Report on the work programme of the BIPM electricity laboratories 2019-2021

CCEM meeting

14-15 April 2021

Bureau
International des
Poids et
Mesures

BIPM ongoing comparisons

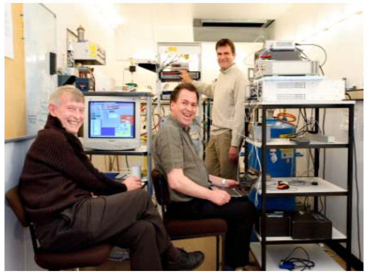
On-site comparisons of quantum standards, using transportable BIPM quantum standards

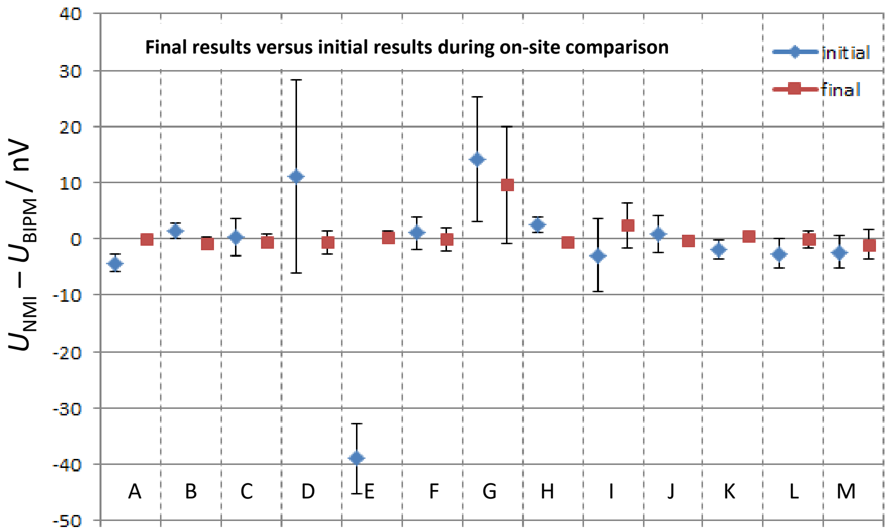
BIPM.EM-K10.a/b	JVS on-site comparison: 1.018 V and 10 V
BIPM.EM-K12	QHR on-site comparison: $R_H(2)$/100 Ω, 100 Ω/1 Ω, 10 kΩ/100 Ω

Bilateral comparisons using conventional BIPM transfer standards

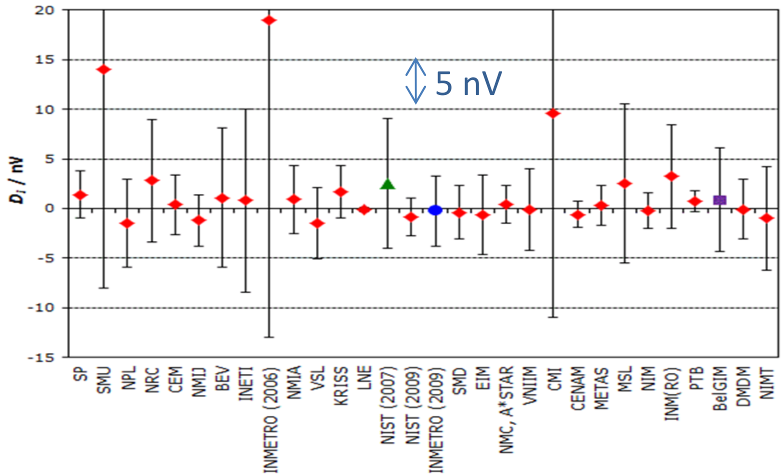
BIPM.EM-K11.a/b	voltage: 1.018 V and 10 V
BIPM.EM-K13.a/b	resistance: 1 Ω and 10 kΩ
BIPM.EM-K14.a/b	capacitance: 10 pF and 100 pF at 1592 Hz and/or 1000 Hz

BIPM.EM-K10: on-site Josephson comparison (1.018 V and 10 V)



