Metrology for Temporal Light Modulation

20NRM01 MetTLM

Friday 12th April 2024

Online

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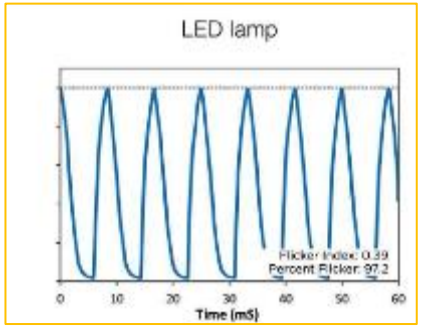
Background and need

- Many LED-lighting sources show temporal modulation of the light output
- Temporal light modulation (TLM) can dramatically change the visual perception of the environment compared to natural light
- TLM can negatively impact human health, well-being and safety



Flicker

$P_{\mathrm{st,LM}}$

Stroboscopic effect

M_{sv}

Phantom array effect

Background and need

EU Ecodesign regulation sets limits on Flicker and Stroboscopic Effect of light sources:

COMMISSION REGULATION (EU) 2019/2020

of 1 October 2019

laying down ecodesign requirements for light sources and separate control gears pursuant to

…….but standardized and validated methods for measuring TLM are still missing.

EC Mandate 519/M

"*Incomplete standardisation has been identified as a **major barrier to a faster take-up of LED-based** lighting in the European market…*"

*Existing standards addressing **flicker** and **stroboscopic effects** must be enhanced or new standards need to be developed to cover LED lighting and to make sure the **health and safety effects** are monitored.*"

CIE request to EURAMET

*"**Currently no international agreed standard exists** that addresses the measurement of flicker and stroboscopic effect explicitly."*

*'there is currently **no predictor for the visibility of the phantom array** and the proposed work aims to fill this gap*

Chief Stakeholder

LightingEurope

"*LightingEurope is concerned that there is **little understanding** and capacity across Europe about how to correctly measure and report TLM"*

LIGHTINGEUROPE

Delivering the Value of Lighting

MetTLM: Project goal and objectives

The overall goal is to provide **lighting industry, instrument manufacturers, market surveillance authorities** and other stakeholders with **undisputable** measurements of Temporal Light Modulation.

Objective 1
Methods for traceable TLM measurement with a focus on flicker and stroboscopic effect.

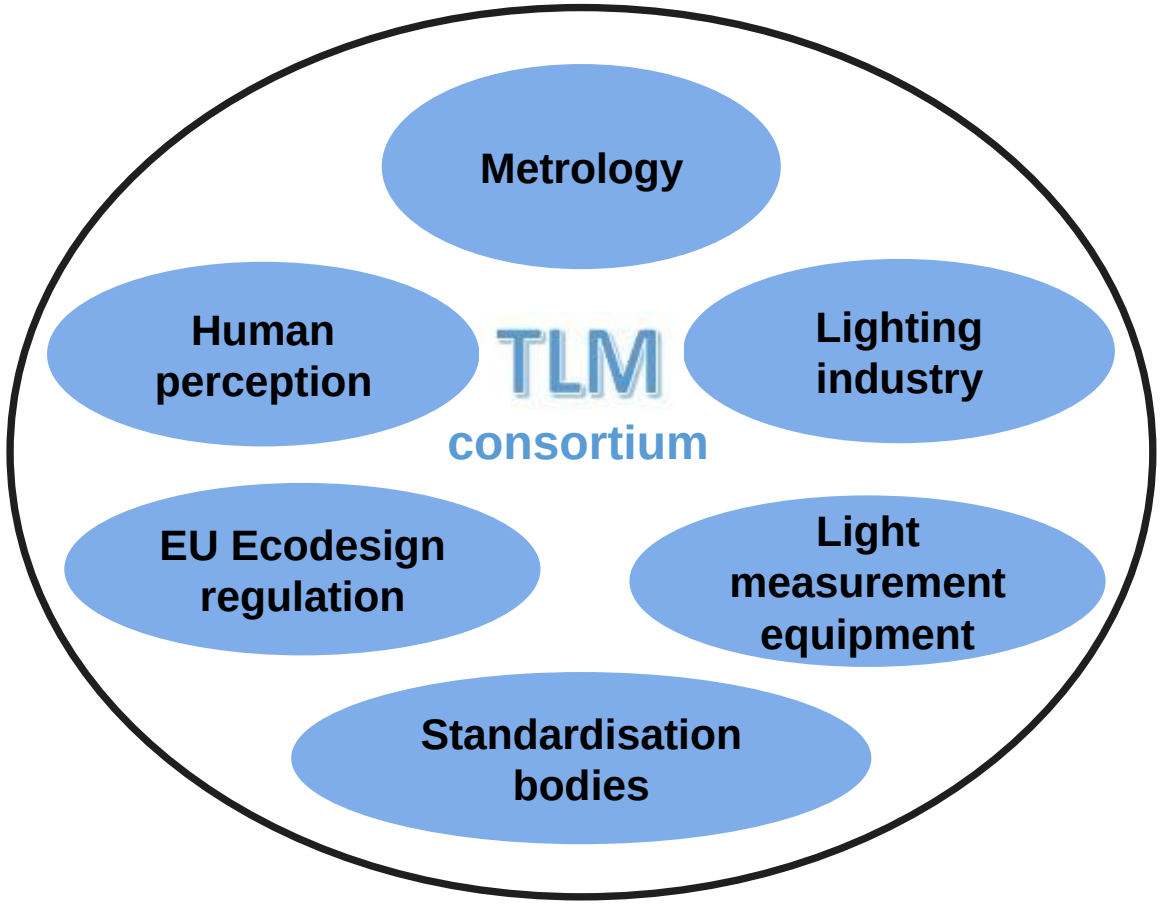
Objective 2
To validate the traceable TLM measurement methods

Objective 3
Spatially and spectrally resolved methods

Objective 4
Sensitivity curve for the phantom array effect

Objective5
Input for:
- new CIE standard on TLM measurement
- Definition of metric for phantom array
- CIE TC on spatial and spectral TLM (to be established)

Consortium



Multidisciplinary consortium consisting of 4 metrology institutes, 4 research institutes and 4 companies from 7 different countries. Strong involvement of partners in **standardization bodies and TCs**.

