



International Commission on Illumination  
Commission Internationale de l'Éclairage  
Internationale Beleuchtungskommission

# RESULTS OF IEA 4E SSL ANNEX INTERLABORATORY COMPARISON ON TEMPORAL LIGHT MODULATION MEASUREMENT

Ohno, Y., et al.

DOI 10.25039/x051.2025/kprwf9

This article is also published as part of:

Proceedings of the CIE 2025 Midterm Meeting Vienna, Austria, July 4-11, 2025:  
Scientific Conference (July 7-9, 2025)

DOI 10.25039/x051.2025

in

Proceedings of the CIE (International Commission on Illumination)

ISSN no. 3061-015X (print), 3061-0168 (online)

The paper has undergone double-blind peer review and its final version has been presented at the CIE 2025 Midterm Meeting, Vienna, Austria, July 4–11, 2025.

© CIE 2025

All rights reserved. This work is licensed under the Creative Commons Attribution-NonCommercial 4.0 International License (<https://creativecommons.org/licenses/by-nc/4.0/>). Any mention of organizations or products does not imply endorsement by the CIE.

CIE Central Bureau  
Babenbergerstrasse 9/9A  
A-1010 Vienna, Austria  
Tel.: +43 1 714 31 87  
e-mail: [ciecb@cie.co.at](mailto:ciecb@cie.co.at) — [www.cie.co.at](http://www.cie.co.at)

## RESULTS OF IEA 4E SSL ANNEX INTERLABORATORY COMPARISON ON TEMPORAL LIGHT MODULATION MEASUREMENT

Ohno, Y.<sup>1</sup>, Coyne, S.<sup>2</sup>, Oh, J-S.<sup>3</sup>, Dam-Hansen, C.<sup>4</sup>, Scholand, M.<sup>5</sup>, Li, J.<sup>6</sup>, Isoardi, G.<sup>2</sup>

<sup>1</sup> National Institute of Standards and Technology, Gaithersburg, USA, <sup>2</sup> Light Naturally, Brisbane, AUSTRALIA, <sup>3</sup> KIEL Institute, Bucheon-si, REPUBLIC OF KOREA, <sup>4</sup> Technical University of Denmark, Roskilde, DENMARK, <sup>5</sup> IEA 4E SSLC Platform, London, UK, <sup>6</sup> École nationale des travaux publics de l'État (ENTPE), Lyon, FRANCE

ohno@nist.gov

### Abstract

The International Energy Agency (IEA) 4E SSL Annex has conducted an Interlaboratory Comparison (IC 2023) of the measurement of temporal light modulation (TLM) of solid-state lighting (SSL) products. Designed to meet proficiency test requirements, IC 2023 compared measured TLM quantities including short-term flicker indicator ( $P_{st}^{LM}$ ) and stroboscopic effect visibility measure (SVM,  $M_{vs}$ ), as well as three other TLM quantities, on four LED lamp artefacts and on five waveforms produced by a TLM generator source as a technical study. IC 2023 was prepared by five Nucleus and Link Laboratories and had 19 participating laboratories worldwide. The results showed larger variations than expected, especially in  $P_{st}^{LM}$  measurements. The causes of these variations were investigated and are discussed. The analytical results of IC2023 identified the need for more robust test methods, an improvement in performance specifications for TLM instruments, and clearer guidance on determining measurement uncertainties.

**Keywords:** flicker, interlaboratory comparison, short term flicker indicator, stroboscopic effect visibility measure, SVM, temporal light modulation, TLM

### 1 Introduction

The International Energy Agency (IEA) 4E Solid-State Lighting (SSL) Annex has conducted an Interlaboratory Comparison (IC 2023) of the measurement of temporal light modulation (TLM) quantities of SSL products. TLM can cause flicker and stroboscopic effects, leading to discomfort or health issues in lighting applications. For the flicker, *short-term flicker indicator* ( $P_{st}^{LM}$ ) defined by International Electrotechnical Commission (IEC) TR 61547-1 (IEC, 2020) is commonly used. For the stroboscopic effect, *stroboscopic effect visibility measure* (SVM,  $M_{vs}$ ) defined in IEC TR 63158 (IEC, 2018) is commonly used. Perceptual modulation ( $M_p$ ) (ASSIST 2015), flicker index, and modulation depth, are also used in some technical publications and commercial instruments. IC 2023 compared measurements of these five TLM quantities.

Measurement of TLM quantities is receiving high attention, as many governments around the world have adopted market regulations that put limits on the TLM quantities of SSL products. For example, the European Commission's Ecodesign regulation established mandatory limits on  $P_{st}^{LM}$  ( $\leq 1.0$  at full load) and SVM ( $\leq 0.9$  at full load from September 2021, and  $\leq 0.4$  at full load from September 2024) for all products sold in Europe (EU, 2019). Variations in measurement conditions, such as duration, sampling rate, and anti-aliasing filter settings, have been shown to affect  $P_{st}^{LM}$  and SVM results (Li & Ohno, 2025). Such regulations are increasing the need for measurement verification and possibly accreditation of testing laboratories for TLM quantities, where proficiency testing through interlaboratory comparison may be required.

IC 2023 was conducted in compliance with ISO/IEC 17043 (ISO/IEC, 2023) to serve as a proficiency test to address such a need, building on the experience and successes of the SSL Annex's previous interlaboratory comparisons (ICs) on measurements of SSL products, i.e., IC 2013 on measurement of LED lamps (IEA SSL Annex, 2014) and IC 2017 on goniophotometry

of LED luminaires (IEA SSL Annex, 2021). In IC 2023, four types of commercial LED lamps and a TLM generator source were used as TLM artefacts. The IC was organised by four Nucleus Laboratories, three Link Laboratories (two of which were also Nucleus Laboratories), and it had 19 participating laboratories in the main round. In total, therefore, 24 laboratories were involved in IC 2023. In addition, IC 2023 was linked to two regional ICs of TLM quantities, bringing a comparison of 45 laboratories in total. The results and findings from the Nucleus Laboratory comparison were previously reported and discussed (Ohno et al., 2024).