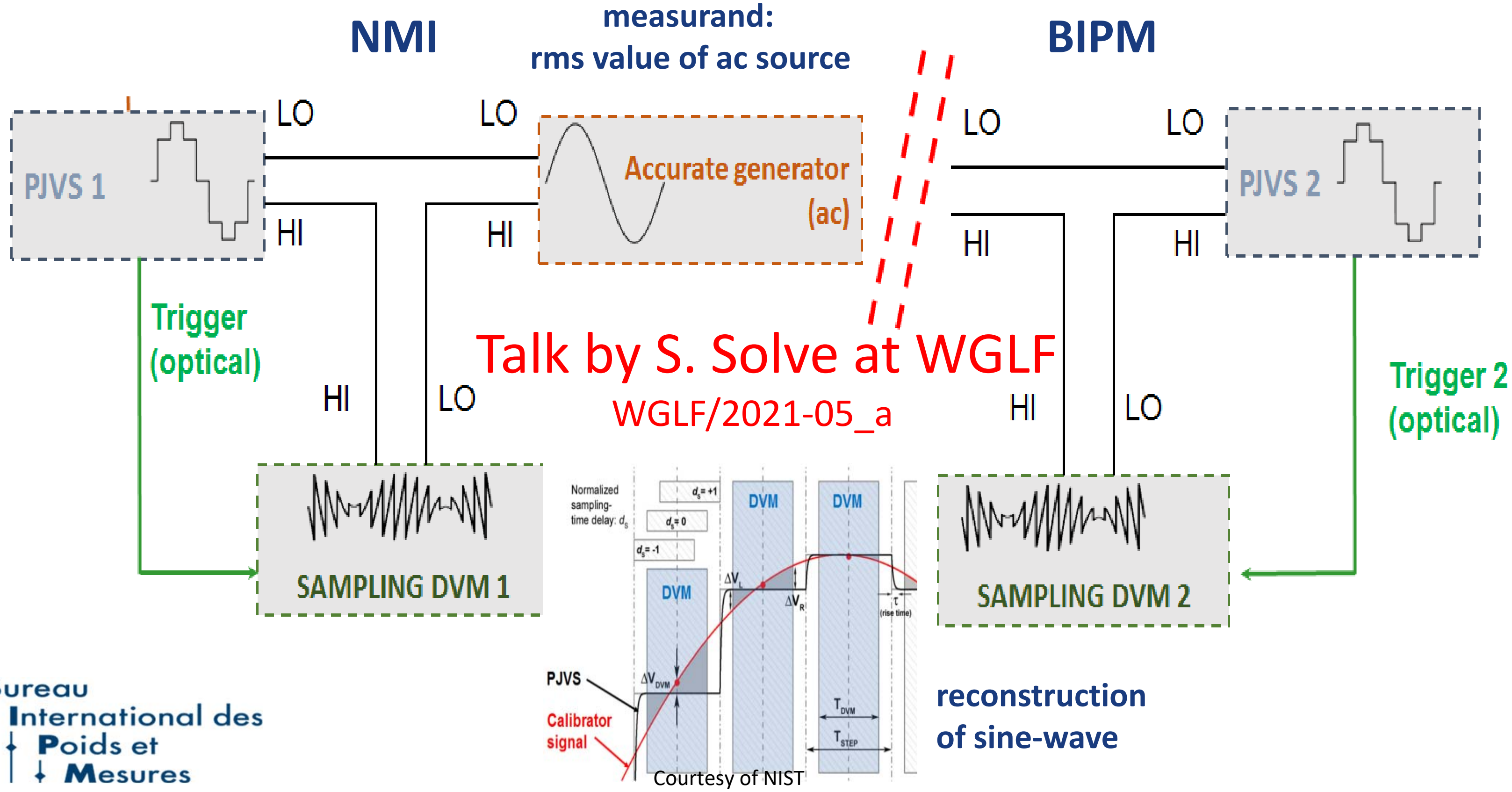


10 V Josephson voltage, degrees of equivalence in nV



- Comparison with MIKES (10 V), Finland, in Oct. 2019
  under review by WGLF chair
- Comparison planned with BIM, Bulgaria, in 2020: cancelled

Future on-site comparison using PJVSs at ac – Possible measurement scheme using differential sampling



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Challenges for an on-site comparison protocol for JVSs at low-frequency ac (<1 kHz)

1- Protocol should be applicable over a large range of existing setups:

- turn-key setups with limited flexibility designed for calibration of commercial calibrators;
- versatile systems designed in-house by NMIs;

2- As a consequence, the BIPM system must be adaptable to different configurations;

3- BIPM must propose the participant to measure a transfer standard capable of better metrological characteristics than traditional commercial AC sources;

4- Considering the large number of possibilities, the protocol must ensure that the comparison results are comparable between participants.