Results and outcomes

- [Project | Metrology for Temporal Light Modulation (mettlm.eu)]

Methods for flicker and stroboscopic effects

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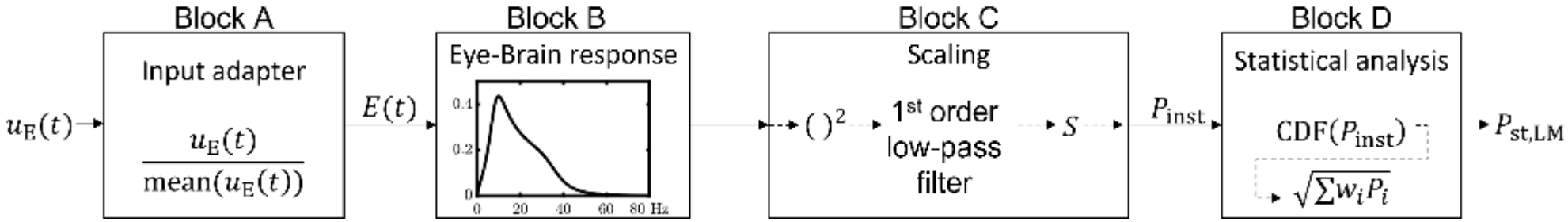
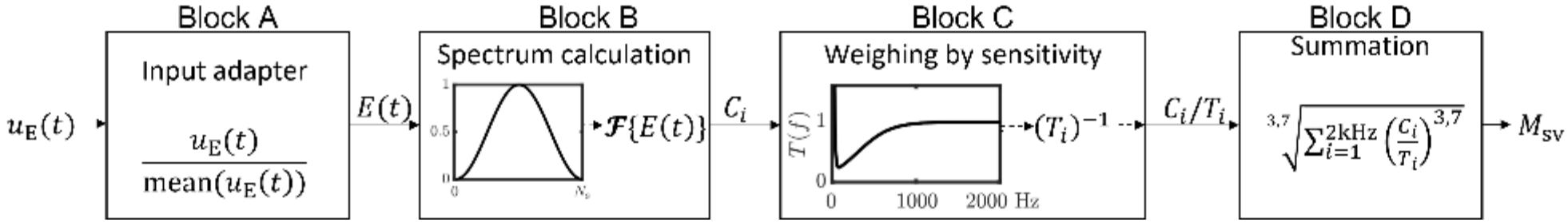
Theoretical background