In this paper the detailed results of the IC 2023 main round are reported and discussed, focussing on the results of the LED lamp artefacts, and highlighting the problems identified.

## 2 Methods

### 2.1 Measurement quantities






IC 2023 compared the measurements of five TLM quantities,  $P_{st}^{LM}$  and SVM as a proficiency test, and three optional TLM quantities – modulation depth, flicker index, and  $M_P$ , as a technical study. All participants were asked to measure  $P_{st}^{LM}$  and SVM, with uncertainty statements, while measurements of any of optional quantities were not required if participants did not have capabilities to measure them. While the uncertainties of all measured quantities were requested, the results were still accepted if some of the uncertainties were not reported.

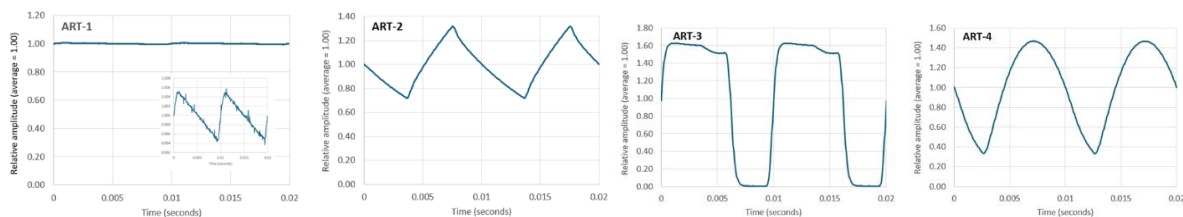
### 2.2 Comparison artefacts

IC 2023 used four different types of LED lamps (purchased from the current market). In addition, a TLM generator source was used for a technical study, with five waveforms specifically designed and installed in the firmware for IC 2023. The details of these are reported in the IC 2023 Technical Protocol (IEA SSL Annex, 2023).

The ratings and photos of these artefacts are shown in Table 1. The artefact lamps were designated as ART-1, ART-2, ART-3, and ART-4, and the TLM generator was designated as ART-5. The lamps were selected for various waveform shapes and the range of  $P_{st}^{LM}$  and SVM values. The assessed values of  $P_{st}^{LM}$  of the LED lamps ranged from near zero to 0.2, and values of SVM from near zero to around 3.5. The authors searched for LED lamps with higher  $P_{st}^{LM}$  values but could not be found. Figure 1 shows the temporal light waveforms of the four artefact lamps. The ART-1 lamp graph includes a magnified plot of a portion of the smooth waveform.

**Table 1 – The comparison artefacts used in IC 2023**

ART-1	ART-2	ART-3	ART-4	ART-5
LED lamp AC 230V 50Hz, 3.8 W	LED lamp AC 230V 50Hz, 3.5 W	LED lamp AC 230V 50Hz, 5 W	LED lamp AC 230V 50Hz, 2.5	TLM generator (5 waveforms)
				



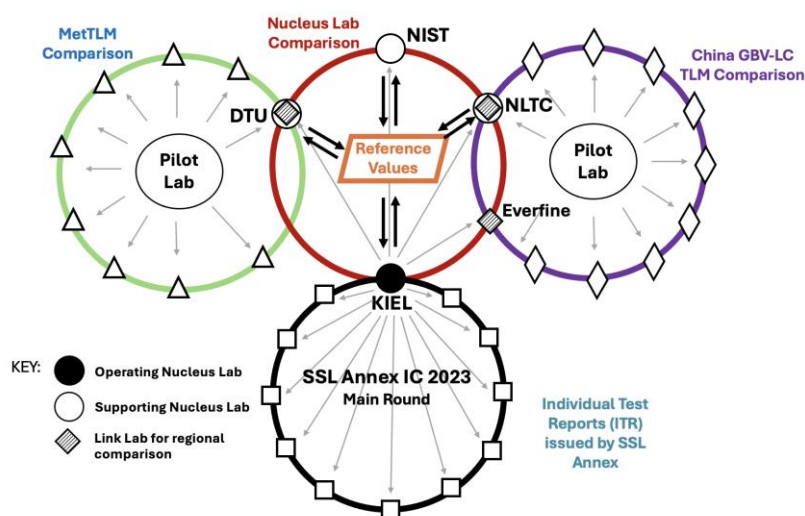
**Figure 1 – The measured temporal light waveforms for ART-1 to ART-4 (for two periods, normalised to the mean)**

## 2.3 Organisation of IC 2023

To establish the reference values for the comparison artefacts, four *Nucleus Laboratories* were selected, which were either national laboratories or publicly supported laboratories that have the capacity and extensive experience with the measurement of TLM. These Nucleus Laboratories include KIEL Institute, Korea, Technical University of Denmark (DTU), Denmark, National Institute of Standards and Technology (NIST), USA, and National Lighting Test Centre (NLTC), China. The details and qualifications of these laboratories are reported in the IC 2023 Technical Protocol (IEA SSL Annex, 2023). KIEL served as the *Operational Nucleus Laboratory*, which conducted bilateral comparisons with all participating laboratories. DTU, NIST, and NLTC were *Supporting Nucleus Laboratories*, which participated in the *Nucleus Laboratory Comparison* to establish the reference values for the IC.

In the IC 2023 main round, there were 18 participants, but one of the participants measured the artefacts with two laboratory arrangements using different TLM instruments, so their second laboratory arrangement was counted as another laboratory, making a total of 19 participating laboratories. Individual Test Reports for each participating laboratory for the lamp artefacts have been issued.

IC 2023 was linked to two regional comparisons of TLM measurements; the European Metrology Programme for Innovation and Research (EMPIR) Metrology for Temporal Light Modulation (MetTLM) project, which had eight participating laboratories, and the China National Standard Verification Programme: Laboratory Comparison on Temporal Lighting Modulation (China GBV-LC TLM), which had 13 participating laboratories. To enable linking to IC 2023, these two regional comparisons used the same models of LED lamp artefacts shown in Table 1 and followed the same technical protocol as IC 2023. DTU served as the link laboratory for MetTLM, and NLTC and Everfine (China) served as the link laboratories for China GBV-LC TLM. Note that DTU and NLTC served as both a Supportive Nucleus Laboratory and a Link Laboratory. Figure 2 illustrates an indicative organisational chart of IC 2023 as described above.



