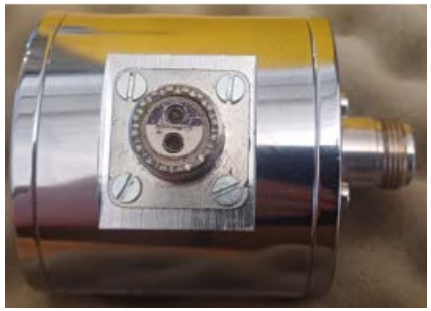
- K6.c: 3 V, 500 kHz - 100 MHz
- Artefact: NIST PMJTC (future availability of devices?)
- Support group: **RISE** (protocol), **NIST** (pilot measurements), **PTB**
- Other participants: **NRC, NIM, LNE, VNIIM, A*STAR**
- Running in parallel with K6a/K9
- Measurements complete June 2024, last reports received Dec 2024, results with INTI for analysis

CCEM-K13 Power Harmonics

- 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 (no longer supported by Fluke)
- Support group **NIST** (technical support), **NRC, RISE** (logistics), **NPL** (analysis and report), **NIM** (pilot measurements)
- Other participants: **PTB, NMIA**
- Started end of 2018, affected by device failures, COVID delays, definition issues
- Final measurements now being carried out by pilot (NIM), to report in Jun
- participant results to be sent asap and with deadline 31 May 2025.
- Analysis may not be simple
- NB: difficult to support RMO follow-up: EURAMET, GULFMET (supplementary for now)

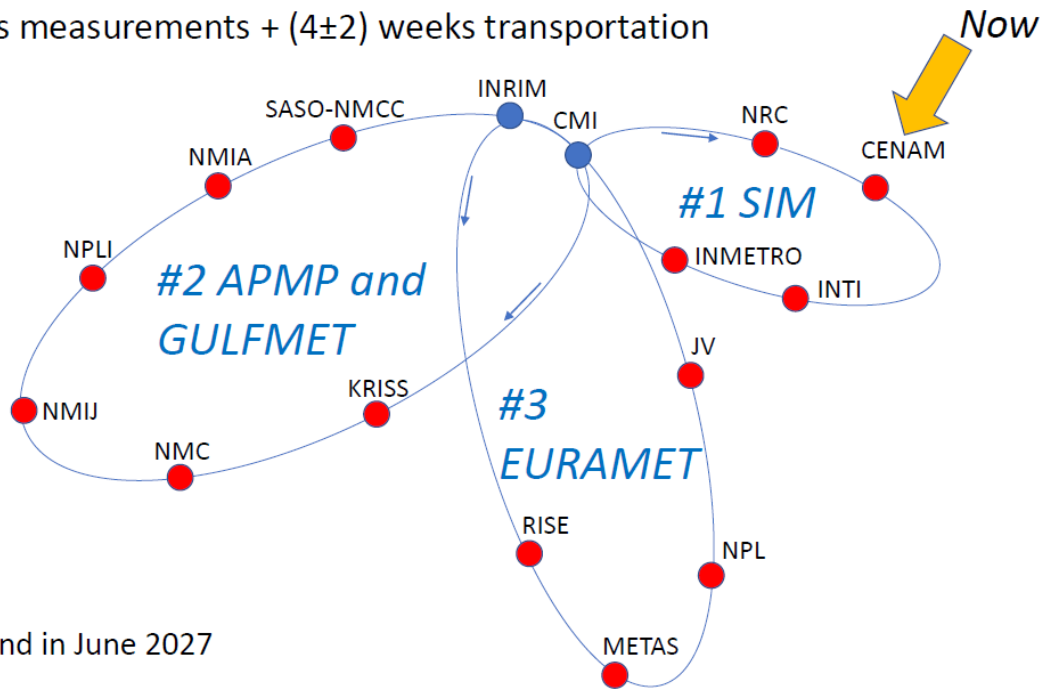
CCEM-K12.2025 AC-DC Current

- 10 mA and 5 A, at 10 Hz, 55 Hz, 1kHz, 10kHz, 20kHz, 50kHz, and 100kHz
- Champion: Ghislain Granger (NRC)
- Support group: **NRC, CENAM, INRIM, NMC, NMIJ, NPL, NPLI, SASO-NMCC, CMI, JV, KRISS, and INTI** (12 of 16 participants!) – add PTB to #3 loop
- Not using ATA Carnet



January 2025: Circulation Starts

3 weeks measurements + (4±2) weeks transportation



Should end in June 2027

4. New CCEM Key Comparisons

Reports regarding:

