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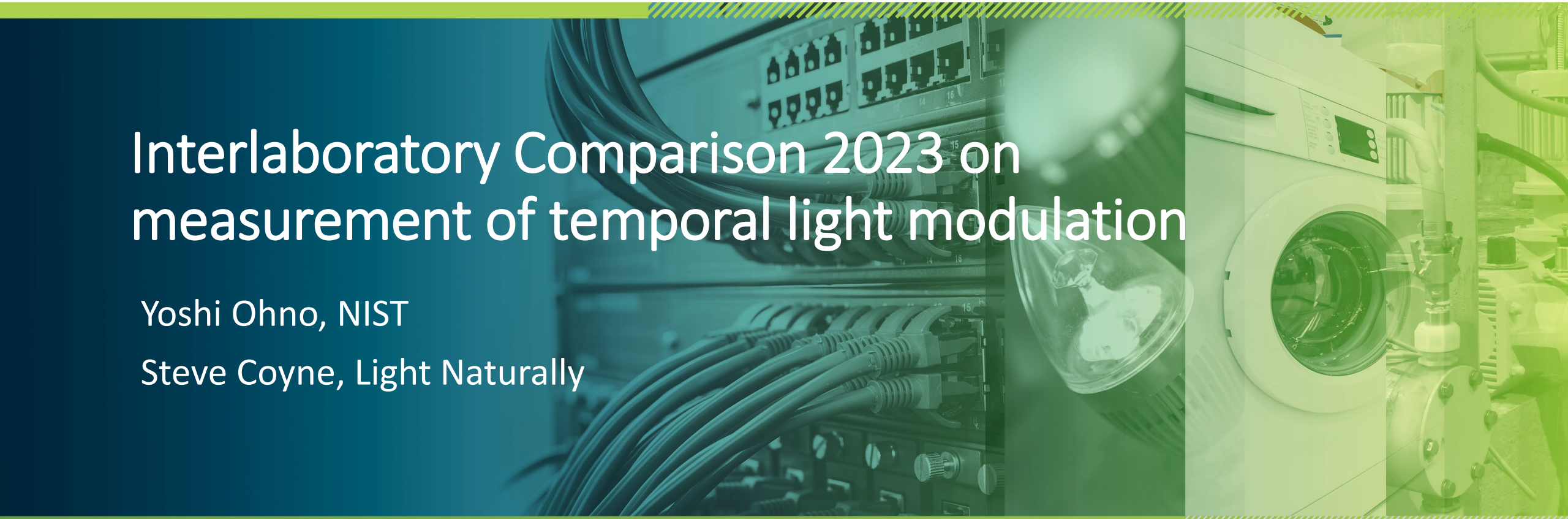


Interlaboratory Comparison 2023 on measurement of temporal light modulation

Yoshi Ohno, NIST

Steve Coyne, Light Naturally

International Lighting Seminar: Perspectives on Sustainability, Performance, Health & Smart Lighting

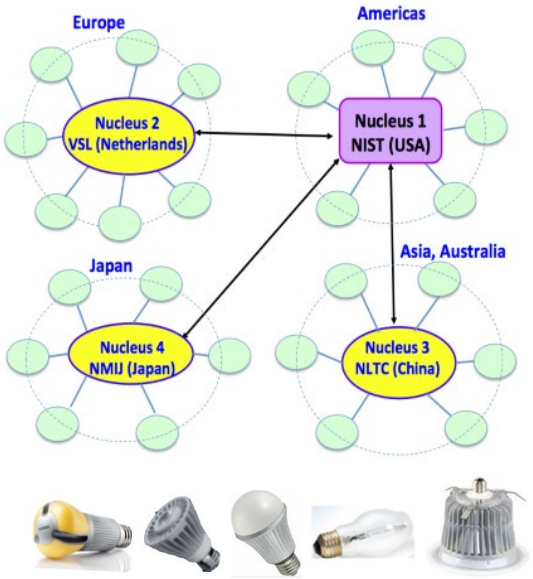
London, UK 14th May 2024

iea-4e.org

SSL Annex Previous Interlaboratory Comparisons

IC 2013 Interlaboratory Comparison of Measurement of Solid State Lighting Products

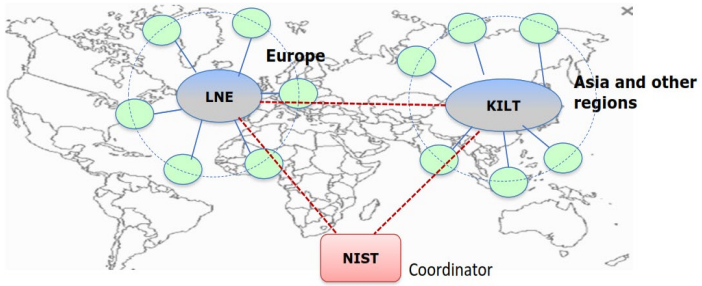
- **54 labs** from 19 countries participated
- Linked 56 labs from regional PT programs, making **total 110 labs**.
- **LED lamps** as comparison artefacts
- Total **8 quantities** (Luminous flux, color quantities, etc.
- Designed as **proficiency test** (compliant w ISO/IEC 17043)



[Link to IC 2013 Final Report]

IC 2017 Interlaboratory Comparison of goniophotometer measurements

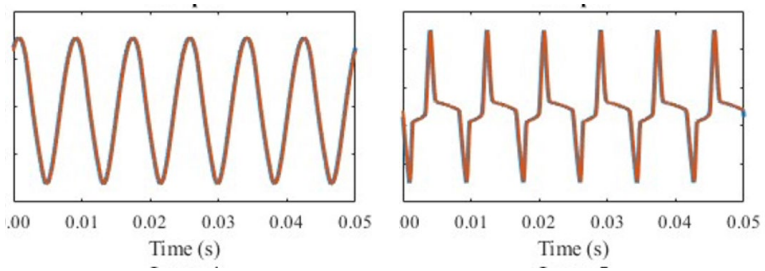
- **36 labs/42 goniophotometers** from 19 countries
- **LED luminaires** (3 types) + narrow-beam LED lamp
- Total **15 quantities** incl. 5 goniophotometric quantities
- Designed as **proficiency test**
- **CIE S 025** as the test method



[Link to IC 2017 Final Report]

IC 2023 on measurement of temporal light modulation

Background



- **Flicker and stroboscopic effects:**
  - → negative health effects,
  - → discomfort, traffic safety concerns
- **EU Ecodesign regulation** enforced requirements of PstLM (<1) and SVM (<0.9) in Sep. 2021 for all products sold in Europe. - Proposed to be adopted by **Australia** and **New Zealand.**
- Other regulatory programs (US Energy), California Energy Commission, U4E also have TLM requirements for some products.
- **Needs for measurement assurance and testing accreditation**
- **Metrics often used**

  Short term flicker indicator (PstLM) - IEC TR 61547-1:2020
  Stroboscopic effect visibility measure (SVM) - IEC TR 63158:2018
  Mp – ASSIST vol. 11, Issue 3, 2015

IC 2023 Objectives

1) **Provide technical study** to investigate the level of agreement in measurements of temporal light modulation (TLM) quantities by laboratories worldwide, focusing on measurements of:
   - Short-term flicker index (P_{st}^{LM}) in IEC TR 61547-1
   - Stroboscopic effect visibility measure (SVM) in IEC TR 63158
2) **Provide proficiency test** for measurement of P_{st}^{LM} and SVM for accreditation programs
3) Promote a harmonised and accurate measurement of TLM quantities globally.