Possible comparison schemes

- Direct comparison of two approximated stepwise sinewaves : ‘fast DC comparison’;
- Differential sampling measurements using a commercial calibrator as a transfer standard (for turn-key systems);
- Differential sampling measurements of a “BIPM” transfer standard with better metrological capabilities (for NMI-designed systems).
- Several pilot studies and collaborations carried out with NMIs:
  - 2015: NMIJ
  - 2016: CENAM
  - 2017: PTB
  - 2018: NMIA, VNIIM, KRISS
  - 2019: NMIA, VNIIM, KRISS, PTB
  - 2020: PTB (interrupted)

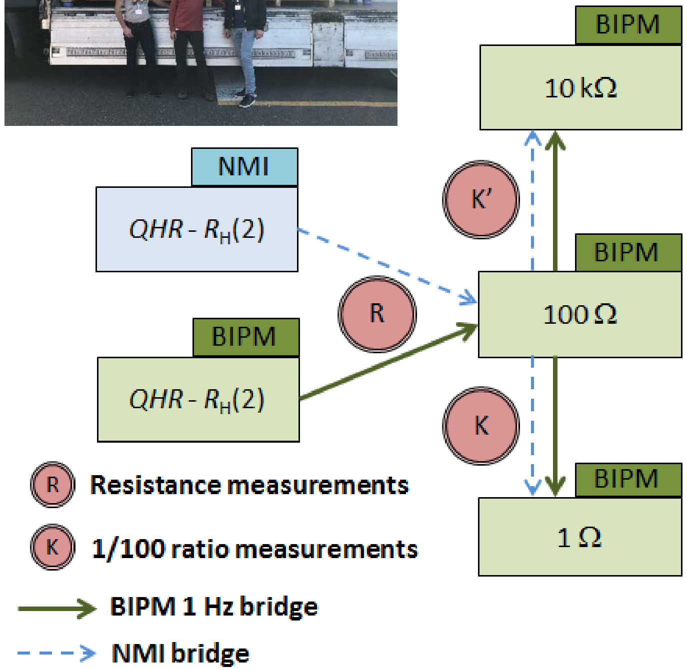
At WGLF meeting support group created:

CENAM, KRISS, METAS, MIKES, NMIA, NMIJ, NPL, NRC, PTB

« how to create maximum impact »

On-site quantum Hall resistance key comparisons (BIPM.EM-K12)

- To verify coherence of primary resistance standards by comparing quantum Hall effect based standards of the NMIs with that of the BIPM
- Resumed in 2013 at the request of the CCEM
- Programme now fully operational with 2-3 comparisons per year



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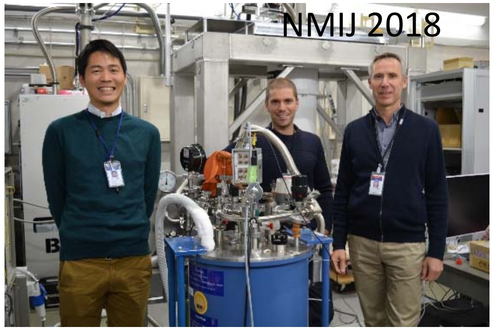
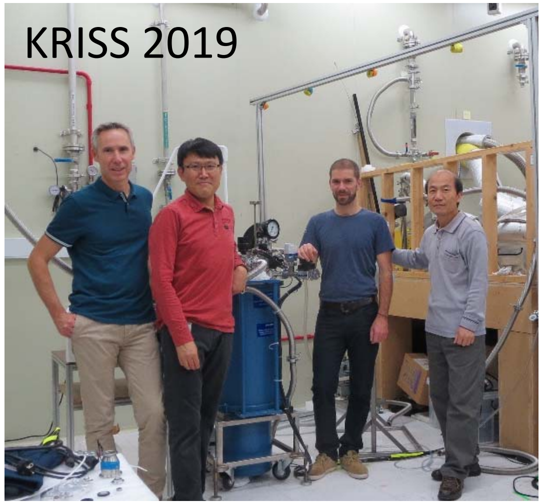
On-site quantum Hall resistance key comparisons (BIPM.EM-K12)