4.1 Update on preparation for CCEM-K3.X, 10 mH inductance (Luca/Yan Yang)

4.2. Update on preparation for high voltage comparison (K14?) (Jari)

CCEM-K3 Inductance (10 mH at 1 kHz)

Organisation:

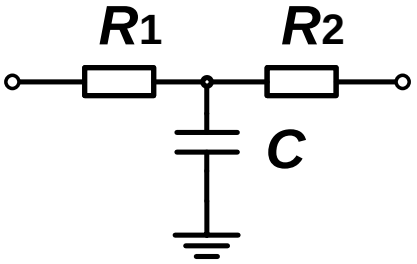
- PTB – characterisation of standards, pilot laboratory measurements
- NIM – logistics, scheduling, transportation and participant report submission
- NMIA – comparison protocol, KCDB registration, analysis and reporting

14 Laboratories:

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

CCEM-K3X Inductance

- Artefact: GR 1482 inductors – needs thermosetting, airline transport not viable
- Investigations – research on temperature changes (Luca, Florien). Possibly the dominant effect is humidity rather than temperature?
- Alternative option: use simulated inductors developed by NIM (Yan Yang) that perform remarkably well but unproven in comparison process



Proposal – agreed!

Loop 1: EURAMET

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

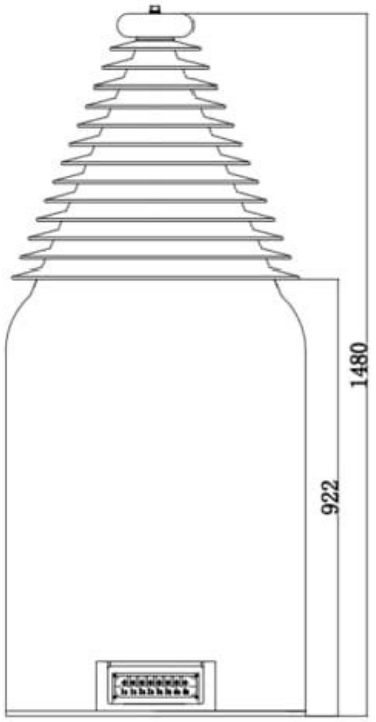
Loop 2-4: Other RMOs

- Air transport - GR & NIM inductors in unpowered enclosures
- Target uncertainty <10 µH/H?

CCEM-K14X High Voltage

- Measurand: AC voltage ratio error and phase displacement:
- Artefacts: two custom dry two-stage transformers
  - 20 kV:100 V (200:1), available
  - 100 kV:100 V (1000:1), June 2025 Provided by CEPRI, China
- Champion: Jari Hällström, VTT MIKES,
- Task group: **VTT, NMIA, RISE, INTI, VNIIMS**

20 kV



100 kV

CCEM-K14X High Voltage

- About 30 NMIs with CMCs, propose two parallel loops
  - CCEM-K14 : VTT, NMIA, PTB, VSL, RISE, CEPRI
  - EURAMET.EM-K14 : PTB, VSL, VTT, RISE, CEPRI
  - PTB acts as pilot lab for both comparisons
  - PTB, RISE and VTT will take part on both comparisons
- Timing:
  - protocol March 2025,
  - first pilot measurements June – August,
  - final pilot measurements late 2027 – early 2028

4.3: 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

4.3: New Comparisons (updated 2021 plan)

CCEM Key Comparisons (March 2025)	Repeat	Next (Support)	Start	RMO
K14: high ac voltage	15	2023	2025	?
K12: ac-dc current, 10mA/5A	15	2023	2025	Y
K3: inductance, 10mH	20	2021	2025	Y
K8: dc voltage ratio?	20	**2025**	2027	?
K11: low ac-dc voltage, 10mV/100mV	15	**2025**	2027	Y
K2: high dc resistance, 10MΩ, 1GΩ and 1TΩ?	15	**2025**	2027	Y
K7: ac voltage ratio, 1kHz	20	2027	2029	?
K5: single phase ac power, 50/60Hz	15	2029	2031	Y
K6.a: mid ac-dc voltage, 3V to 1MHz	15	2029	2031	Y
K6.c: RF-dc voltage, 3V to 100MHz	15	2029	2031	Y
K9: high ac-dc voltage, 500V/1000V (was K6.b)	15	2029	2031	Y
K4: capacitance, 10pF/100pF	20	2033	2035	Y

4.3 Forward Look on Comparisons

4.3.1 K8: DCV to 1 kV feedback (NMIA, NRC, NMC, VSL)

- Form support group (add INRIM, EMI, RISE, KRISS)
- Champion: David Aviles (NRC)
- Need to find a suitable artefact (resistive divider)