IC 2023 Outline

- **Instruments**: commercially available or custom-made instruments/systems to measure light waveforms, PstLM and SVM of light sources, meeting the requirements in CIE TN 012
- **Artefacts:** 4 LED lamps + TLM generator source
- **Test methods:**

  IEC TR 63158 (for SVM)

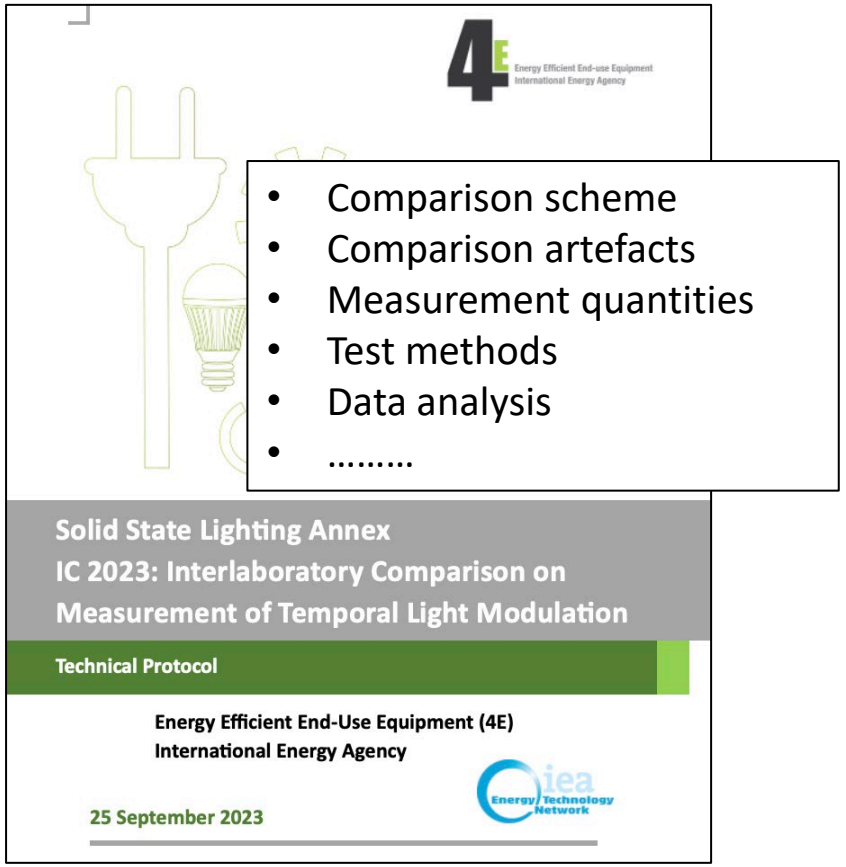
  IEC TR 61547-1 (for P_{st}^{LM})

  CIE TN 012:2021 (for data sampling and measurement)
- **Target participants:** Testing labs, lighting manufacturers, instrument manufacturers, research laboratories
- **Linked with**
  - **MetTLM** comparison of TLM measurement
  - **China GBV-LC** comparison of TLM measurement
- **Measurement quantities** PstLM, SVM, and 3 other TLM quantities

IC 2023 launched in Sep. 2023

- **Registration** opened for Sep. 2023 to Dec. 2023
- **IC 2023 Technical Protocol** published in Sep. 2023
- Fees €2,600 (early), €2,900 per lab. Additional €800 for TLM generator
- **Participants: 18 labs / 19 instruments (9 labs for TLM generator)**
- Measurement rounds started Jan. 2024

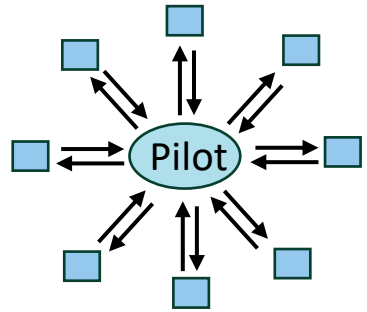
IC 2023 Technical Protocol (Sep. 2023)



Available at https://www.iea-4e.org/wp-content/uploads/2023/09/IC-2023-Technical-Protocol-Final.pdf

IC 2023 Scheme

IC 2023 measurement rounds are star-type: bilateral comparisons between each participant lab and Nucleus Lab (pilot lab).



Nucleus Laboratories (Operating Nucleus Lab)

KIEL Institute, Korea (formerly, Korea Institute of Lighting and ICT)

Denmark University of Technology (DTU), Denmark -- for TLM generator

Supporting Nucleus Laboratories

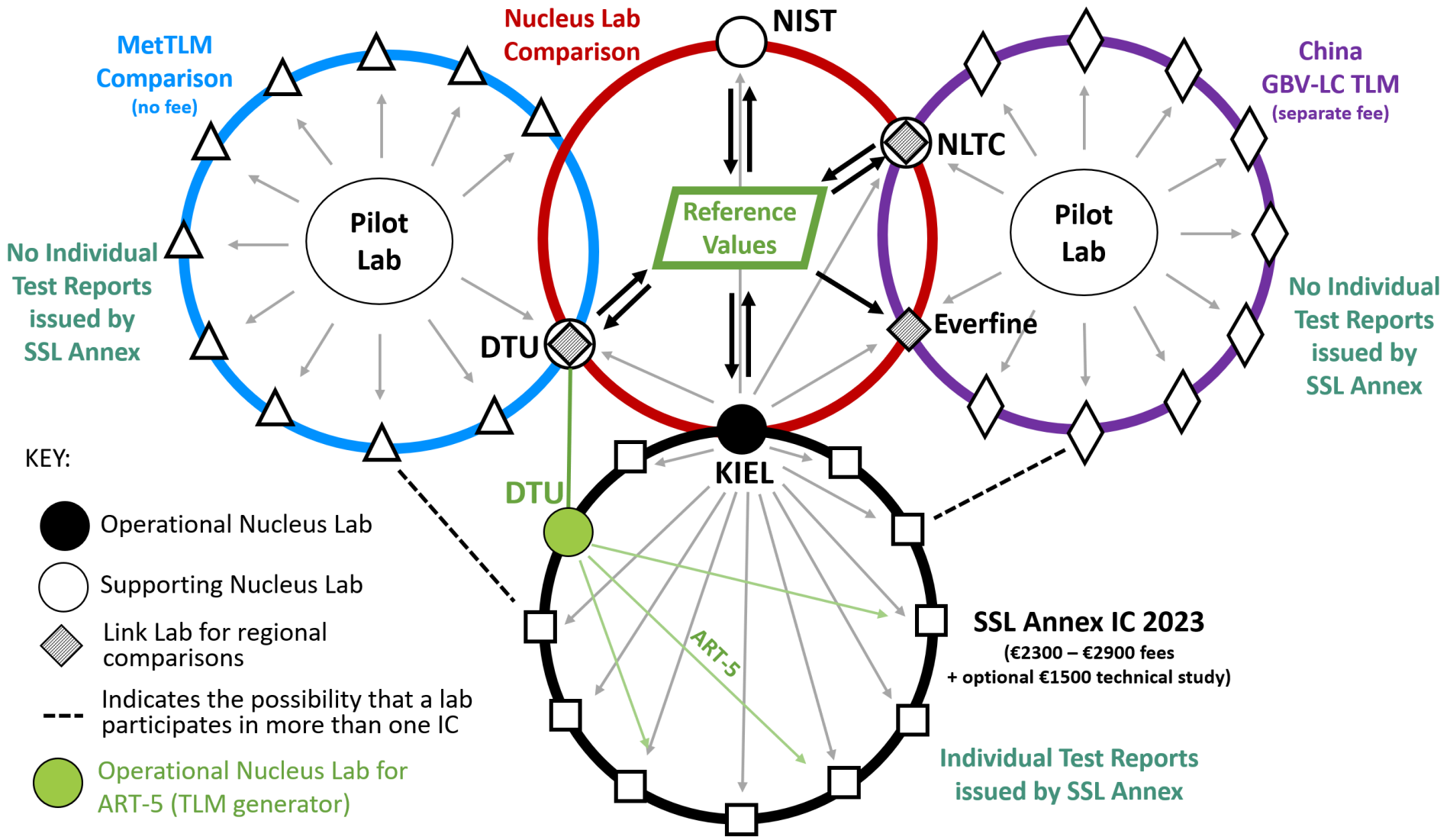
National Institute of Standards and Technology (NIST), USA

National Lighting Test Centre (NLTC), China

IC 2023 is linked with

- **MetTLM** comparison in Europe
  Link Lab – DTU, Denmark
- **China GBV-LC** TLM comparison in China
  Link Lab – NLTC, China

IC 2023 Structure



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Measurement Quantities

For PT and Technical study

	Comparison Quantities	Symbol
1	Short-term flicker index	P_{st}^{LM}
2	Stroboscopic effect visibility measure	M_{VS}