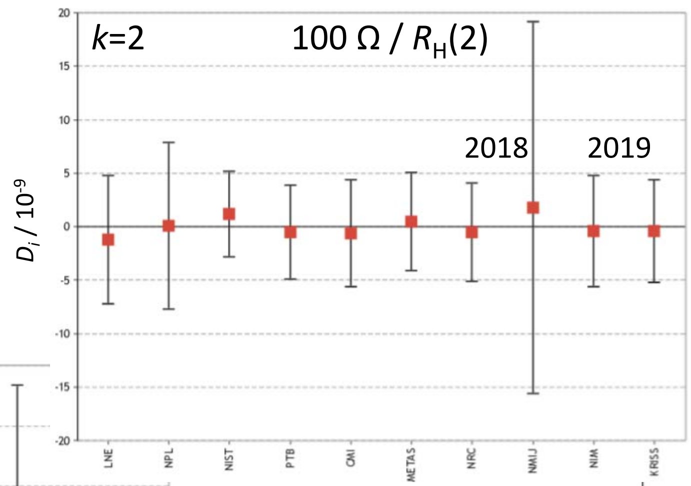
2013: PTB
2015: VSL
2017: CMI, METAS
2018: NRC, NMIJ
2019: A*STAR, NIM, KRISS

planned
2021: INMETRO (??)
2022: LNE, INRIM

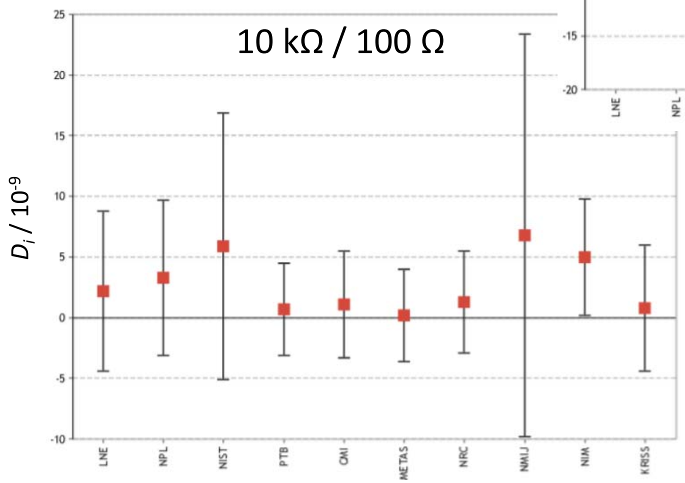
interested:
NIST, NMIA, RISE, MSL, UME, CEM

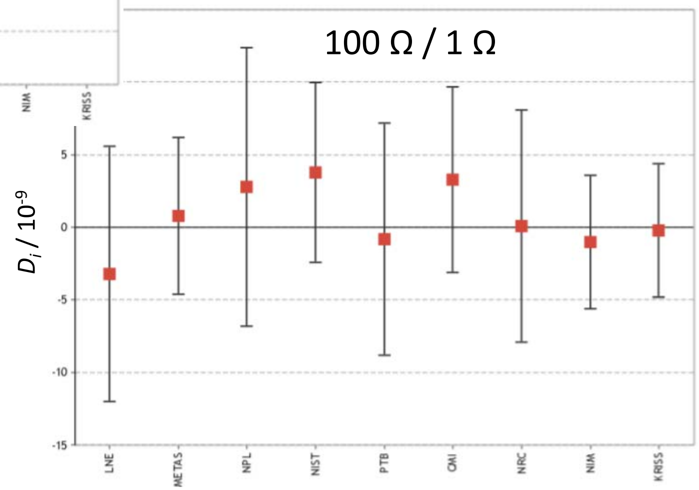


On-site quantum Hall resistance key comparisons (BIPM.EM-K12)