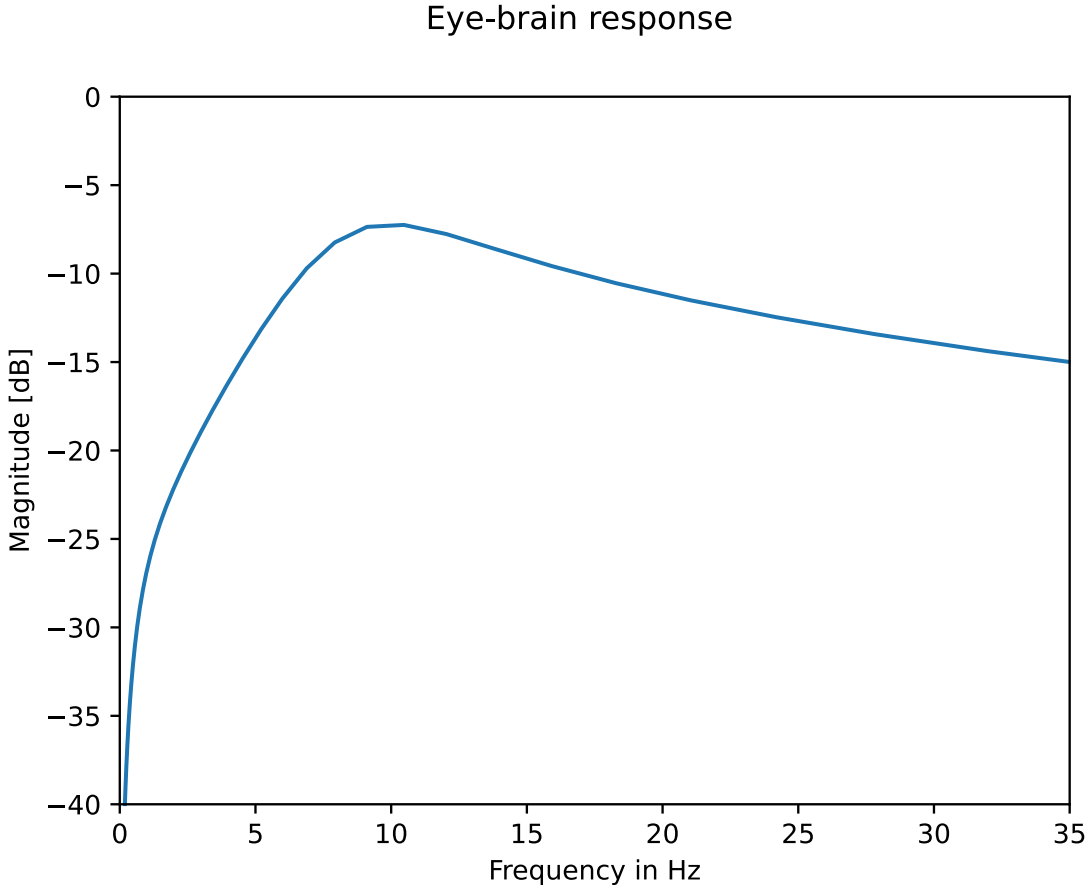
- Flicker IEC TR 61547-1

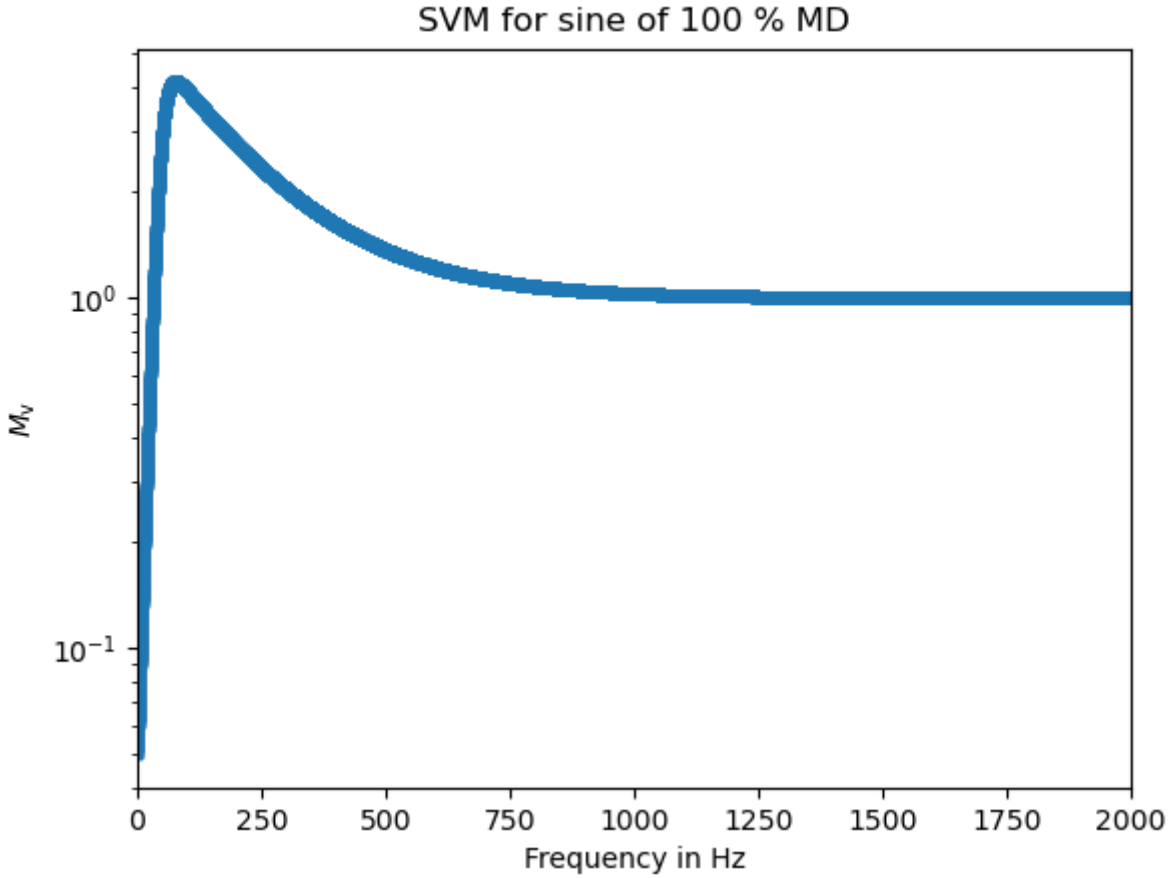


- Stroboscopic visibility (SVM) IEC TR 63158



Flicker and stroboscopic visibility





Traceable TLM measurement and validation

- Primary standards for temporal light measurements
  - P.R. Dekker and A.L. van Bloois, '**Facility for calibration of photometers for measurement of temporal light modulation**', Lighting Research & Technology, p. 147715352311592, Mar. 2023, doi: 10.1177/14771535231159289
  - P.R. Dekker and A. L. van Bloois, '**Facility for calibration of photometers for temporal light modulation**', in Proceedings of the Conference CIE 2021, Online (hosted by NC Malaysia), Dec. 2021, pp. 240–244. doi: 10.25039/x48.2021.OP27
- Uncertainty propagation
  - A. Thorseth, J. Lindén, and C.A. Bouroussis, '**Sensitivity analysis on the effect of measurement noise and sampling frequency on the calculation of the temporal light artefacts**', in Proceedings of the Conference CIE 2021, Online (hosted by NC Malaysia), Dec. 2021, pp. 245–254. doi: 10.25039/x48.2021.OP28
  - C.A. Bouroussis, A. Thorseth, & P. Dekker. (2023). **MetTLM TLM waveform set 1** (Version 1) - Dataset available online

Traceable TLM measurement and validation

Model implementations

- R. Koch and R. Zuber, '**Anti-aliasing filter effects on sampling frequency and effects of mathematical implementation**', in Proceedings of the 'CIE Expert Tutorial and Symposium on the Measurement of Temporal Light Modulation, October 2022, National Technical University of Athens, Greece', p.46-53, DOI 10.25039/x49.2022.P10
- V. Mantela, R. Nordlund, J. Askola, P. Kärhä and E. Ikonen, '**Novel implementations of digital meters for flicker and stroboscopic effect**', presentation and abstract for the 'CIE Expert Tutorial and Symposium on the Measurement of Temporal Light Modulation, October 2022, National Technical University of Athens, Greece' – Abstract available online
- R. Nordlund, '**Validation for measurement of Temporal Light Artefacts on LED light sources**', Master's thesis. Aalto University, March 2022 – Available online

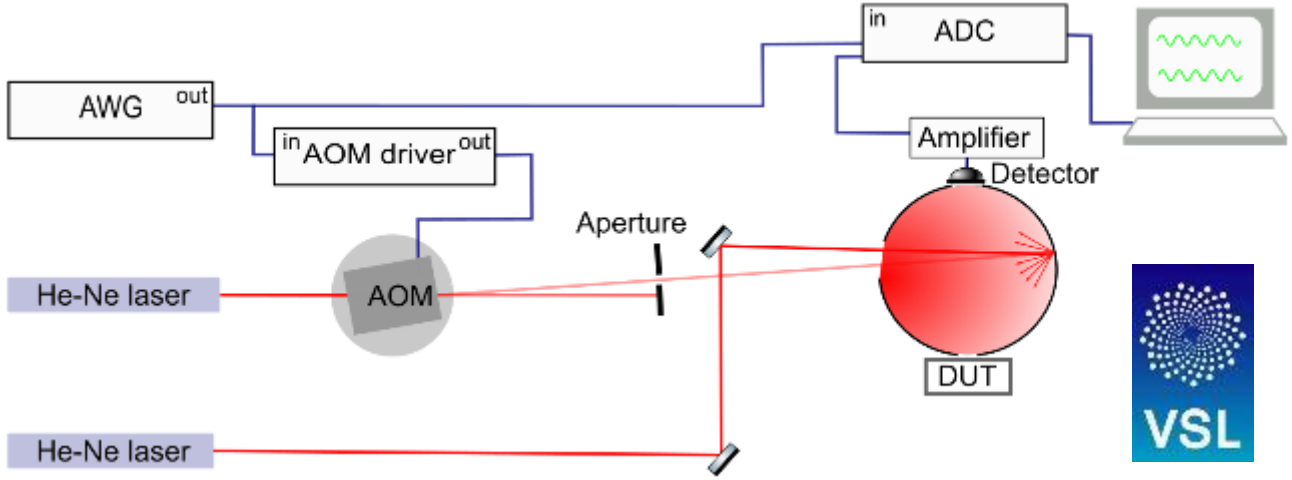
Market surveillance

- E. Ikonen, R. Nordlund, V. Mantela, J. Askola and P. Kärhä, '**Improvement in the temporal light artefact metrics of commercial LED lamps**', presentation and abstract for the 'CIE Expert Tutorial and Symposium on the Measurement of Temporal Light Modulation, October 2022, National Technical University of Athens, Greece' – Abstract available online