Report of expanded uncertainties (k=2) requested

	Measurement conditions reported
1	Supply voltage measured
2	RMS current of the lamp
3	Sampling frequency
4	Measurement duration
5	Optical waveform data
6	Dominant frequency (optional)

For Technical Study

Optional Quantities
Percent Flicker <200 Hz (California Eng. Com)
Modulation depth
Flicker Index
Mp

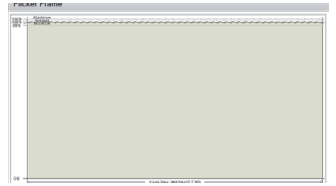
Lab information reported
TLM measurement device used
Optical input method (sphere or bench)
Power supply and AC power meter used

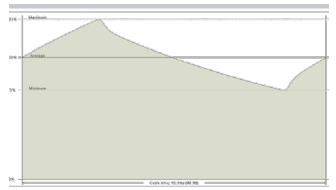
Comparison Artefacts

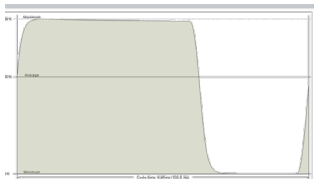
Table 1. Artefact Set for IC 2023

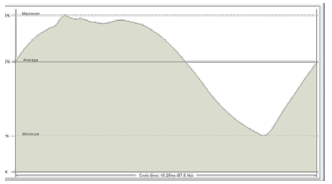
	Artefact	Photo	Electrical Rating	Feature	ID# for NLC
ART-1	LED lamp		230 VAC, 50Hz, 3.8 W	low SVM (<0.5) P_{st}^{LM} (<0.5)	1-01 to 1-08
ART-2	LED lamp		230 VAC, 50Hz, 3.5 W	Higher SVM (0.5 – 1.0) P_{st}^{LM} (<0.5)	2-01 to 2-08
ART-3	LED lamp		230 VAC, 50Hz, 5 W	High SVM (>2.0) P_{st}^{LM} (<0.5)	3-01 to 3-08
ART-4	LED lamp (complex waveform)		230 VAC, 50Hz, ~2.5 W	High SVM (>1.0) P_{st}^{LM} (<0.5)	4-01 to 4-08
Artefact for Optional Technical Study					
ART-5	TLM waveform generator (VISO Systems Labarazzi)		100 VAC to 230 VAC	Five preset test profiles	**LAZ-1** (L1-01 to L1-05) **LAZ-2** (L2-01 to L2-05)

Waveforms









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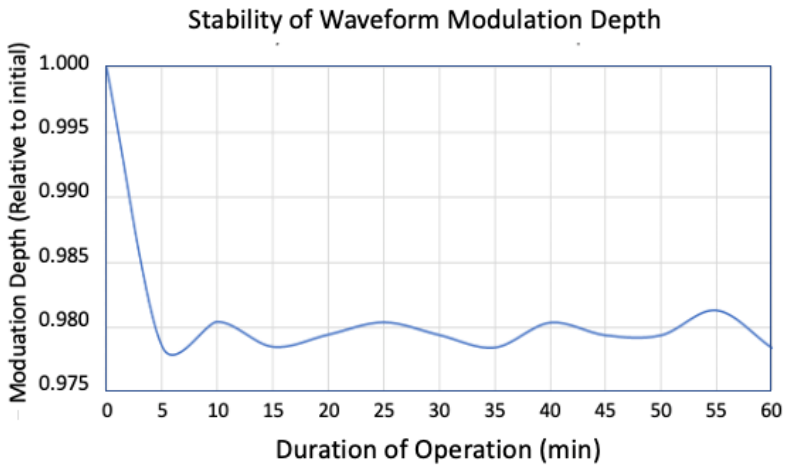
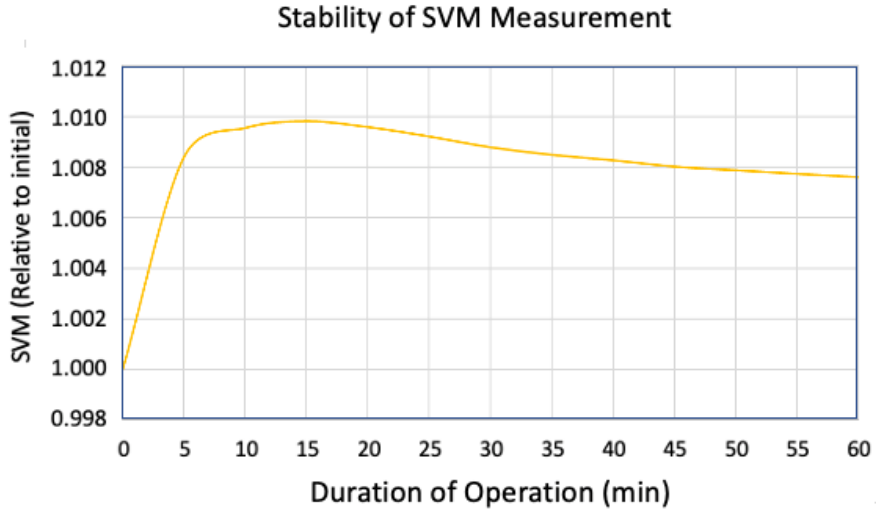
Comparisons Artefacts ART-5

ART-5

TLM Generator Source: VISO Systems –
Temporal Light Modulation Simulator “Labarazzi”

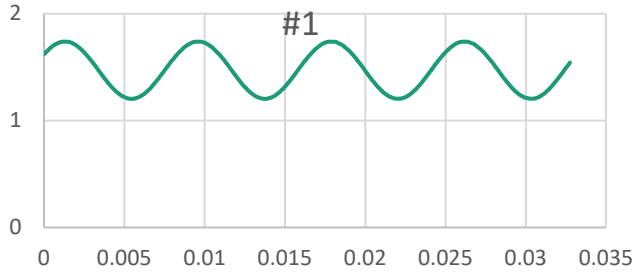
- Waveforms: Square, PWM, Sine, Triangle, Sawtooth
- Frequency range: 2 - 10,000 Hz
- Modulation: 1 – 100%
- Duty Cycle (PWM): 1 – 100%



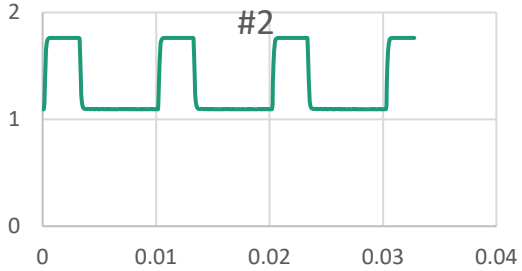


Waveforms used in ART-5

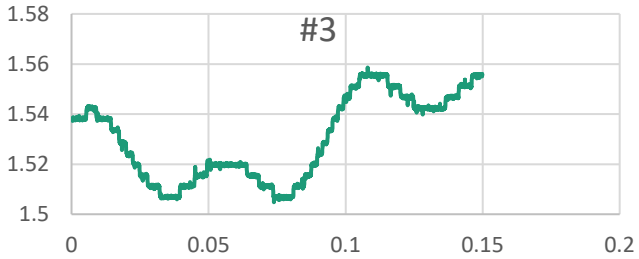
(1) Sine wave, 120.5 Hz



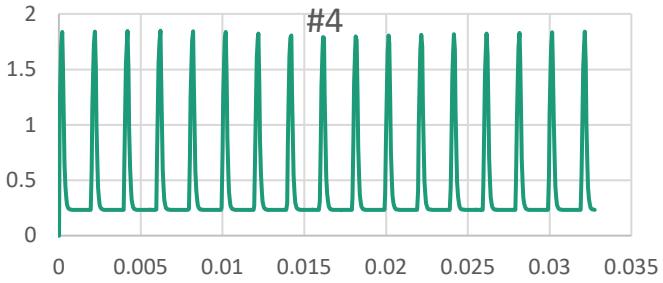
(2) PWM wave at 99.5 Hz



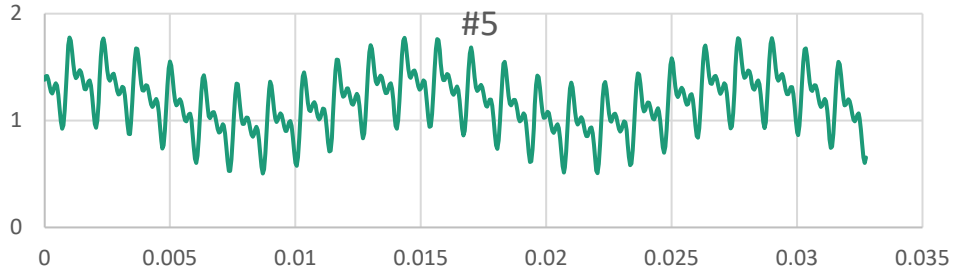
(3) Multiple low freq. components. (high PstLM, low SVM)



(4) PWM wave at 500 Hz, multiple high freq. components.