**Figure 2 – Depiction of IC 2023 Nucleus Laboratory comparison, participant testing rounds and link to two regional comparisons**

All measurements were conducted following the IC 2023 Technical Protocol (IEA SSL Annex 2023), and comply with the technical reports: IEC 2018, IEC 2020, and CIE 2021.

## 3 Results

### 3.1 Nucleus Laboratory Comparison (NLC)

The NLC was conducted prior to the main round of IC 2023 to establish the reference values for the comparison artefacts. The NLC compared measurements of all five TLM quantities of the four artefact lamps and the five waveforms of the TLM generator source by the five Nucleus

and Link Laboratories. The reference values and their uncertainties for each quantity for each artefact were established from the results of the four Nucleus Laboratories. The final results for  $P_{st}^{LM}$  showed good agreement of five Nucleus and Link Laboratories within  $\pm 0.02$  for all artefacts, and for SVM, within  $\pm 0.03$ . The deviations of each Nucleus laboratory results from the reference values, for each quantity and each artefact were determined and used to transfer the reference values to the IC 2023 main round by the Operational Nucleus Laboratory and to the regional comparisons (EMPIR MetTLM and China GBV-LC TLM) by the Link Laboratories. The details of the procedures and the results of NLC are reported in the Nucleus Laboratory Comparison Report (IEA SSL Annex, 2024).

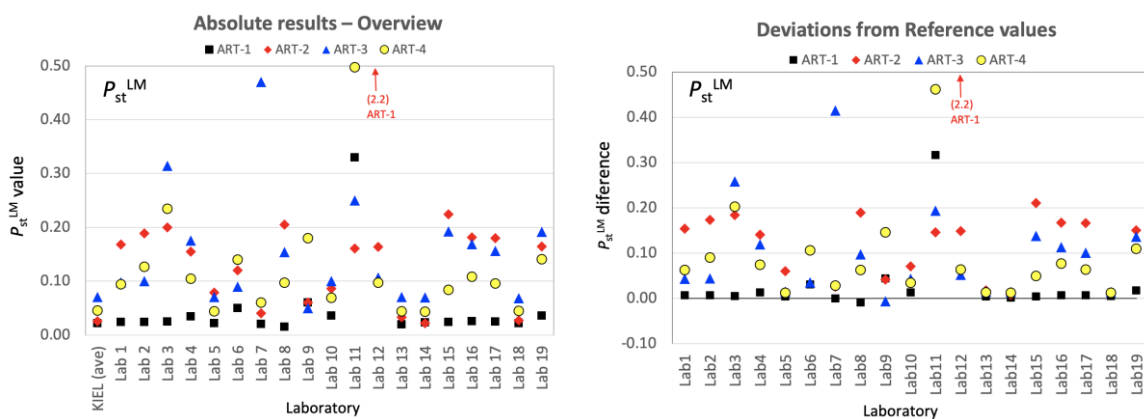
In the NLC, however, some problems were identified. The results for  $P_{st}^{LM}$  initially revealed larger deviations (up to  $\approx 0.2$ ) among the laboratories. The main cause of the  $P_{st}^{LM}$  variation was found to be the effects of the AC power supplies used to operate the LED lamp artefacts. This triggered a full-scale investigation undertaken by the IC 2023 Core Team on  $P_{st}^{LM}$  measurement on halogen lamps (Dam-Hansen et al 2024). Also, the comparison of  $M_P$  suffered from poor reproducibility of measurements. This was also investigated, and as a result, an improved method of the calculation of  $M_P$  was developed and proposed (Li et al., in review).

### 3.2 IC 2023 main round results

The results of the measurements of all participating laboratories for each TLM quantity for all artefacts are presented in this section.

#### 3.2.1 $P_{st}^{LM}$

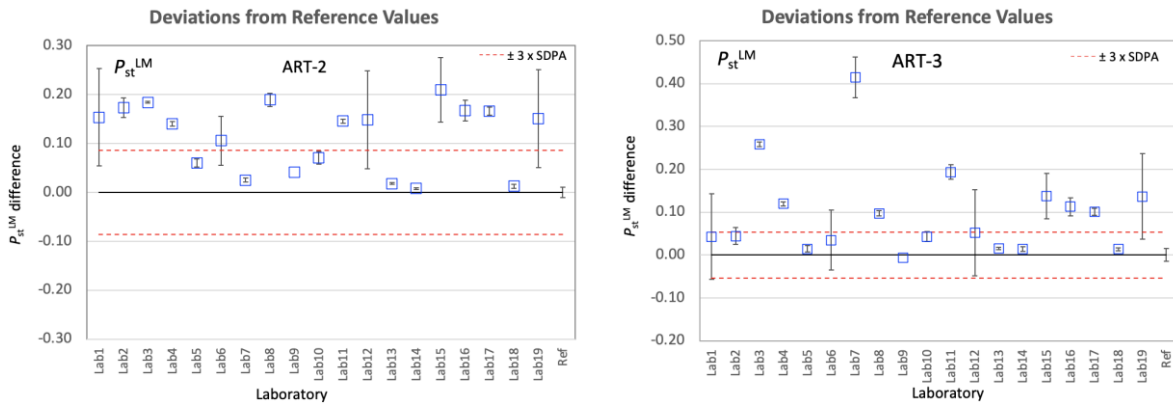
Figure 3 shows the results of all participating laboratories for  $P_{st}^{LM}$ . The horizontal axis shows the participating laboratories numbered 1 to 19. These numbers are different from the lab codes that were confidentially assigned to each laboratory. The graph on the left shows the absolute values reported for the four lamp artefacts by each laboratory. The graph on the right shows the deviations of each laboratory's results from the reference values. The results showed much larger deviations than expected (about  $\pm 0.09$  or less was expected from the results of the NLC). The  $P_{st}^{LM}$  deviations in most of the results are in a positive direction, which indicates that the errors are caused by some additional light fluctuation components that may have been caused by the power supplies used by the participants. The Nucleus Laboratories had identified this problem earlier during the NLC and started an investigation. Also, in the graph on the left, the leftmost laboratory marked "KIEL (ave)". This shows the average values of all the artefact lamps KIEL measured before and after shipping to participants. Since there were only small variations in the individual lamps measured, the plots of "KIEL (ave)" in the graphs are close to the reference values, which were less than 0.10 for all lamp types.