Key comparison

Facility to generate and measure TLM

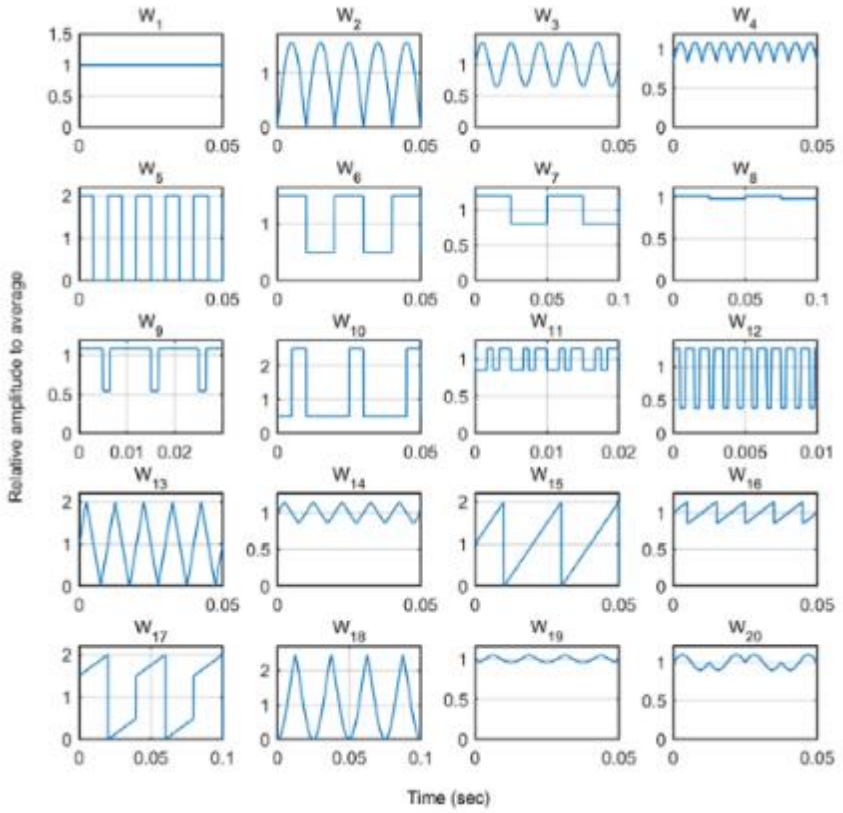
- LED- and laser-based reference source
- Reference TLM meter:
  - Time scale: Traceability through 10 MHz reference
  - Voltage scale: Traceable to Josephson voltage standard through multifunction calibration facility
  - V-lambda filtered
- Fully transparent models for stroboscopic visibility and flicker
  - Proper anti-aliasing
  - Proper windowing
  - Proper zero padding



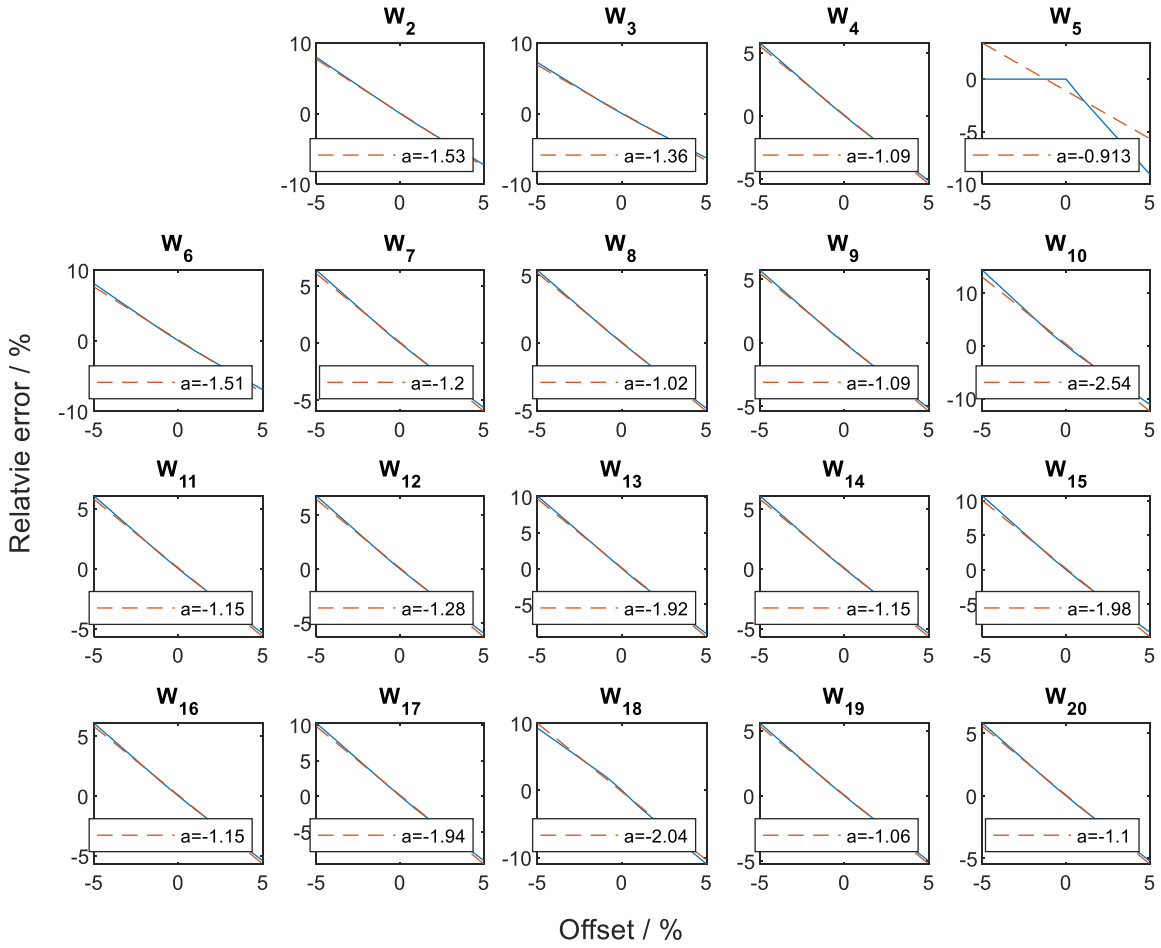
Top view https://doi.org/10.1177/14771535231159289, Dekker,P.R