(5) Mixture of multiple frequency sine waves.



Data Analyses

(1) Differences (x-X)

x: participants' result
X: reference value

for each participant and for each artefact, for P_{st}^{LM} and M_{VS},

(2) z' score

For proficiency test purposes, z' score (ISO 13528) is calculated by

$$z' = \frac{x - X}{\sqrt{\hat{\sigma}^2 + u_X^2 + u_{\text{drift}}^2}}$$

Where

$\hat{\sigma}$ SDPA value
u_X: standard uncertainty of the reference value
u_{drift}: standard uncertainty for artefact drift calculated by

$$u_{\text{drift}} = \frac{0.8 \cdot \hat{\sigma}}{2\sqrt{3}}$$

(3) En number

For proficiency test purposes, En number (ISO/IEC 17043) is calculated by

$$E_n = \frac{x - X}{\sqrt{U_{\text{lab}}^2 + U_{\text{ref}}^2}}$$

where

U_{lab} expanded uncertainty (k=2) of a participant's result
U_{ref} expanded uncertainty (k=2) of the reference value.

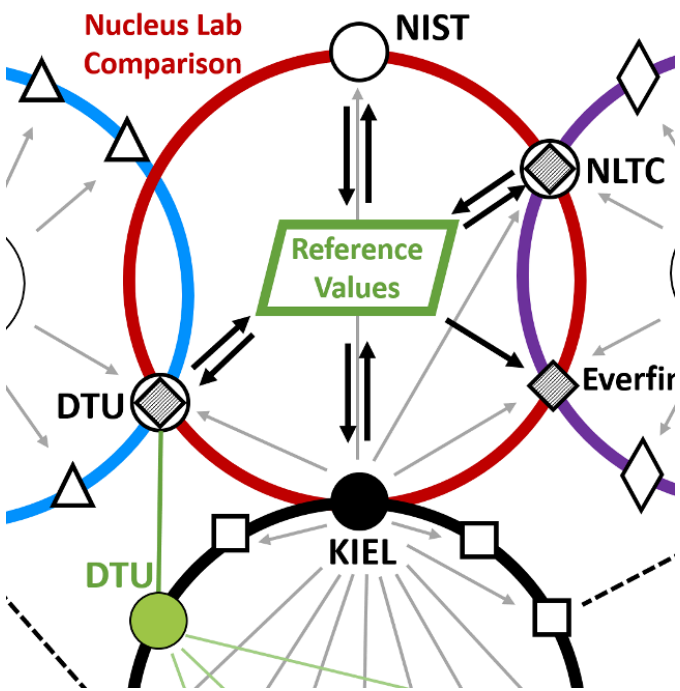
Comparison Reports to be issued

(1) **Nucleus Laboratories Comparison Report** – issued after completion of the Nucleus Laboratories Comparison

(2) **Individual Test Reports (ITR)** – issued to each participant after each measurement round is completed. The ITRs may be used for a proficiency test in laboratory accreditation programs that recognize IC 2023.

(3) **Final Report** – presenting the results comparing measurements of all participants in an anonymous manner. The report will provide results for each artefact type and each of the measurement quantities, and discuss problems observed and considerations made in the results.

Nucleus Laboratory Comparison



Purpose

1) Establish Reference Values for each artefact.
2) Provide the link (of Reference Values) to regional comparisons.
3) Check possible problems in the Comparison Protocol

Test method: IC 2023 Technical Protocol was used, but two sets of artefact were measured by each lab.

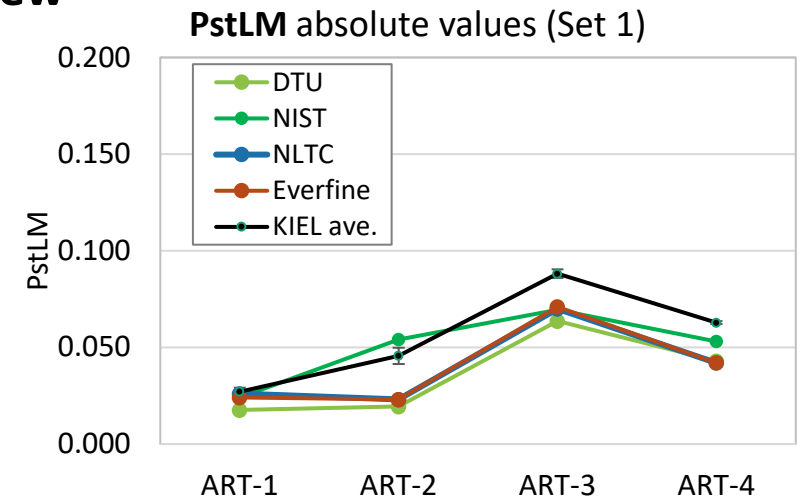
Participants:

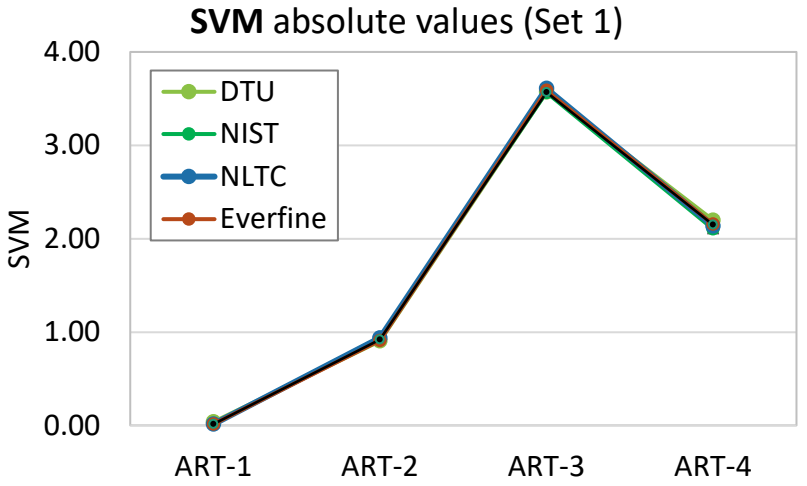
KIEL …. Operating Nucleus Lab
DTU …. Supporting Nucleus Lab and Link lab for MetTLC
NIST …. Supporting Nucleus Lab
NLTC …. Supporting Nucleus Lab and Link Lab for China GBV-LC
Everfine … Link Lab (2nd) for China

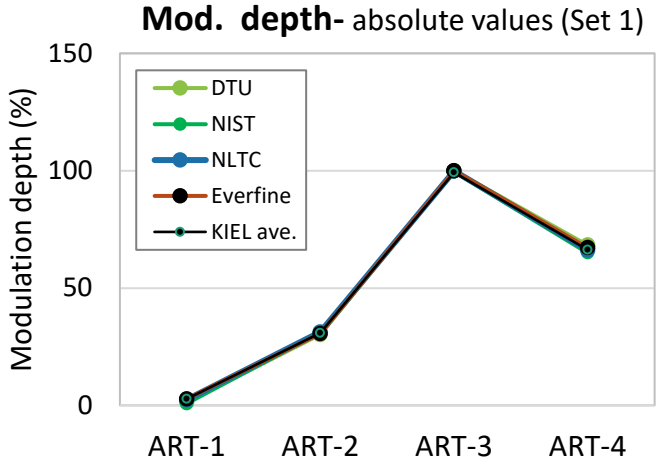
Status – Completed. NLC Report to be published soon.