K8 (DCV)	Proceed/Artefact	Support	Participate
NMIJ	×	×	×
METAS		×	✓
NMISA		×	×
NRC	?	✓	✓
NIST	✓	×	✓
SASO-NMCC		?	✓
INMETRO			
CMI		×	×
NPLI	✓	×	✓
INRIM			

4.3 Forward Look on Comparisons

4.3.2 Low AC-DC Voltage (K11) – discuss possibility

- Does BIPM Onsite PJVS displace this? No need high frequency measurements
- Form support group and proceed

K11 (mV AC-DC V)	Proceed	Support	Participate
NMIJ	✗	✗	✓
METAS	✓	✗	✓
NMISA	✓	✗	✓
NRC		✗	✓
NIST	✓	✗	✓
SASO-NMCC			✗
INMETRO		✗	✓
CMI	✓	✗	✓
NPLI	✓	✗	✓
INRIM	✓	✓	✓

4.3 Forward Look on Comparisons

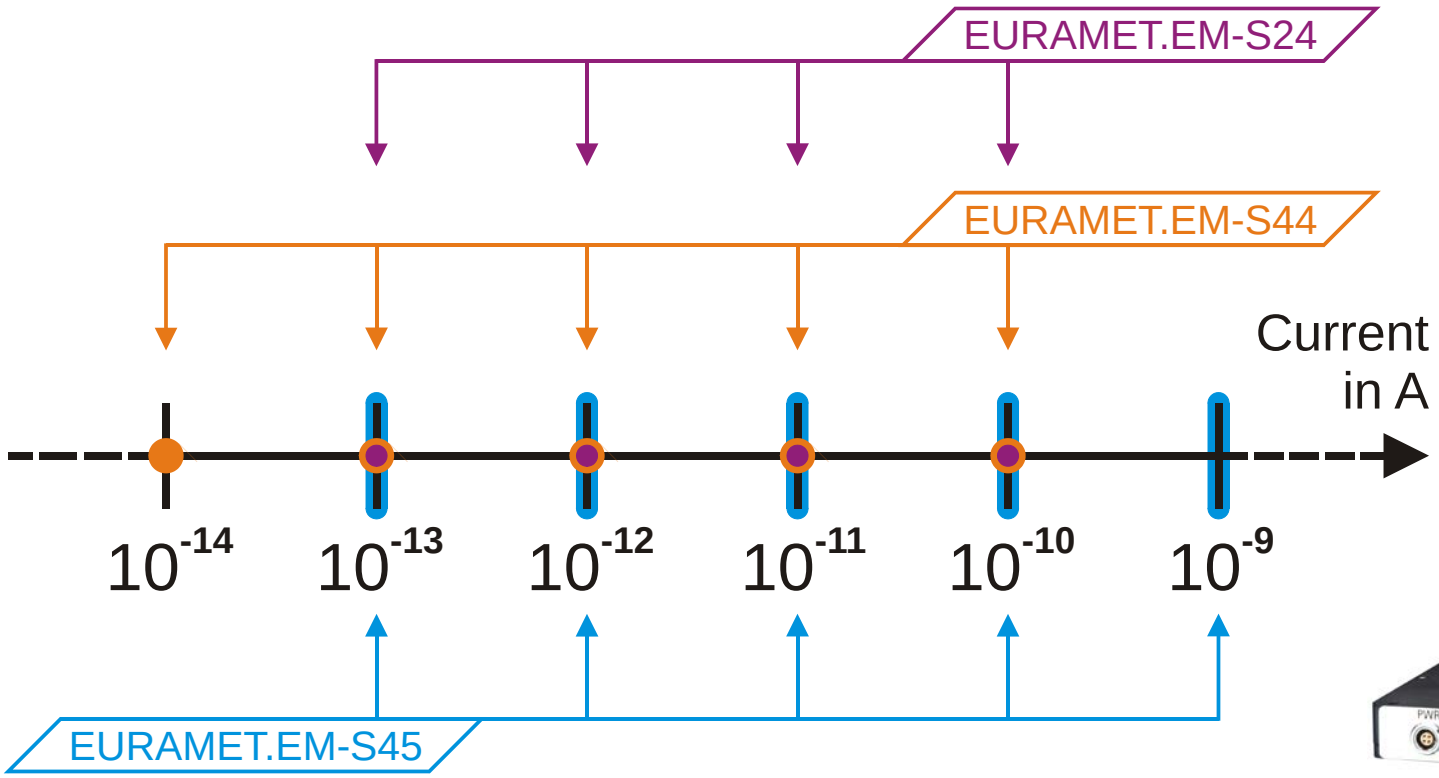
4.3.3 Future High Resistance (TΩ?, K2.X) or Small Current? [Nobu-Hisa]

4.3.4 Small current comparison possibility: report on EURAMET.EM-S45 [Rolf]

- Agree to proceed with K2 include 1 T Ω as optional
- Basis for support group: NMIJ, CENNAM, EMI, KRISS
- Consider future low current – supplementary?