**Figure 3 – Overview of the  $P_{st}^{LM}$  results; the absolute results reported by each participant (left) and the deviations of the participants' results from the reference values (right) for all four artefacts.**

Figure 4 shows examples of detailed results of  $P_{st}^{LM}$  (deviations from the reference values shown as squares) for lamps ART-2 and ART-3 with the expanded uncertainties ( $k=2$ ) reported by each participant shown as error bars. In many cases, the uncertainties are extremely small

compared to the results deviations, meaning that the uncertainties were significantly underestimated. The results shown with no uncertainty bar means the uncertainty was not reported by the participant. The red dashed lines show  $\pm 3$  times of Standard Deviation of Proficiency Assessment (SDPA) values, which were determined for each lamp type in the NLC as an estimate of participants' measurement variations. The ratio of a laboratory's deviation to SDPA is close to its  $z'$  score, thus, the laboratory deviations outside the  $\pm 3 \times$  SDPA lines is an indication that the results may be unsatisfactory ( $|z'| > 3.0$ ). See 3.2.7 also for  $z'$  score.

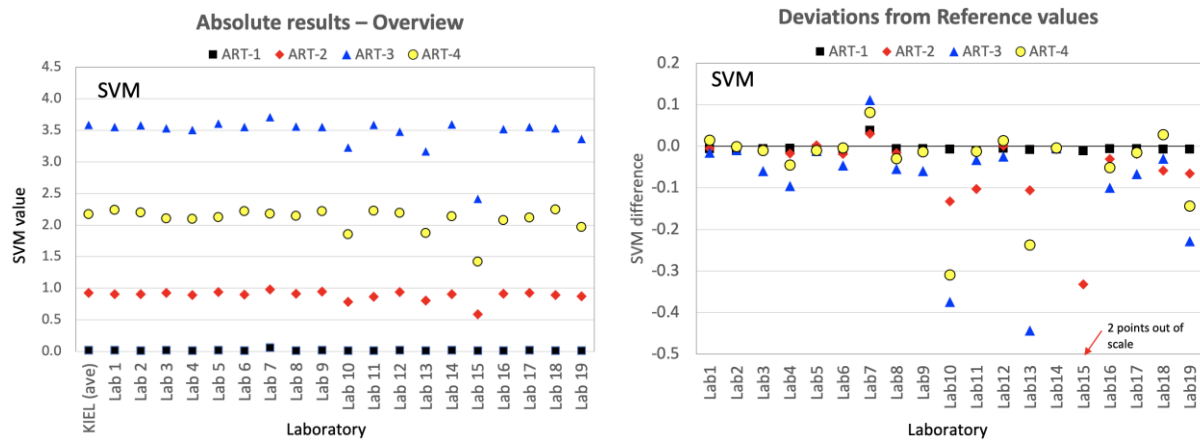


**Figure 4 – Detailed  $P_{st}^{LM}$  results for ART-2 and ART-3; the deviations of the participants' results from the reference values and reported uncertainties**

The right end plot of each graph (marked “Ref”) shows the expanded uncertainty ( $k=2$ ) of the reference values. If a participant's uncertainty bar is not overlapping with this, the participant's result and their uncertainty are not statistically consistent with the reference value. The uncertainties of the reference values were determined from the results of the NLC (see the NLC report (IEA SSL Annex 2024) for the equations and other details).

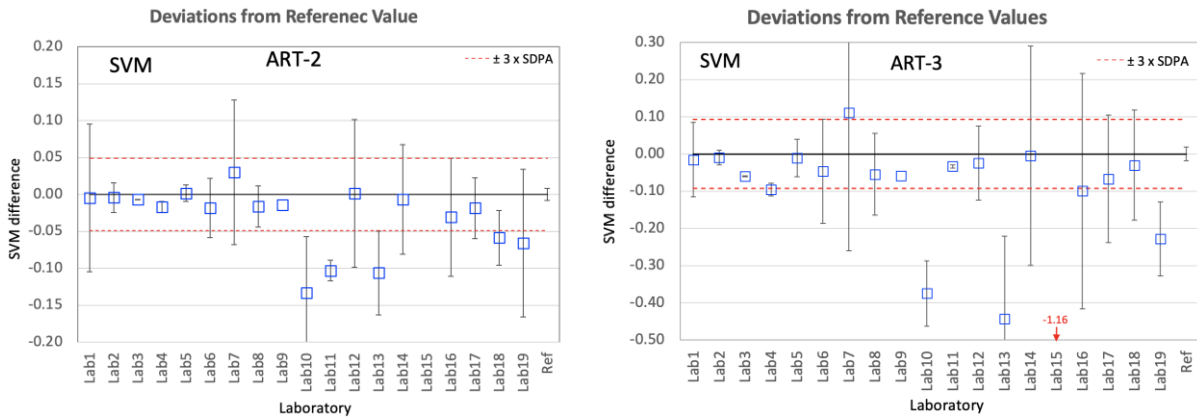
**3.2.2 SVM**

Figure 5 shows the SVM results; the absolute values reported by each participant (left) and the deviations of the participants' results from the reference values (right). The artefact lamps were selected to provide a large range of SVM values (nearly zero to about 3.5). The SVM results show the laboratory deviations in a negative direction in most cases, which indicates that the dominant waveform frequency components were reduced by inappropriate anti-aliasing filter characteristics in their TLM instruments, leading to lower values of SVM. The magnitude of the deviation from the reference value is up to -0.4, which is significant.