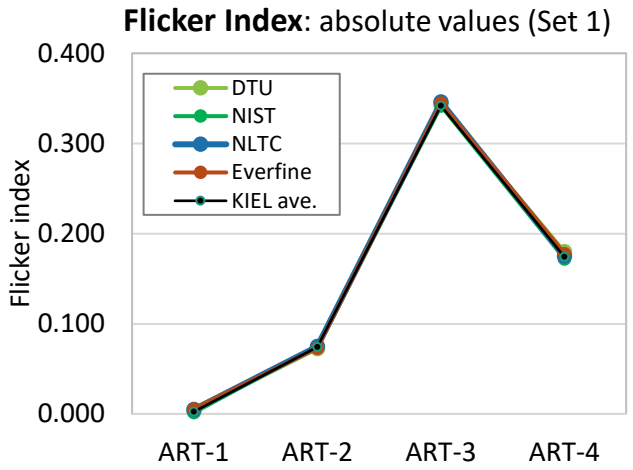
Results of Nucleus Laboratory Comparison

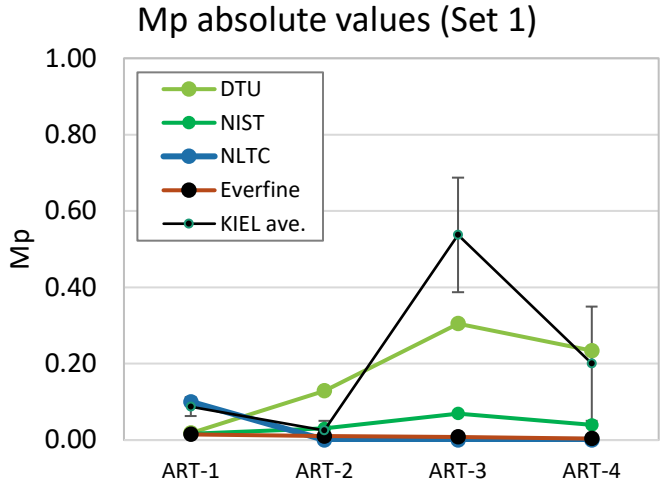
1) Overview







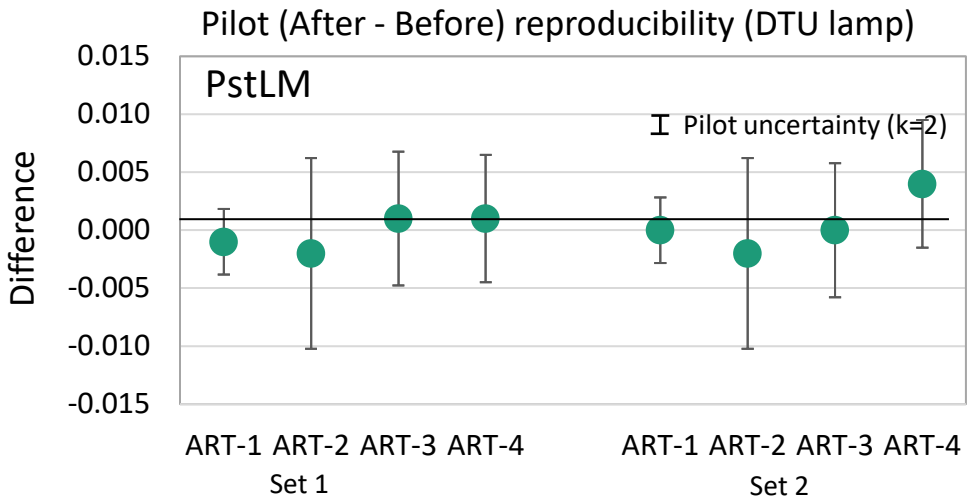


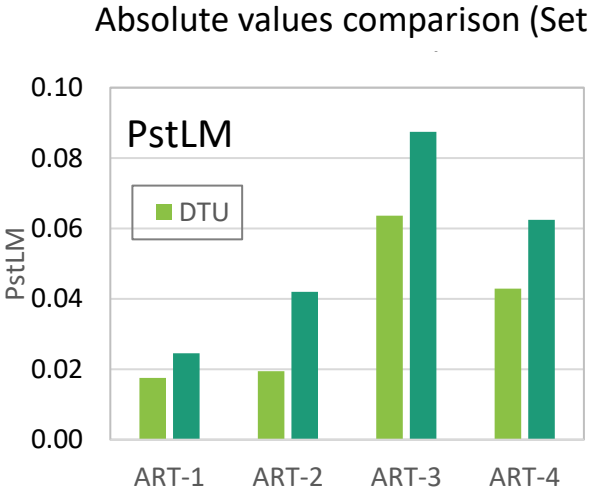


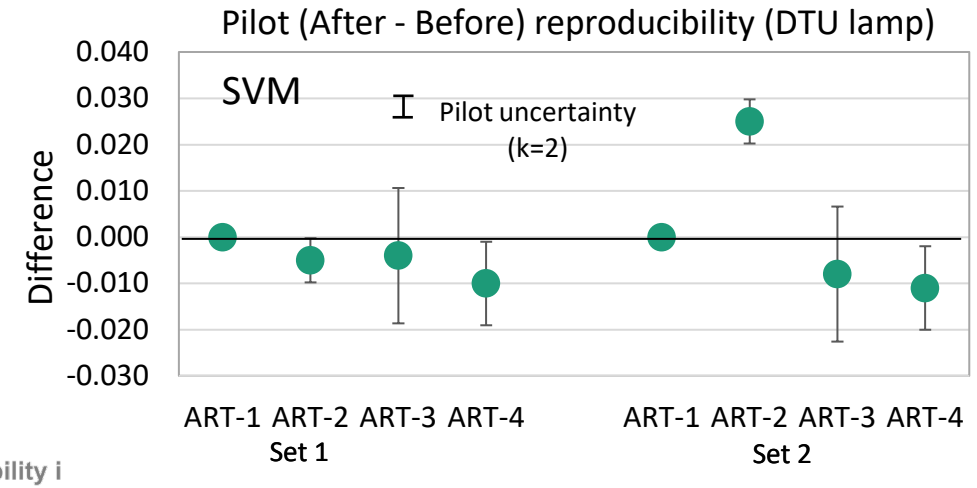
Results of Nucleus Laboratory Comparison

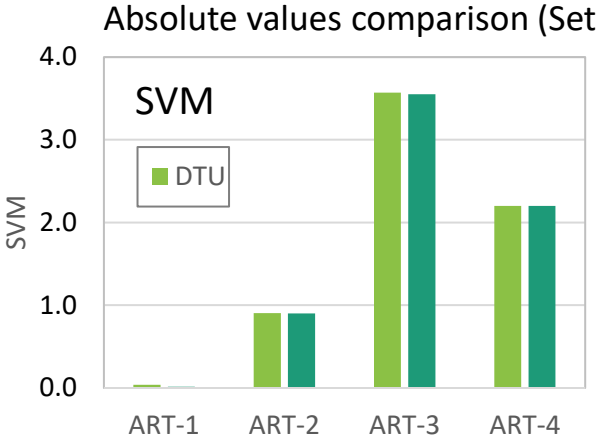
2) Reproducibility of pilot lab (After – Before)