Propagation of uncertainties

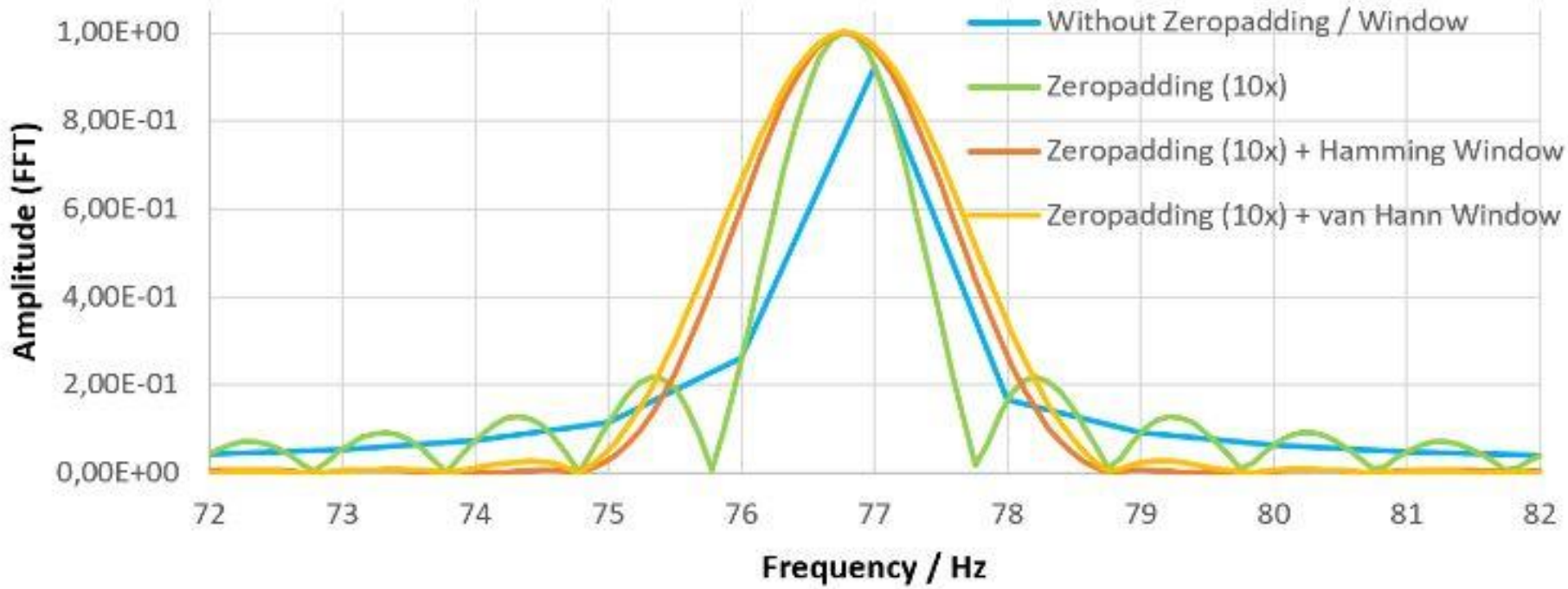
- **Propagation of uncertainties** through Monte Carlo Method (MCM)
- Dataset online: https://zenodo.org/record/7707987



Propagation of uncertainties: Error in $P_{st,LM}$ and M_{sv} for DC offset



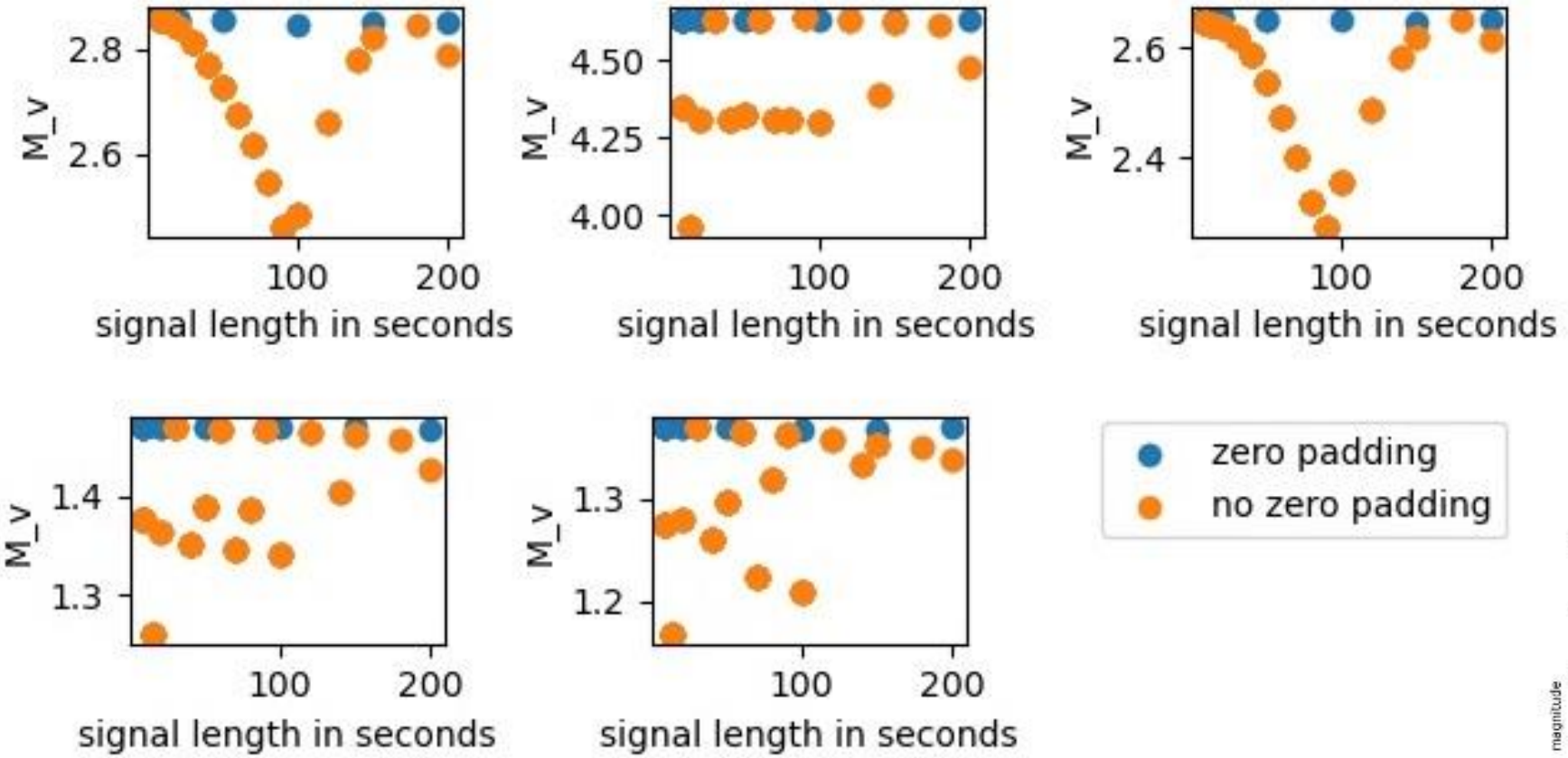
Model implementations: Anti-aliasing, windowing and zero padding