**Figure 5 – Overview of the SVM results; the absolute results reported by each participant (left) and the deviations of the participants' results from the reference values (right) for all four artefacts.**

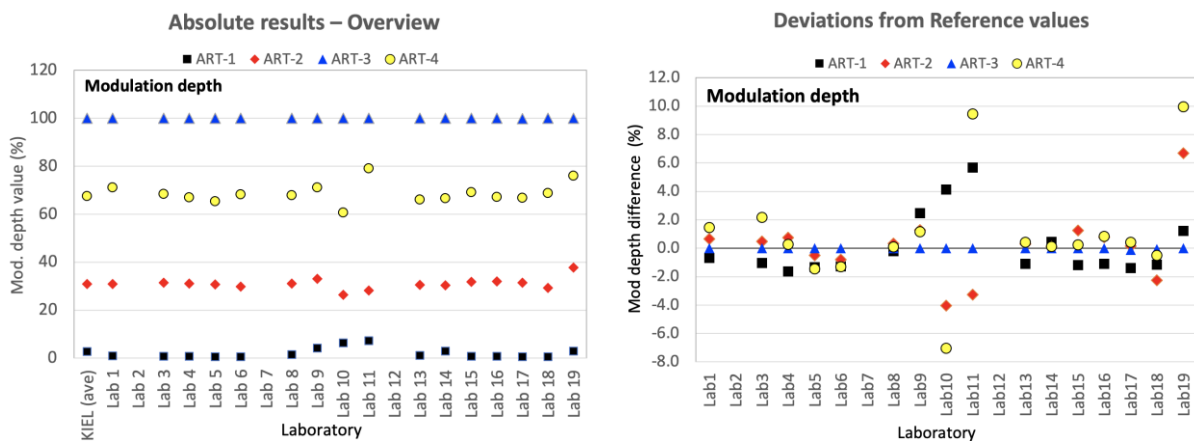
Figure 6 shows examples of detailed results of SVM (deviations from the reference values, shown as squares) for lamps ART-2 and ART-3 with the expanded uncertainties ( $k=2$ ) reported by each participant shown as error bars. The reported uncertainties for SVM appear more appropriate than those of  $P_{st}^{LM}$ . The deviations of ART-3 are relatively small compared to the large value of SVM ( $\approx 3.5$ ).



**Figure 6 – Detailed SVM results for ART-2 and ART-3; the deviations of the participants’ results from the reference values and reported uncertainties**

### 3.2.3 Modulation depth

Figure 7 shows the results in the same way for modulation depth. Three laboratories (numbered 2,7 and 12) did not measure this quantity. The results show larger variations for ART-2 and ART-4, likely caused by the fact that there are sharp edges in their waveforms and the modulation depth is determined by the waveform amplitude and is therefore sensitive to the peak heights. If the antialiasing filter is not appropriate, it would cause negative errors. Positive errors in this metric may be caused by overshooting of the measured waveform due to antialiasing filter’s step response. ART-3 deviations are nearly zero as the modulation depth is nearly 100 %.



**Figure 7 – Overview of the results of modulation depth; the absolute results reported by each participant (left) and the deviations of the participants’ results from the reference values (right) for all four artefacts**

Figure 8 shows examples of detailed results of modulation depth for ART-1 and ART-4 with the uncertainties ( $k=2$ ) reported by each participant. These graphs show that the reported uncertainties for modulation depth are significantly underestimated and are much smaller than the deviations in many cases. Furthermore, six laboratories did not report uncertainties.

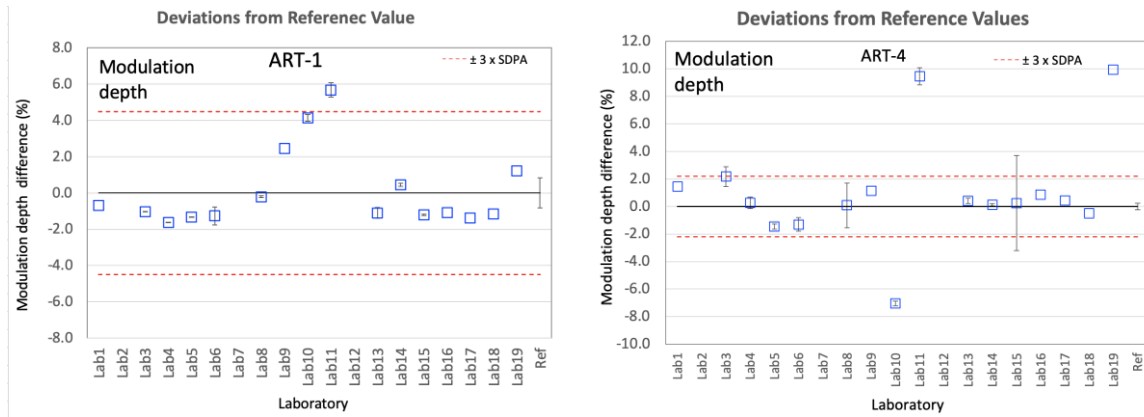


Figure 8 – Detailed results of modulation depth for ART-1 and ART-4; the deviations of the participants’ results from the reference values and reported uncertainties

### 3.2.4. Flicker Index

The results of flicker index in Figure 9 show much smaller variations (mostly within  $\pm 0.01$ , except two outliers) because flicker index is calculated by the ratio of the areas of portions of the waveform and is therefore less affected by the antialiasing filters. However, this index has no consideration of frequency, so it is not suitable as a general metric for flicker. Flicker index is only useful for assessing a fixed modulation frequency.