Examples









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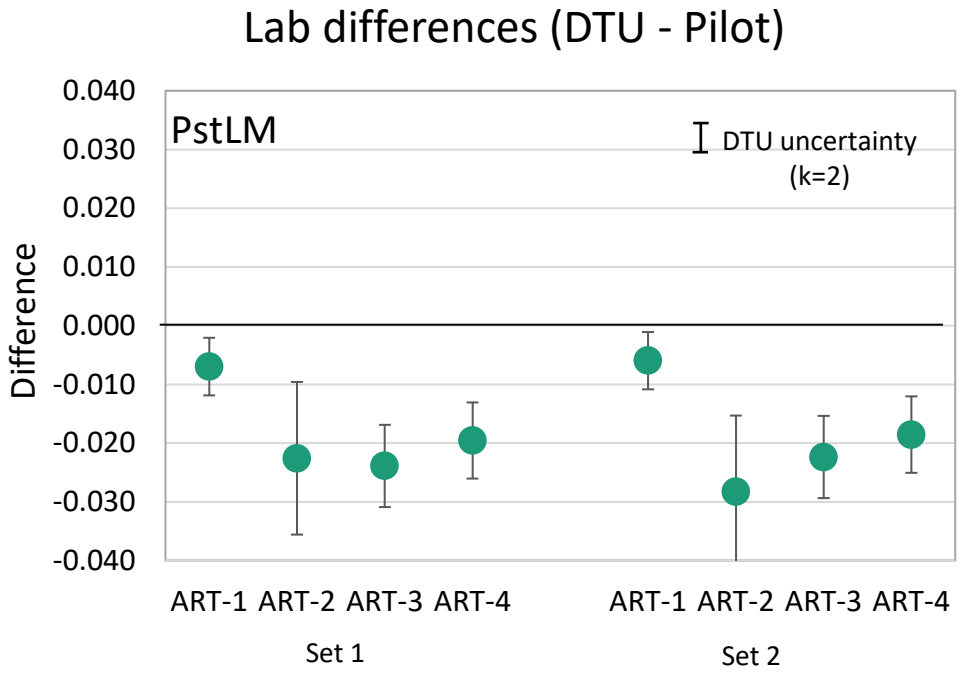
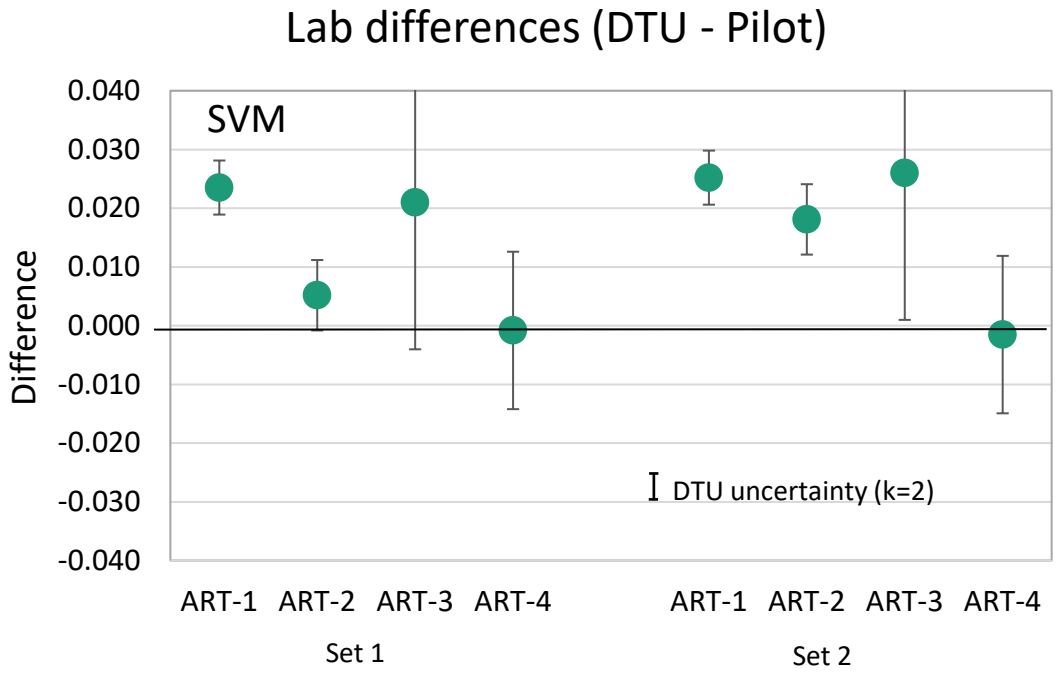
Results of Nucleus Laboratory Comparison