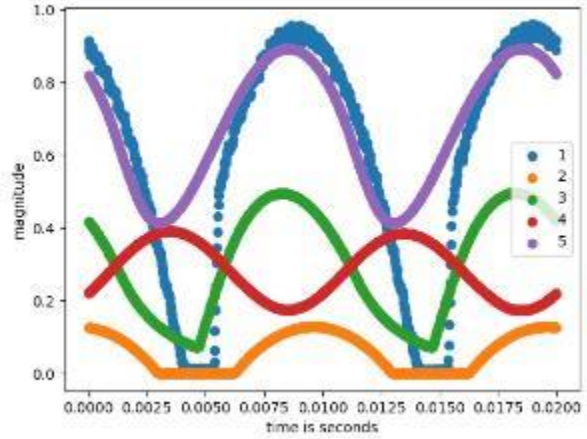


DOI 10.25039/x49.2022.P10

Koch, R. and Zuber, R.

Model implementations: Effect of zero padding on SVM

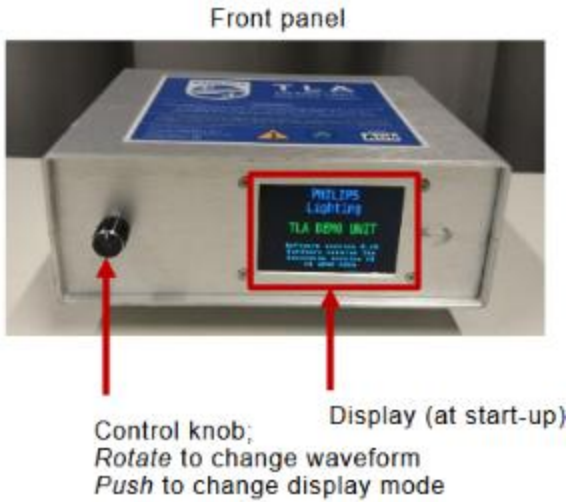




Market surveillance: Improvement in the temporal light artefact metrics of commercial LED lamps

- Type A: lamps have a full-wave rectifier with a smoothing capacitor and a DC-DC converter circuit at the output;
- Type B: lamps have a capacitive dropper circuit;
- Type C: lamps have a linear constant current regulator circuit, and type
- Type D: lamps have switch-mode driver circuits.
- “The new EU Ecodesign regulation set requirements for lighting equipment on the European market starting September 2021. This regulation defined restrictions for two temporal light artefact (TLA) metrics, short-term flicker severity index ($P_{st\ LM}$) and stroboscopic visibility measure (SVM): $P_{st,LM} < 1$ and SVM < 0.4, to limit TLA effects. For both metrics, the value 1 means that an average observer has 50 % chance to perceive these TLAs. When these values are less than one, as their limits are set, they are not visible on the average.”
- “By comparing the TLA results obtained from the older and new lamp groups , it can be concluded that the **luminaire manufacturers have taken the EU Ecodesign regulation into account**. This has been done by **favouring the type A LED** driver topology, which in general results in lower $P_{st\ LM}$ and SVM values as compared with the other driver types. They also have stopped using the B and D type lamp driver topologies which exhibit bad TLA behaviour”
- https://files.cie.co.at/Abstract_Booklet_TLM_Symposium_2022.pdf, Ikonen, E.