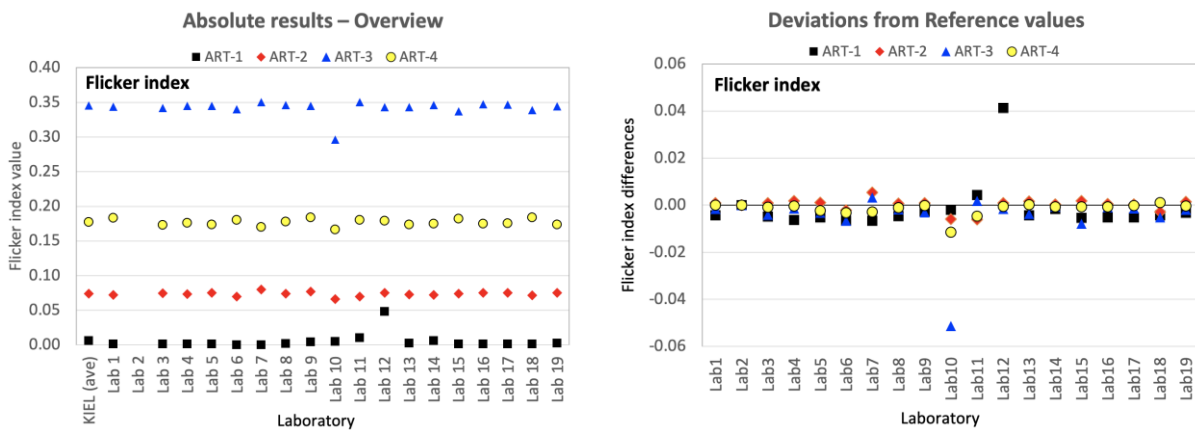


Figure 9 – Overview of the flicker index results; the absolute results reported by each participant (left) and the deviations of the participants’ results from the reference values (right) for all four artefacts

### 3.2.5 $M_P$

Figure 10 shows the absolute results of  $M_P$  reported by the participating laboratories. Eight laboratories did not measure  $M_P$  (no plots in the figure), and six laboratories among eleven laboratories did not report uncertainties. The results show large variations in participants’  $M_P$  measurements, as was also found in the NLC. The variations are up to  $\approx 0.3$  in  $M_P$  (with even larger deviations in two laboratories), which is significant, as  $M_P = 1$  is considered to be the flicker detection threshold. The poor reproducibility of  $M_P$  was investigated, and the causes were identified as problems in the original formula of  $M_P$ , and therefore an improved version,  $M_{P,2024}$ , is proposed (Li et al., in review).

The deviations of laboratories from the reference values for  $M_P$  are not available because the reference values were not determined for  $M_P$  due to the pilot laboratory’s significant poor reproducibility of  $M_P$  results in the NLC (as detailed in the NLC report). Instead, the average measured values of  $M_P$  by the four Nucleus laboratories on each artefact lamp were used only

for a reference purpose. These average values, labelled “NLC ave.,” are shown in Figure 10. The uncertainties of the NLC ave. were large due to the large variations among the Nucleus Laboratories, plus they included individual variations of the lamps.

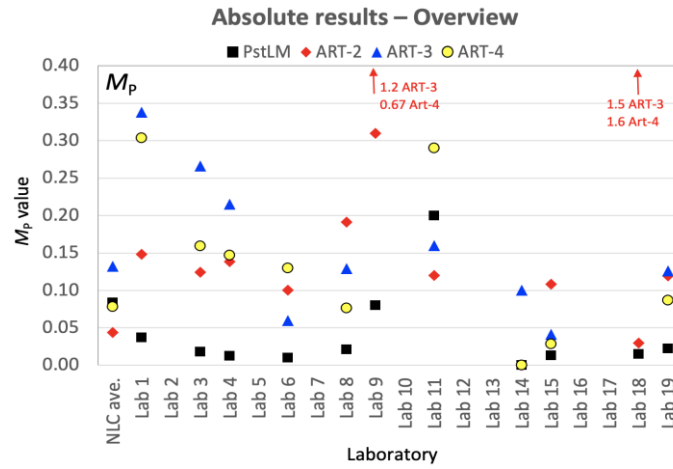


Figure 10 – The absolute results of  $M_p$  reported by each participant and the Nucleus Laboratory Comparison average (NLC ave.) for all four artefacts

### 3.2.6 Linking the regional comparisons

The results of the two regional comparisons were linked based on the results of the link laboratories showing 40 laboratories compared to the IC 2023 reference values (five Nucleus/Link laboratories are not included in this total). Figure 11 shows the linked results of  $P_{st}^{LM}$  as an example. The results of both MetTLM and China GBV-LC show similar trends as those in IC 2023 (positive deviations from reference values). The deviations in GBV-LC are smaller than those of the IC 2023 participants because many of the GBV-LC participants used TLM instruments and power supplies from the same manufacturer. The linked results of SVM showed a similar trend.