3) Difference between each Lab and Pilot

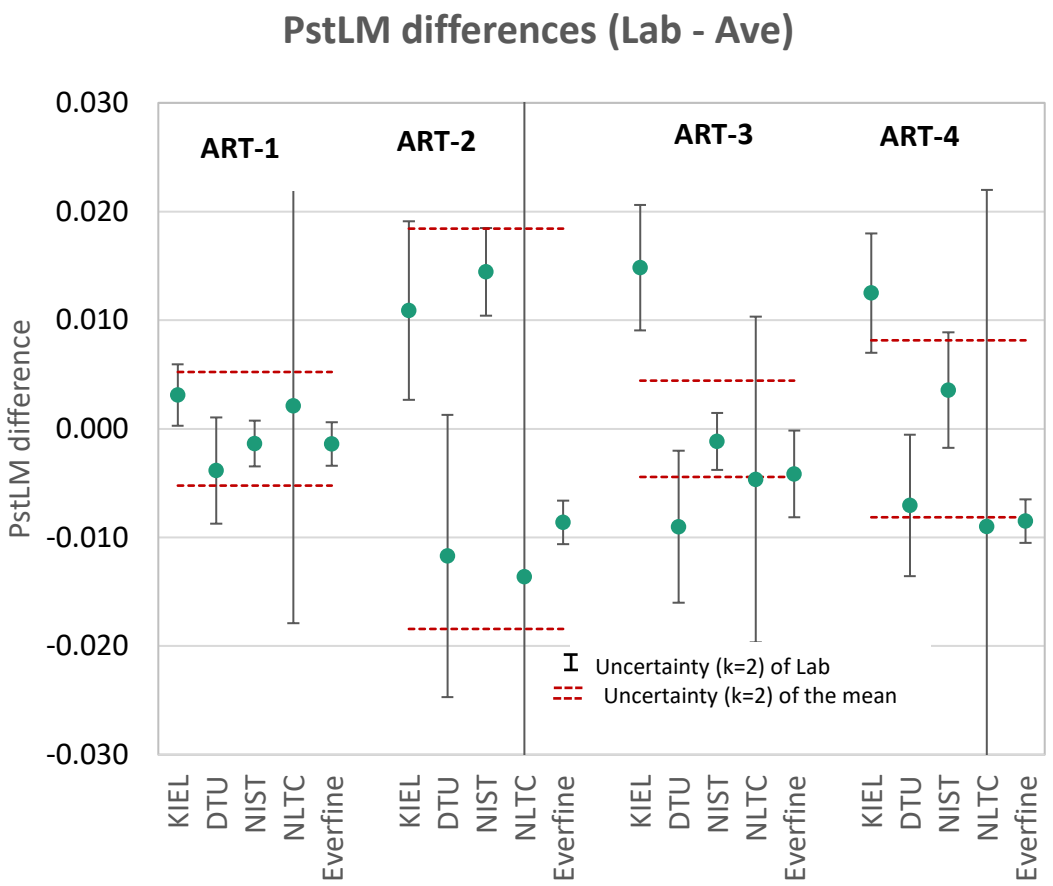
Examples

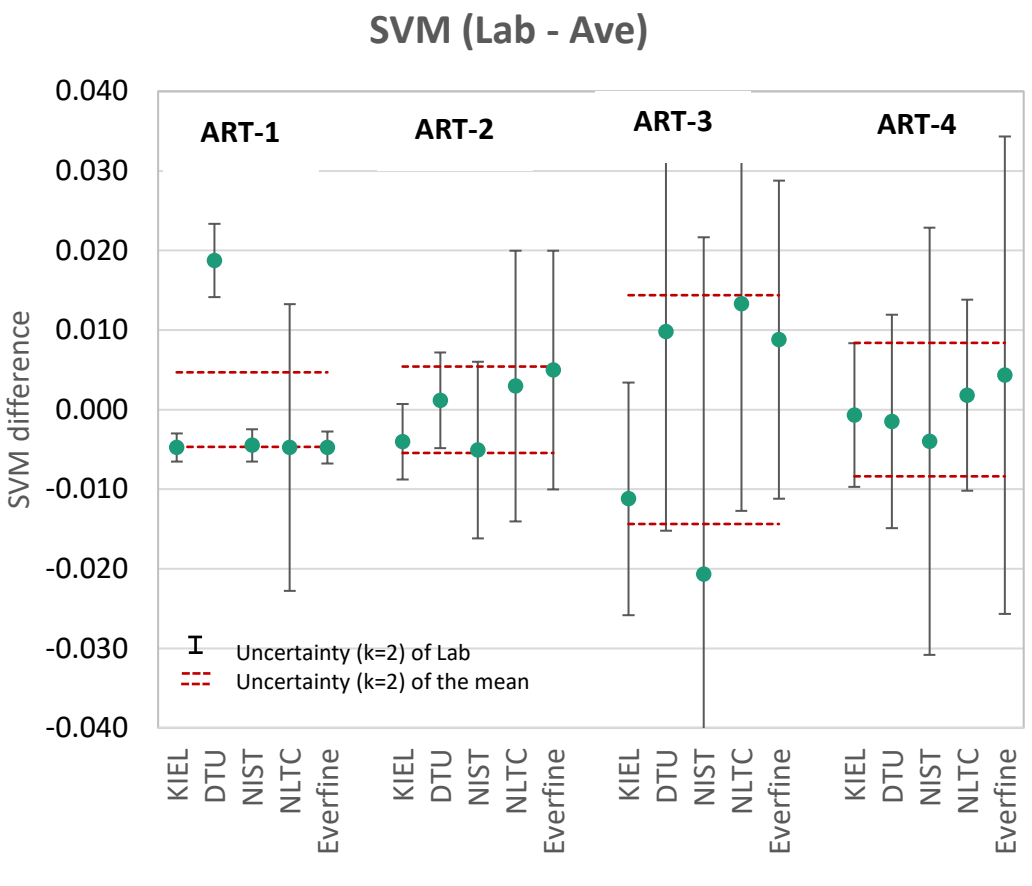




Results of Nucleus Laboratory Comparison

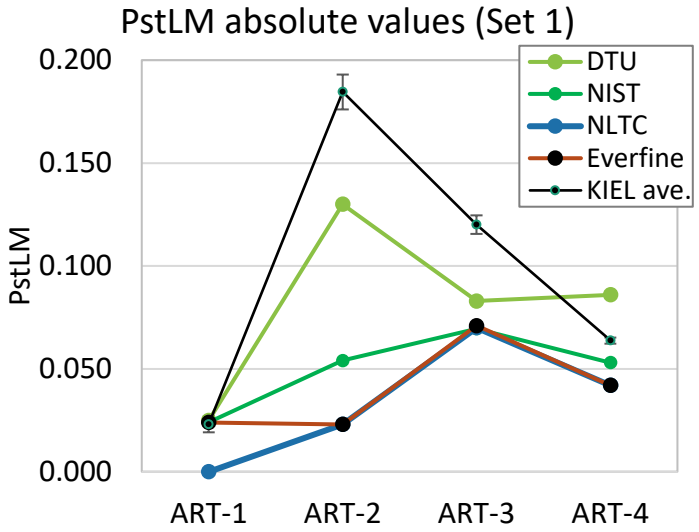
4) Comparison of all the labs





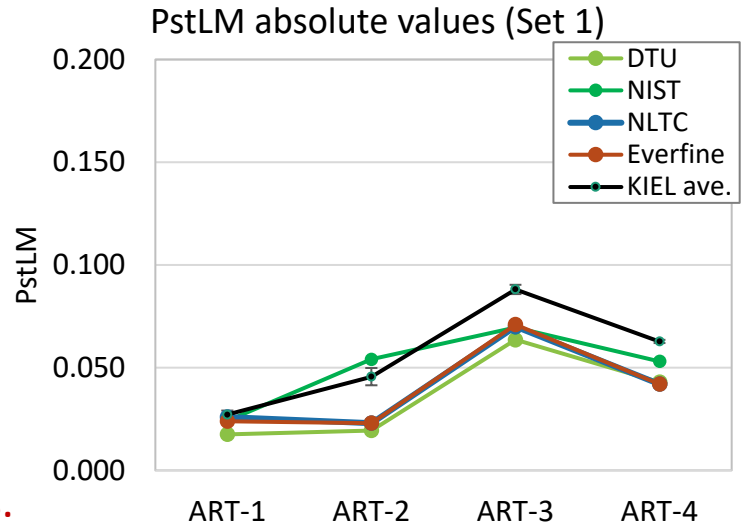
Problem (1) identified in PstLM

Original results



KIEL and DTU changed their power supplies.

KIEL, DTU Re-measured

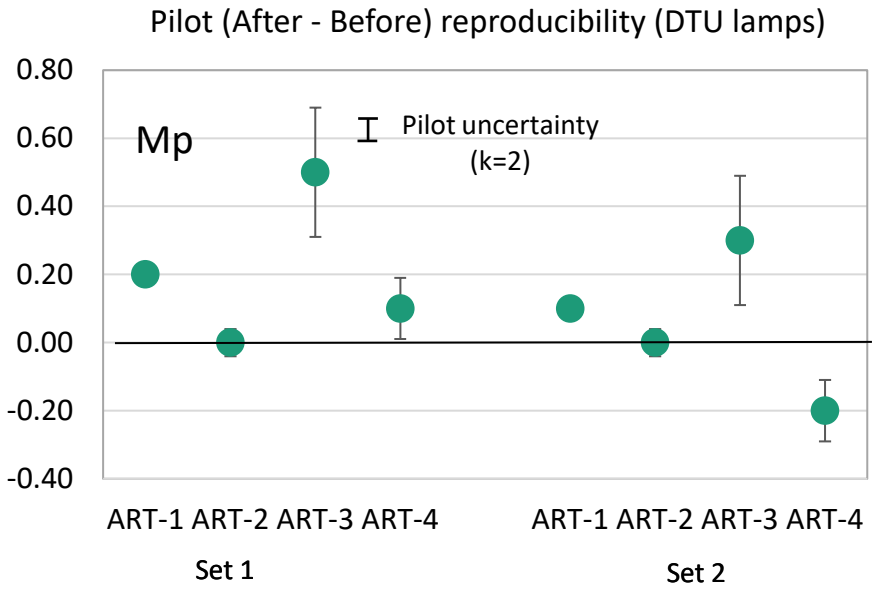


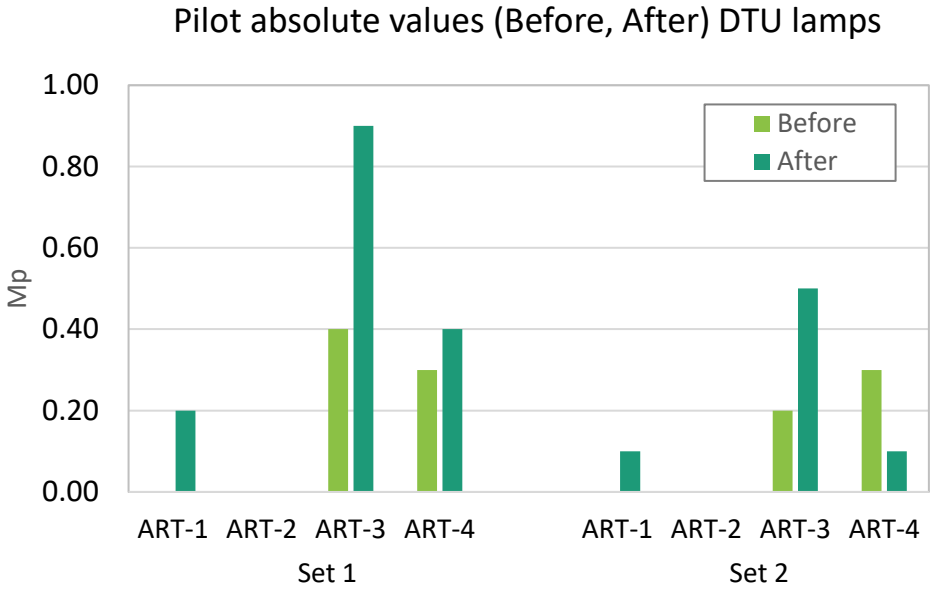
This triggered full investigation at IC 2023 CoreTeam on PstLM measurement affected by power supplies used.

Further details in next talk by Carsten Dam Hansen.