Key comparison: Artefacts



$P_{st,LM}$: from 0 to 5

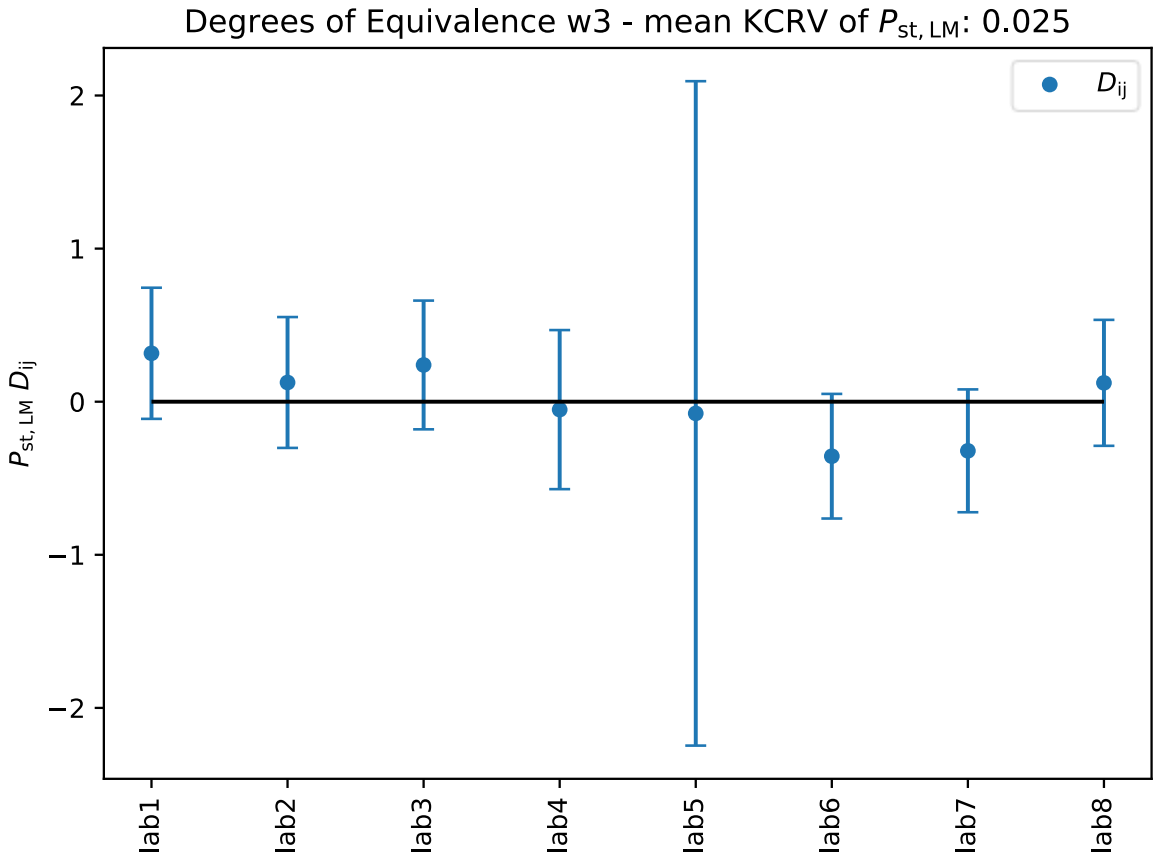
M_{vs}: from 0 to 5

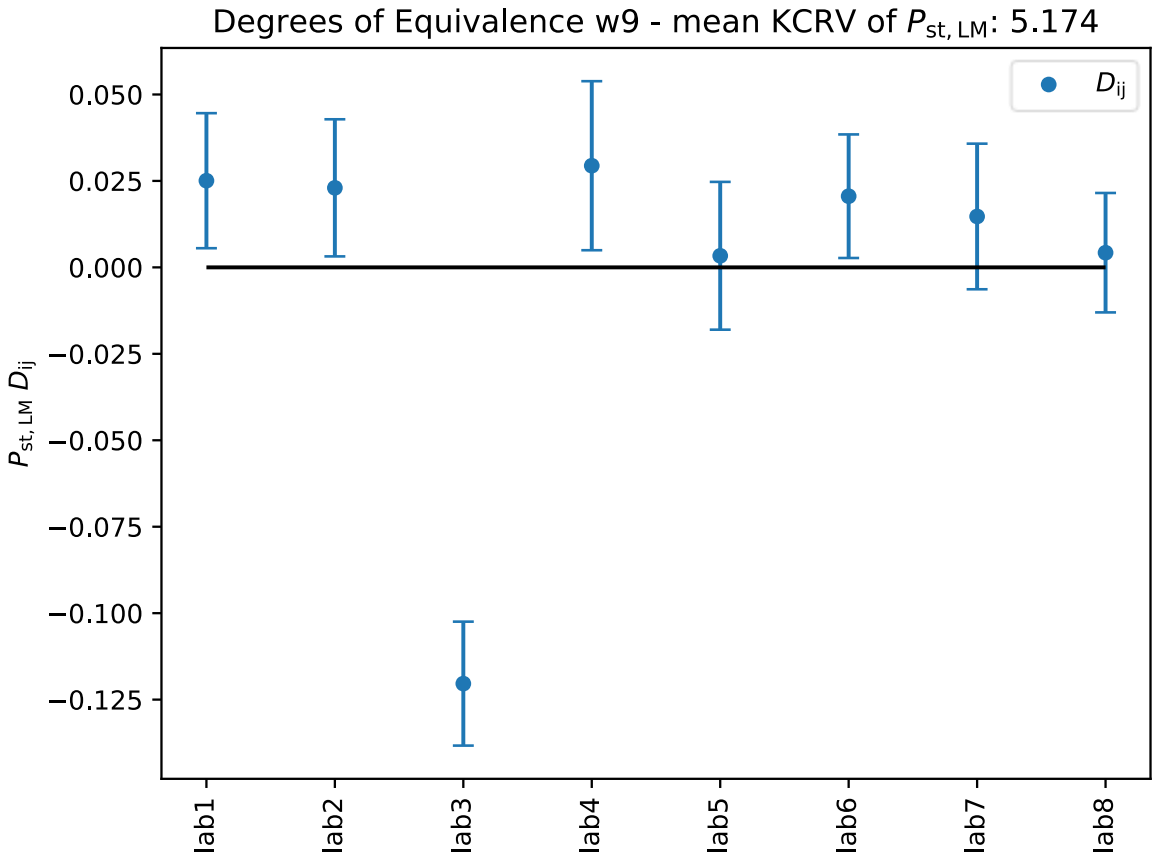
Table 1. Artefact Set for IC 2023

	Artefact	Photo	Electrical Rating
ART-1	LED lamp		230 VAC, 50Hz, 3.8 W
ART-2	LED lamp		230 VAC, 50Hz, 3.5 W
ART-3	LED lamp		230 VAC, 50Hz, 5 W
ART-4	LED lamp (complex waveform)		230 VAC, 50Hz, ~2.5 W