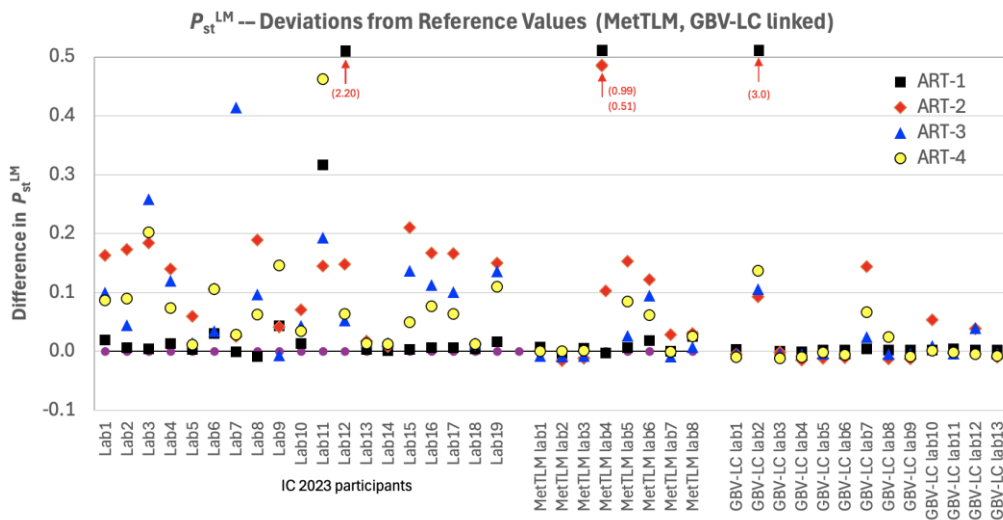


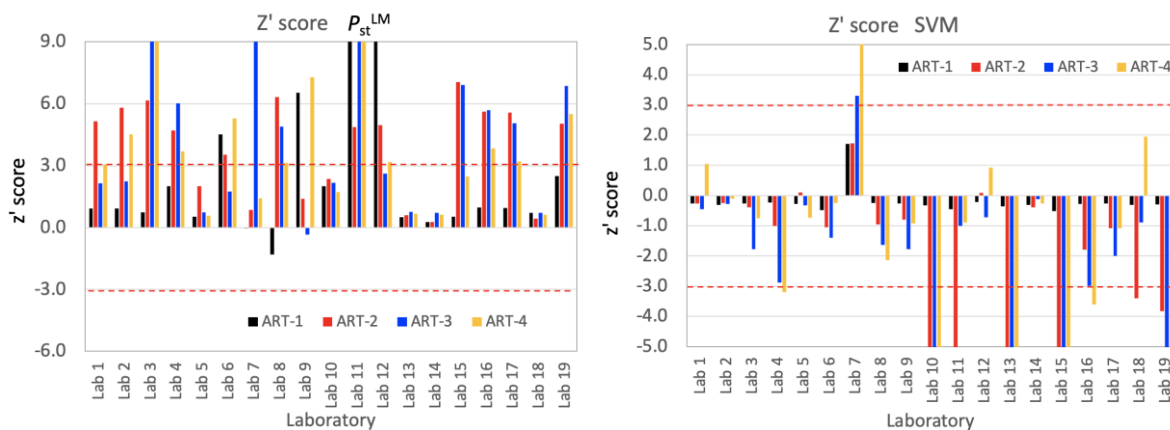
Figure 11 – The results of  $P_{st}^{LM}$  linked with the results of MetTLM and China GBV-LC TLM comparisons

### 3.2.7 z' score and $E_n$ number

The  $z'$  score and the  $E_n$  number (ISO/IEC, 2023) are generally used to evaluate the performance of participating laboratories in proficiency tests. The  $z'$  score is the ratio of

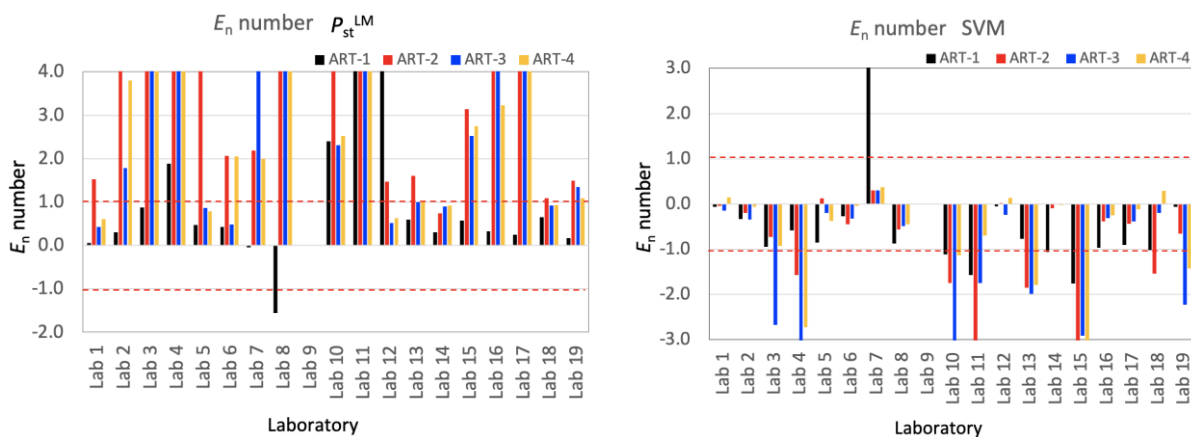
the deviation of a participant’s result from the reference value to the combined value of the expected standard deviation of all participants results, called Standard Deviation of Proficiency Assessment (SDPA), and the uncertainty of reference value. For details of the  $z'$  score formula, see IC 2023 Technical Protocol (IEA SSL Annex, 2023).  $|z'| \leq 2$  is considered satisfactory,  $2 < |z'| \leq 3$  is questionable, and  $|z'| > 3$  is considered unsatisfactory.

Figure 12 shows the plots of  $z'$  scores for  $P_{st}^{LM}$  (left) and SVM (right) for all participants, for all artefacts. Several bars in the graphs are beyond the displayed Y-axis scale. 43 % of all measured results of  $P_{st}^{LM}$  were unsatisfactory, which was an unexpectedly large percentage apparently caused by the aforementioned power supply issue. SVM data showed that 24 % of all results were unsatisfactory, which is also high. The  $P_{st}^{LM}$  graph shows that the deviations were mostly in a positive direction and the SVM graph shows the deviations in a negative direction. Likely causes for these deviations are discussed in earlier sections of this paper.



**Figure 12 –  $z'$  scores of  $P_{st}^{LM}$  and SVM for all participants’ results, for all artefacts**

The  $E_n$  number is used to evaluate the participants’ claimed uncertainties and is calculated as the ratio of the deviation of a participant’s result from the reference value to the combined value of the expanded uncertainty of the participant’s reported uncertainty and that of the reference value. Usually, the participants’ reported uncertainty is dominant.  $|E_n| \leq 1$  is considered satisfactory and  $|E_n| > 1$  is unsatisfactory. The  $E_n$  number cannot be calculated without the participants’ reported uncertainty.