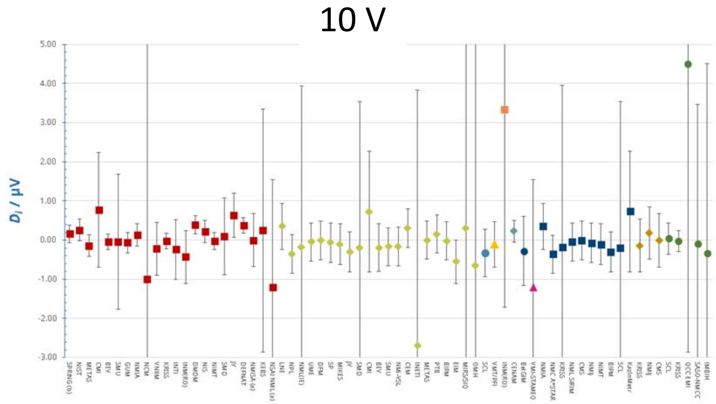


Also 2019: A*STAR
Draft B submitted to WGLF



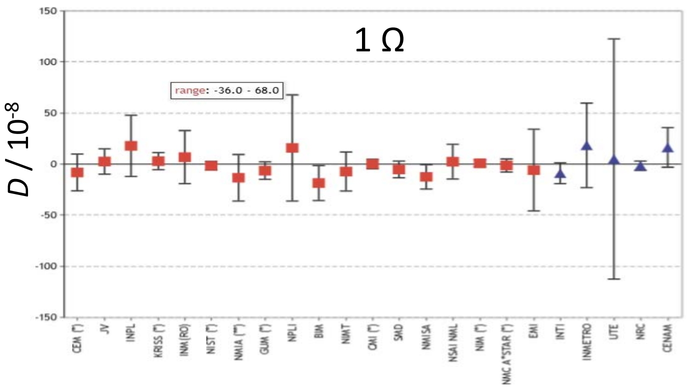


Bilateral comparisons using transfer standards

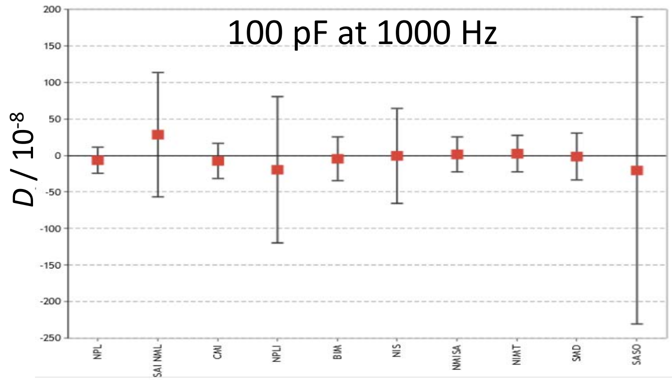


BIPM.EM-K11
Voltage 1.018 V, 10V
2019/20: BIM, NSAI
planned 2021: NPLI, SASO

BIPM.EM-K13
Resistance 1 Ω, 10 kΩ
2019/20: NIM, A*STAR, EMI, NSAI, INMETRO
planned 2021: NPLI, KazInMetr

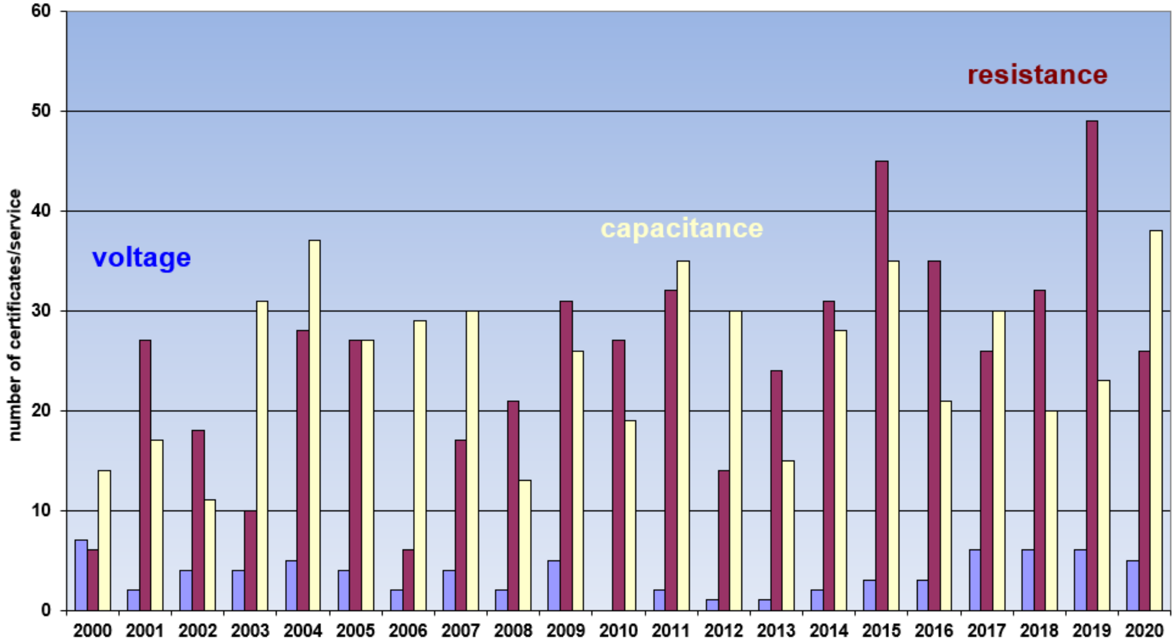


BIPM.EM-K14
Capacitance 10 pF, 100 pF
2019/20: SMD, SASO
planned 2022: LNE, UMTS



Calibrations

voltage:	1.018 V, 10 V	3-5 per year
resistance:	1 Ω, 100 Ω, 10 kΩ	25-35 per year
capacitance:	1 pF, 10 pF, 100 pF	25-30 per year