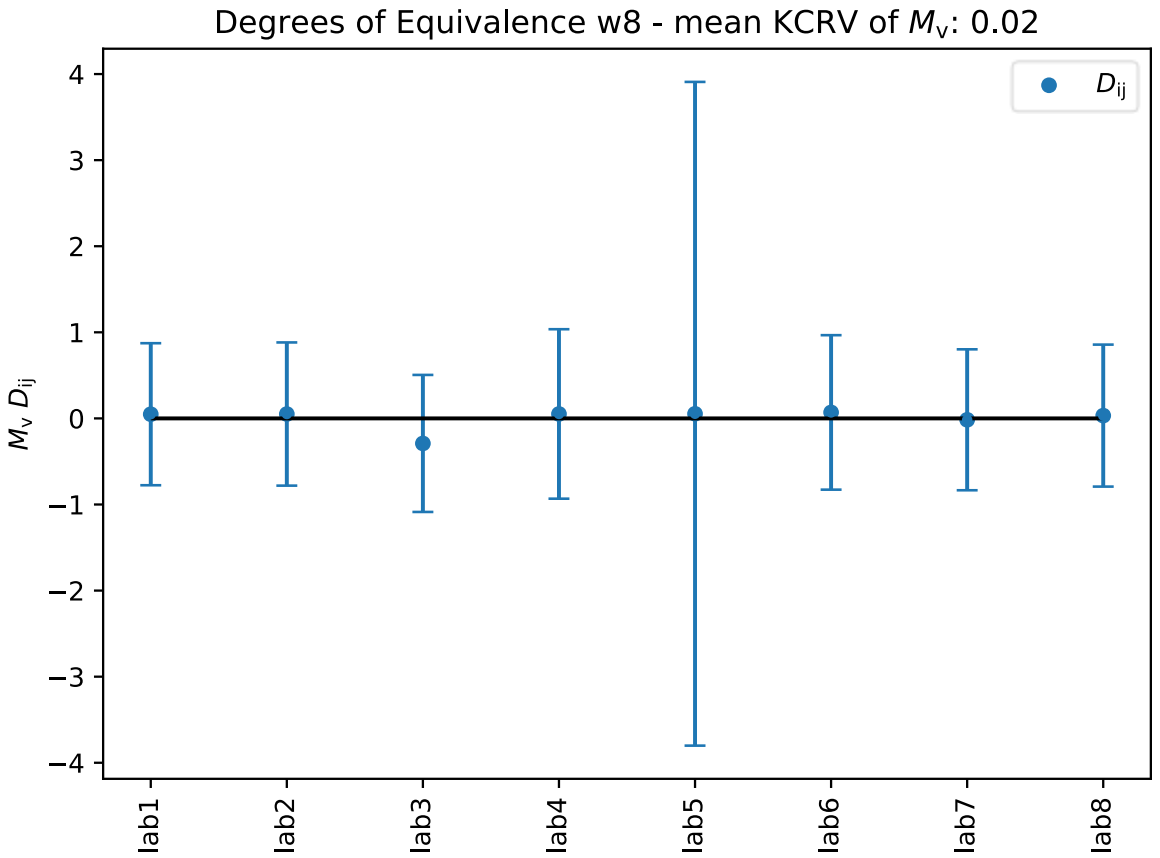
Supplied by: IEA 4E SSL Annex

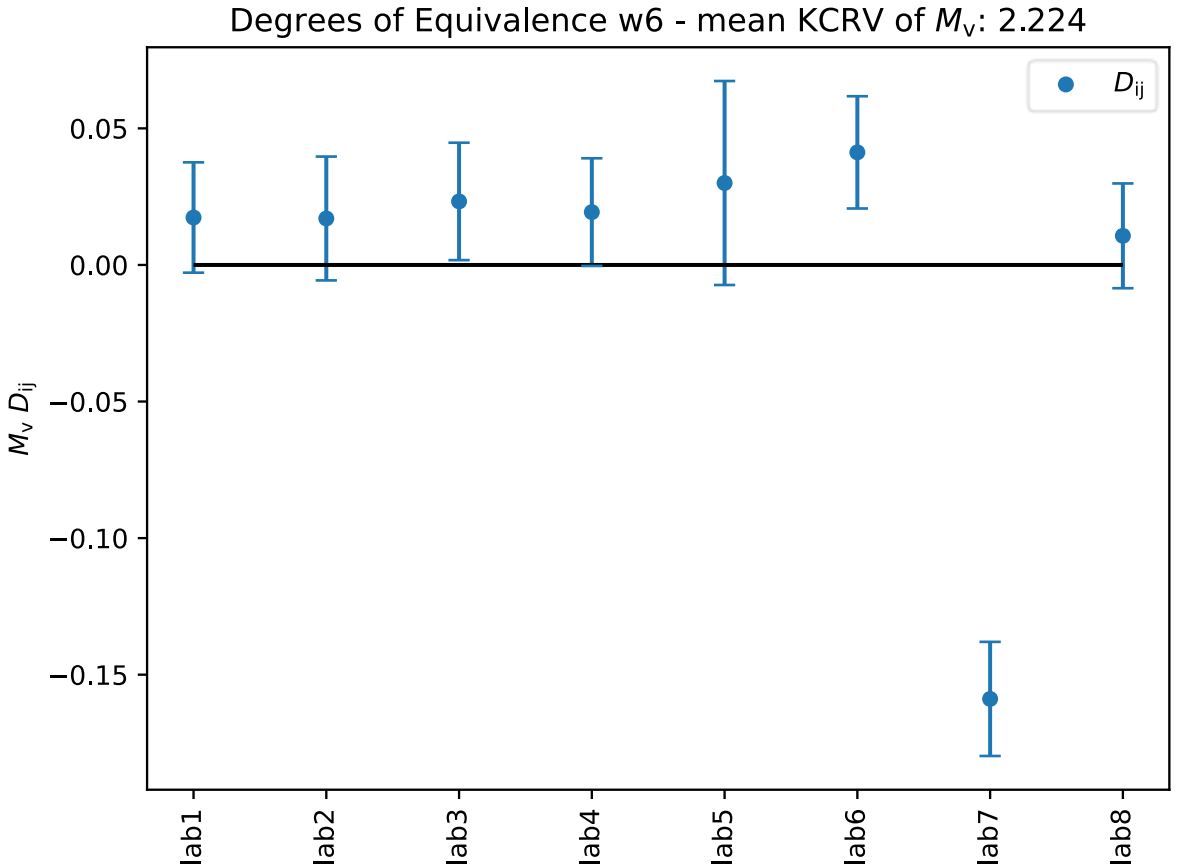
Key comparison: Results





Key comparison: Results





Key points for traceable TLM measurements

- Transparent implementation of models is a requirement for traceable measurements
  - Zero padding
  - Windowing
- Traceability to primary TLM measurement devices, in turn traceable to voltage, as well as to time and frequency
- For black box devices, verify and calibrate against primary TLM Measurement devices at different waveforms
- The impact of ecodesign on the market is noticeable

- Keep an eye on the MetTLM project webpage for further results: Project | Metrology for Temporal Light Modulation (mettlm.eu)

Acknowledgement

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- Project | Metrology for Temporal Light Modulation (mettlm.eu)

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