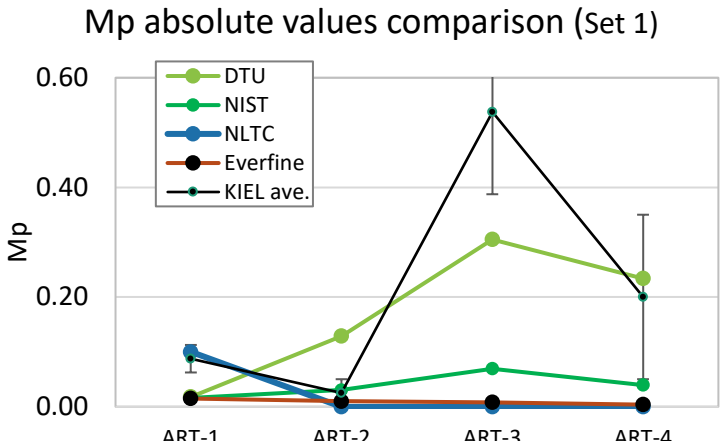
Problem (2) identified in Mp

Poor reproducibility





Poor agreement in measurements



The variations depend on different lamps (waveforms).

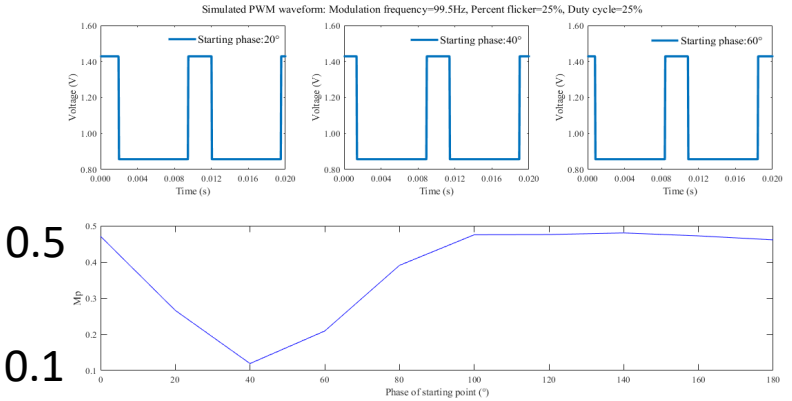
Also some effects of power supplies used.

Problem (2) identified in Mp

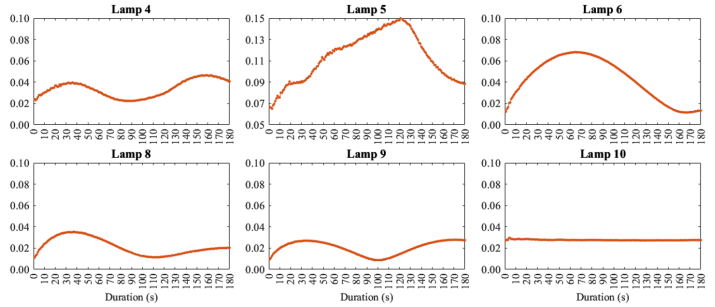
NIST started investigation on this Mp problem, with Andrew Bierman (the main author of Mp metric).

- There is general support for Mp in the USA
- Mp requires only 2 s for measurement (compared to 180 s for PstLM)

1. **Variation of M_P due to different starting phase**



2. **Variation of M_P due to different measurement duration**

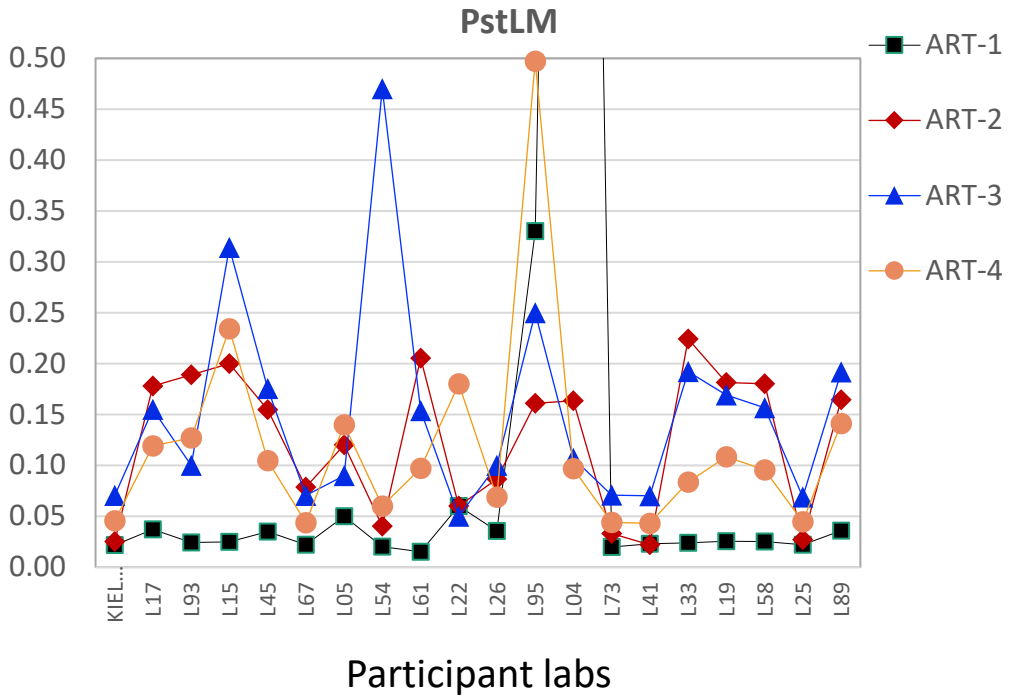


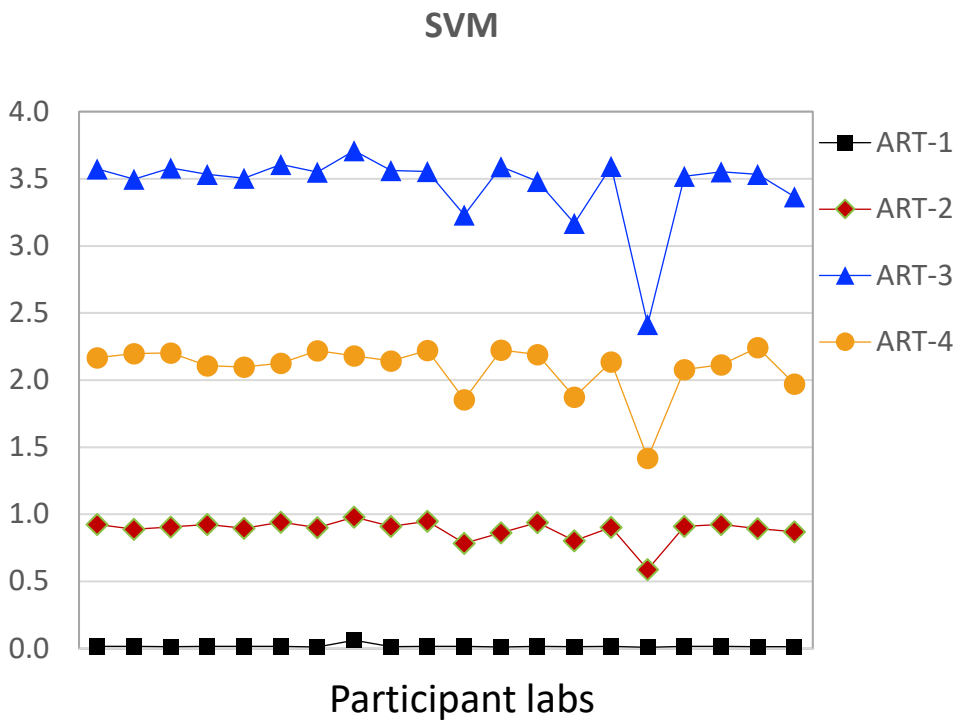
3. **Improved Mp metric** (with Hann window incorporated) is being developed. A journal paper being submitted.

IC 2023 Main Rounds

Status – All measurement rounds were completed. Data analyses are still in progress.

Some preview of results:





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Thank you for your attention.

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