**Figure 13 –  $E_n$  numbers of  $P_{st}^{LM}$  and SVM for all participants’ results, for all artefacts**

Figure 13 shows the plots of  $E_n$  numbers for  $P_{st}^{LM}$  (left) and SVM (right) for all participants, for all artefacts. Several bars in the graphs are out of the displayed scale. 65 % of all measured

results of  $P_{st}^{LM}$  were unsatisfactory, which indicates a serious problem in participants' reported uncertainties. SVM data showed 33 % of all results unsatisfactory, which was also high.

## 4 Conclusions

A large-scale interlaboratory comparison (IC) of measurements of five TLM quantities was conducted, prepared by five Nucleus/Link laboratories and having 19 participating laboratories worldwide. The IC linked two regional comparisons of  $P_{st}^{LM}$  and SVM measurements, MetTLM in Europe and China GBV-LC TLM, resulting in a comparison of 45 laboratories in total. The results revealed a serious problem in  $P_{st}^{LM}$  measurements due to the effects of AC power supplies used to operate the artefact LED lamps. Certain power supplies caused large variations in  $P_{st}^{LM}$  results which triggered an extensive investigation into this issue. The IC also identified a problem in SVM measurements related to anti-aliasing filters used in TLM instruments. IC 2023 also found a serious problem in  $M_P$  causing it to have poor measurement reproducibility. This also triggered an extensive study leading to the development and proposal for an improved  $M_P$  metric. The IC showed that the measurement uncertainties reported by the participants were generally too small, and that this was a big problem. Practical guidance for uncertainty evaluation of the TLM quantities is needed.

These identified issues have been communicated to the relevant committees in CIE, IEC, and Illuminating Engineering Society (IES), for possible improvements of standards in the future. The results of the TLM generator comparison (five waveforms) were not reported in this paper due to the limited paper space, but it showed much smaller variations of  $P_{st}^{LM}$  results because there is no influence on the waveform from a power supply. This finding further confirmed our assessment that certain power supplies were causing issues with the lamp measurements. The final report of IC 2023 with all the detailed results is in preparation.

## Acknowledgments

The authors thank all the participating laboratories of IC 2023 for their valuable participation and collaboration in this interlaboratory comparison. The authors thank Dr. Cosmin Ticleanu, Principal Lighting Consultant, BRE, UK, for his valuable comments and discussion for this paper. The authors also thank the Management Committee of IEA 4E SSL Annex (the name is now changed to Smart Sustainability in Lighting and Controls (SSL) Platform) for their valuable support of this work.

## References

- ASSIST 2015. Recommended metric for assessing the direct perception of light source flicker, ASSIST recommends, Volume 11, Issue 3, Jan. 2015.
- CIE 2021. TN 012:2021 Guidance on Measurement of Temporal Light Modulation of Light Sources and Lighting Systems, Vienna, CIE.
- Dam-Hansen, C., Li, J., Coyne, S., Isoardi, G., Ohno, Y. and Scholand, M., 2024. "Influence of AC Power Supply on Light Flicker Measurements," *2024 IEEE Sustainable Smart Lighting World Conference & Expo (LS24)*, Eindhoven, Netherlands, 2024, pp. 1-3, doi: 10.1109/LS2463127.2024.10881688..
- EU 2019. Commission Regulation (EU) 2019/2020 of 1 October 2019, <https://eur-lex.europa.eu/eli/reg/2019/2020/oj>.
- IEA SSL Annex, 2014. IC 2013 Interlaboratory Comparison Final Report, Ohno, Y., Nara, K., Revtova, E., Zhang, W., Zama, T., Miller, C., Published: September 2014. [https://www.iea-4e.org/wp-content/uploads/2020/10/IC2013\\_Final\\_Report\\_final\\_10.09.2014a.pdf](https://www.iea-4e.org/wp-content/uploads/2020/10/IC2013_Final_Report_final_10.09.2014a.pdf)
- IEA SSL Annex, 2021. IC 2017 Interlaboratory Comparison Final Report, Ohno, Y., Gaudemer, J., Oh, J.S., Dubard, J., Jeon, S., Scholand, M., Published: December 2021. <https://www.iea-4e.org/wp-content/uploads/2021/12/SSL-Annex-IC-2017-Goniophotometers-Final-Report-2021.12.20.pdf>

- IEA SSL Annex 2023. IC 2023: Interlaboratory Comparison on Measurement of Temporal Light Modulation, Technical Protocol. Ohno, Y. and Coyne, S., Published: 25 September 2023. <https://www.iea-4e.org/wp-content/uploads/2023/09/IC-2023-Technical-Protocol-Final.pdf>
- IEA SSL Annex 2024. IC 2023 Nucleus Laboratory Comparison Report, Part 1: Lamp Artefacts, Published: November 2024. <https://www.iea-4e.org/ssl/publications/ic-2023-nucleus-laboratory-comparison-report-part-1-lamp-artefacts/>
- IEC 2018. TR 63158:2018 Equipment for general lighting purposes – Objective test method for stroboscopic effects of lighting equipment.
- IEC 2020. TR 61547-1:2020 Equipment for general lighting purposes - EMC immunity requirements - Part 1: Objective light flickermeter and voltage fluctuation immunity test method.
- ISO/IEC 2023. ISO/IEC 17043:2023 Conformity assessment - General requirements for the competence of proficiency testing providers.
- Li, J, and Ohno, Y., 2025. Analysis of  $P_{st}^{LM}$  and stroboscopic visibility measure variations due to different measurement conditions, Lighting Research & Technology;0(0). doi:10.1177/14771535251315475
- Li, J., Bierman, A. and Ohno, Y., 2025. Revision of  $M_P$  calculation method for flicker measurement, Lighting Research & Technology, Under review.
- Ohno, Y., Coyne, S., Oh, J.S., Dam-Hansen, C., Scholand, M., Li, J., Isoardi, G. 2024, Interlaboratory comparison for temporal light modulation measurement. 2024 IEEE Sustainable Smart Lighting World Conference & Expo (LS24), Eindhoven, Netherlands, pp. 1-4, doi: 10.1109/LS2463127.2024.10881501.