K2 (high R)	Support	Participate	> 1 GΩ
NMIJ	✓	✓	✓
METAS	×	✓	?
NMISA	✓	✓	✓
NRC	×	✓	✓
NIST	×	✓	✓
SASO-NMCC	?	✓	✓
INMETRO	×	✓	×
CMI	×	✓	✓
NPLI	✓	✓	✓
INRIM			

Motivation for a new comparison



ULCA

- Nominal source currents: 100 fA, 1 pA, 10 pA, 100 pA, 1 nA
- Target uncertainty: $1 \cdot 10^{-6}$

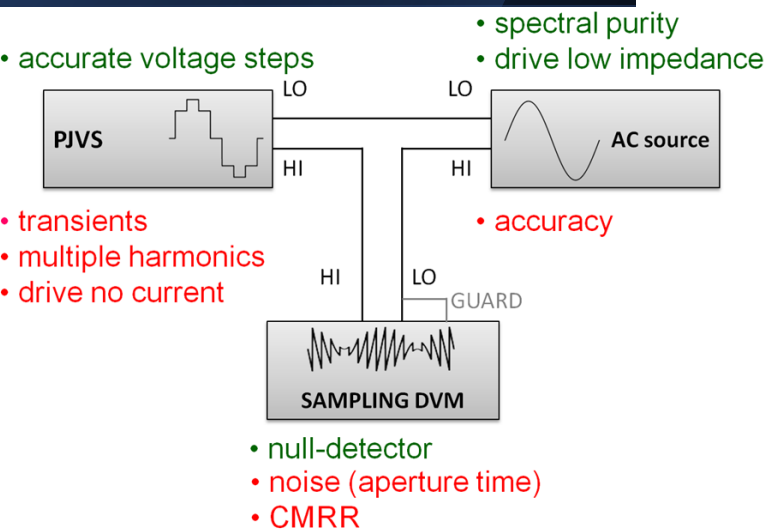
4.3 Forward Look on Comparisons

4.3.1 Future magnetic quantities

- basis for support group to make proposal in 2027

M-KX (flux density)	Proceed	Support	Participate
NMIJ	×	×	×
METAS			
NMISA	×	×	×
NRC		×	×
NIST			
SASO-NMCC	×		×
INMETRO			
CMI	✓	✓	✓
NPLI	✓	×	✓
INRIM	✓	✓	✓

5. BIPM Comparisons



5.1 Status of on-site Josephson comparison of low frequency ac voltage [Stephane] – see Michael's presentation

- Extensive pilot studies to resolve systematic errors in quantum systems!
  - NMIJ – 2015
  - CENAM – 2016
  - PTB – 2017, 2018, 2021, 2022, 2023, 2024
  - with the support of KRISS, NMIA and VNIIM
  - NPL – 2018
  - KRISS – 2018, 2022, 2023, 2024
  - NIST – 2024
- Type A: 2 to 5 parts in 10^8 demonstrated for

0.75 V - 1 kHz

Ready to commence (two per year) – more resource needed?

6. WGLF Matters

Efficiency of comparison reviews

- Thanks to staff of the following institutes: PTB, INMETRO, NMIA, METAS, NMIJ, KRISS, NMC, INRIM, MSL, CENAM, NIST, RISE, MIKES, VSL, NMISA, and INTI for providing competent reviews
- Still requires some moderation by WGLF Chair
- Strongly encourage RMOs to appoint their own third-party reviewer before submitting to WGLF?

6. WGLF Matters

Anyone want to raise a relevant technical matter?

e.g. do we eventually want an onsite Pulse JVS or JAWS comparison? (higher frequency acv)

7. RMO Comparisons

Reports from RMOs will be tabled in working group documents.

NB: RMO key comparisons must be linked to CCEM key comparison – hence two calculations:

1. Calculate comparison reference value (and participant's deviations and uncertainties)
2. Using results of linking labs to calculate results relative to the CCEM KCRV (deviations and uncertainties)

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…