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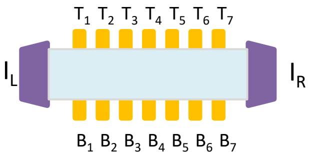
Test of QHR based on graphene (1): Samples

Two commercial samples (Graphene Waves) were received for testing → selection of one of them for purchase and further characterization

These samples are based on the fabrication technology developped at NIST → Epitaxial graphene growth on SiC

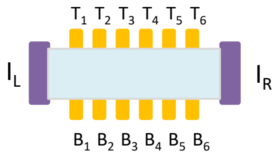
⇒ These devices allow a controllable and reversible tunability of carrier density by annealing in vacuum (up to 90-100°C, typically).

Sample #1

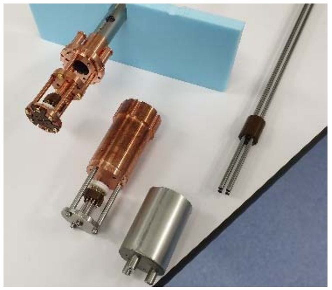


Width: 1600 µm
Length: 3600 µm
Gap between voltage pads: 400µm

Sample #2



Width: 500 µm
Length: 2800 µm
Gap between voltage pads: 400µm

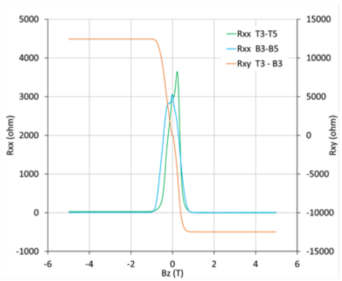


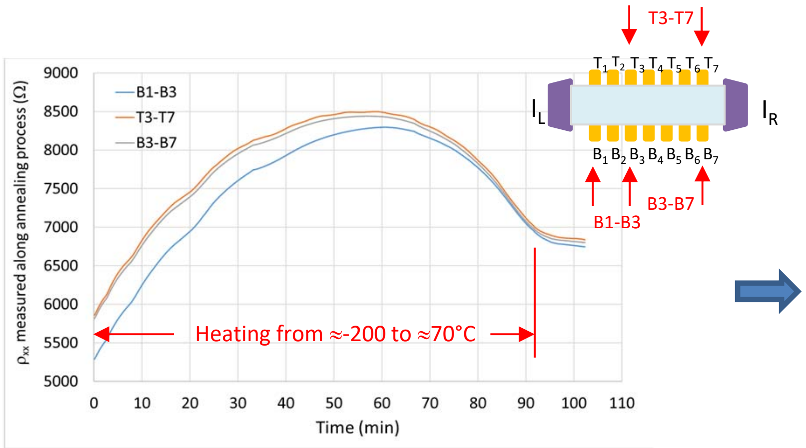
Design of a specific cryo-probe allowing carrier density tuning by vacuum annealing directly in the sample chamber of the cryostat prior measurements

Test of QHR based on graphene (2): Carrier density tuning process

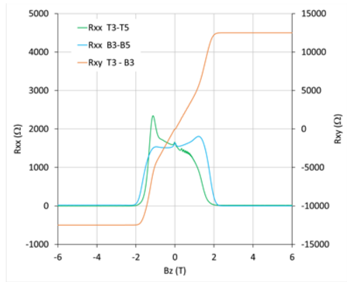
Controllable tuning is possible by annealing the sample in vacuum to the targeted carrier density while monitoring the longitudinal resistivity *Rxx.*

Initial carrier density
n = – 0.45x10[11] cm[-2]





After annealing
n = + 1.35x10[11] cm[-2]



Variation of the value of *Rxx* along the warm up & annealing process

⇒ Tuning process rather easy to implement but requires experience to stop the annealing at exactly the targeted *Rxx*

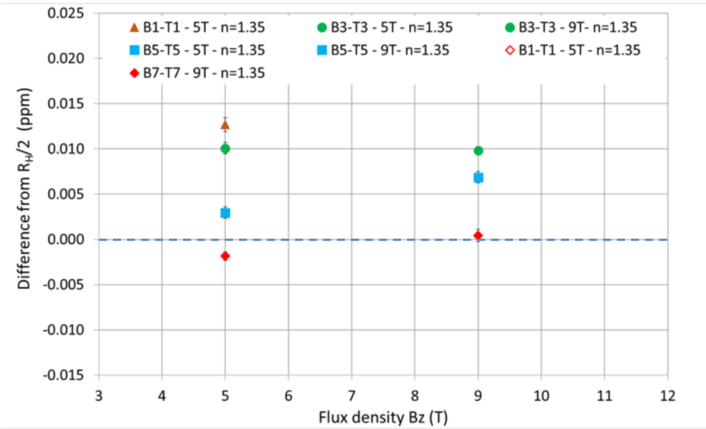
⇒ After tuning, the samples have shown to be reliable for a typical measurement period of – at least – one to two weeks

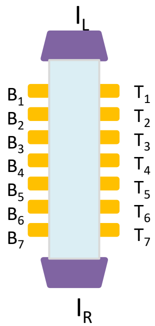
⇒ The tuning process has shown to be reversible after exposition of the sample to air during at least one day

Test of QHR based on graphene (3): comparison to a GaAs reference sample

Comparison measurements between graphene and reference GaAs samples were performed using a 100 Ω transfer standard

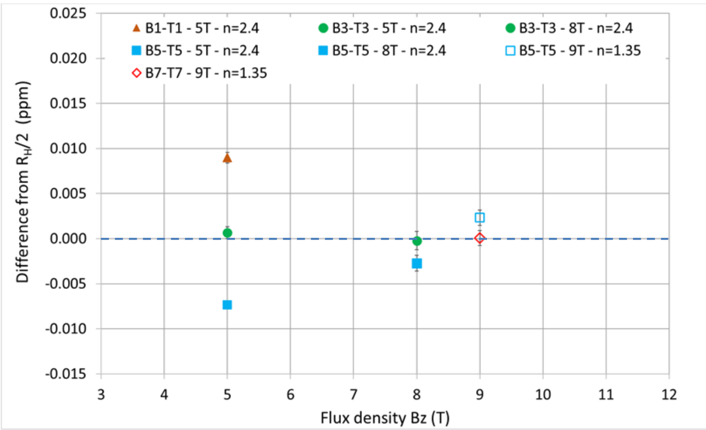
4.2 K – n=1.35 x 10^{11} cm^{-2} – I=40 μA





Sample #1

1.4 K – n=1.35 and 2.4x 10^{11} cm^{-2} – I=40 μA

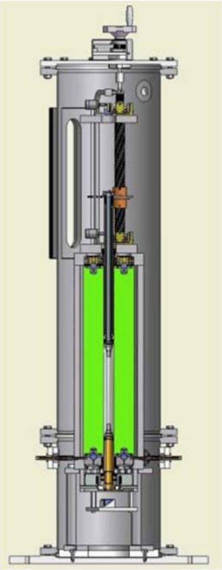


⇒ In the actual operating conditions, dispersion is observed on the measured difference depending on the voltage terminal pair used

⇒ The results are still dispersed at 1.4 K and 5T but less for higher flux density.

⇒ Information from Graphene Waves indicate that less dispersed results can be obtained for higher current values (≥ 80 μA).

Calculable capacitor



The **assembling** of the calculable capacitor (CC) has been resumed recently.

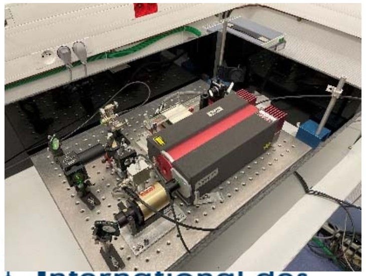
- **Alignment of the main electrode bars:**

⇒ After relocation of the CC in a new room a few years ago, its re-assembling was stopped close the end of the alignment process

⇒ A first step in resuming assembly was then to check the actual alignment and improve it as necessary

⇒ First results show that the alignment of the bars is similar to what was measured few years ago; however, the alignment must still be improved to obtain a better final uncertainty on the realization of the farad

⇒ Improving alignment require the improvement of the capacitive probe – or the design of a new probe – dedicated to the measurement of the adjacent main bar gaps (poor repeatability with that currently used)

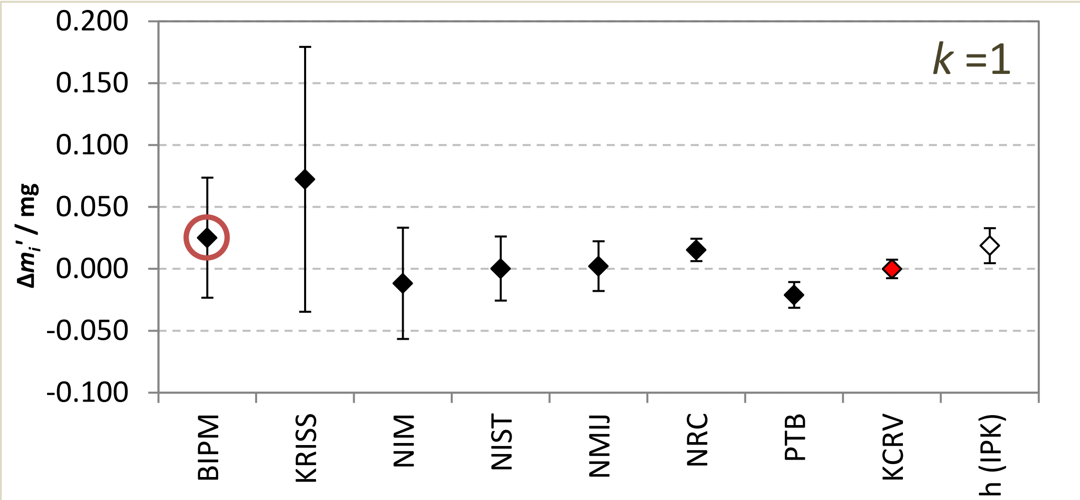


- **Relocation of the laser in the CC room:**

⇒ The laser has recently been relocated in CC lab and its frequency stabilization electronics improved

⇒ The new electronics is based on that developped for the watt balance experiment; it has been implemented and is now operational

BIPM Kibble balance: measurement & improvement



Measurements in 2019

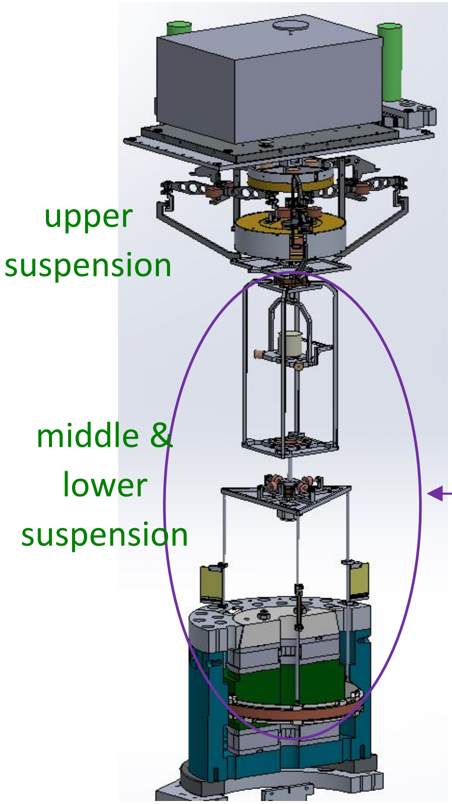
- participation in CCM.M-K8.2019
- standard uncertainty 49 µg
  limited by parasitic coil motion & voltage measurement (electrical grounding)

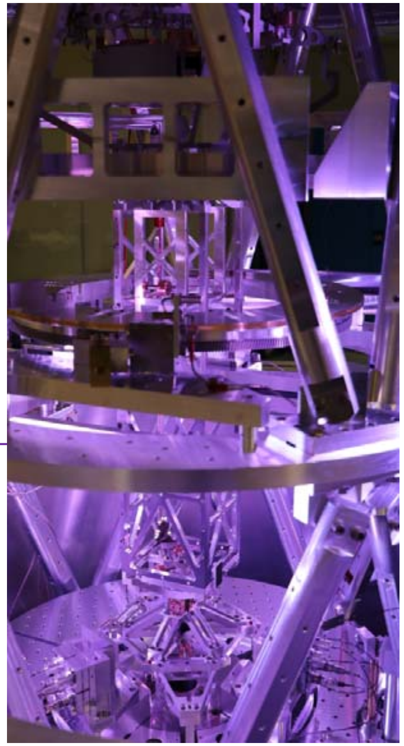
H. Fang, F. Bielsa, S. Li, A. Kiss, M. Stock, *Metrologia* **57** (2020) 045009

Various improvements in 2020

- Upgrade of laser frequency servo-control and of various electronics for position sensors
- automation & refinement of data processing programs
- investigation & improvement of electrical circuit → further investigation is required

BIPM Kibble balance: towards Mark II apparatus





- STEP I: new middle & lower suspension
  - much stiffer and more easily adjustable mechanics
  - new bifilar coil having a larger wire length
  - operation in vacuum confirmed

- STEP II: replacing upper suspension (motor + 3 levers for generating the coil vertical motion) → minimize unwanted coil motion (reduce type B uncertainty)
  - replacing commercial weighing cell
  - a first beam balance prototype being fabricated

Thank you for your attention !