

21NRM01 HiDyn  
{HiDyn}

**D1:** Report describing the design, development and technical specification of a type of high-contrast-luminance reference standard (covering at least 6 orders of magnitude), including the determination of luminance with an expanded uncertainty no larger than 1 % for the brightest source and no larger than 2 % for the dimmest one

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**Deliverable Cover Sheet**

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## Glossary

ILMD Imaging Luminance Measurement Devices

HDR High-dynamic-range

Hidyni High contrast luminance reference standard for characterizing **High-Dynamic-range imaging** luminance measurement devices

FOV Field Of View

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## 1 Summary

A high-contrast luminance reference source (Hidyni) was developed, as part of HiDyn project at Czech metrology institute (CMI) in collaboration with Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC), for characterizing high-dynamic-range (HDR) Imaging Luminance Measurement Devices (ILMDs) or other imaging measurement devices dedicated to the evaluation of indoor or outdoor lighting conditions. The source consists of seven independent luminance modules that cover six orders of magnitude of luminance, ranging from  $0.1 \text{ cd/m}^2$  to  $100\,000 \text{ cd/m}^2$ . The modules can be used simultaneously or separately in any geometrical arrangement. The Hidyni comprises a light trap for background signal evaluation. The diameter of the luminous area of the modules is adjustable (from 25 mm and smaller). The position of the modules can be adapted to suit different imaging devices, to cover various field-of-views. Each module has a lockable articulating platform for the source-camera alignment and most components to be manufactured are based on 3D-printing with the design data provided as open access. The Hidyni was fully characterised and the luminance of each module was calibrated. The development of the proposed Hidyni is inexpensive and simple to reproduce by other producers, which was demonstrated by METAS, who successfully reproduced the Hidyni modules following this guide.

## 2 Introduction

In this chapter the scope of the report and the need for the implemented development is described.

### 2.1 Scope of this report

This report describes the design and the relevant technical details for guidance to the realization of the high-contrast luminance reference source developed in WP1, Task 1.1 of the HiDyn project by the Czech metrology institute (CMI) in collaboration with the Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC). The purpose of this reference source, named “Hidyni”, is to provide reference for characterizing Imaging Luminance Measurement Devices (ILMDs) or other imaging-based measurement devices dedicated to the evaluation of indoor or outdoor lighting conditions, in aspects as glare or obtrusive light.

### 2.2 Hidyni reference source

The evaluation of the ability of imaging measurement devices for measuring with high dynamic range (HDR) needs high contrast luminance reference sources. The development and characterisation of such a source is presented in this document. The main objective of this research was to develop a versatile light source with a high luminance contrast, with a spatial distribution allowing the capacity of a ILMD for measuring very different luminance levels simultaneously to be characterized. According to this main objective and to previous experience, we targeted to have a Hidyni source providing six orders of magnitude, from  $0.1 \text{ cd/m}^2$  to about  $100 \text{ kcd/m}^2$ , with well-defined luminance levels. They will be realized using source modules with different luminance values, each covering a decade of contrast, and with a size much smaller than the usual field-of-views (FOV), so that all sources can be presented simultaneously to the ILMDs. The distance between the different source modules must be adaptable to the specific FOV.

This light source is composed of seven different sources in order to cover a range from approximately  $0.1 \text{ cd/m}^2$  to about  $100 \text{ kcd/m}^2$  by multiplying by 10 each previous level of luminance, and, in addition, a level of less than  $0.01 \text{ cd/m}^2$  for background signal of ILMDs evaluation. A modular prototype was designed. Independent luminance sources with different luminance levels were developed using off-the-shelf products, with special attention on its reproducibility. The body of the luminance source was composed from 3D printed parts. The sources are mounted on an aluminium profile holder, freely adjustable in both position and angular orientation.

The most important properties of the designed source are the long-term stability of the average luminance of each module, the number of available orders of magnitude, the spectral distribution (matched with spectral distribution of the CIE reference illuminant L41 [CIE 2023]), the spatial uniformity of the radiant exitance of the independent luminance modules, the angular independence within the numerical aperture of the imaging system, its negligible cross-talk among the individual

independent sources, its negligible temporal modulation, its geometrical versatility to be adapted to different field-of-views (FOVs) and configurations, and its portability.

### 3 Design of the source

The Hidyni source was designed as a modular system to support the characterisation of ILMDs with various measurement fields, using freely adjustable mounting positions for seven independent luminance modules. Seven independent modules were designed to cover the luminance levels from  $0.1 \text{ cd/m}^2$  to  $100 \text{ kcd/m}^2$  (6 orders of magnitude). The modules can be used simultaneously or separately in any combination. Each luminance module has an usable diameter of the luminous area of up to 25 mm and independent angular adjustment (for the source-camera alignment). The luminance modules are portable and can be stored in a transport case. Using the developed holder made from aluminium profiles, the modules can be arranged differently, as shown in Figure 1, where hexagonal arrangement is shown. The position of the lighting modules can be adjusted to the required scene, to cover from narrow to very wide field-of-views (fisheye lens). The light trap, surrounded by white square area for better visibility in images of the high contrast scene, was placed close to the central  $0.1 \text{ cd/m}^2$  source. A commercially available light trap is intended for the environmental light background evaluation.

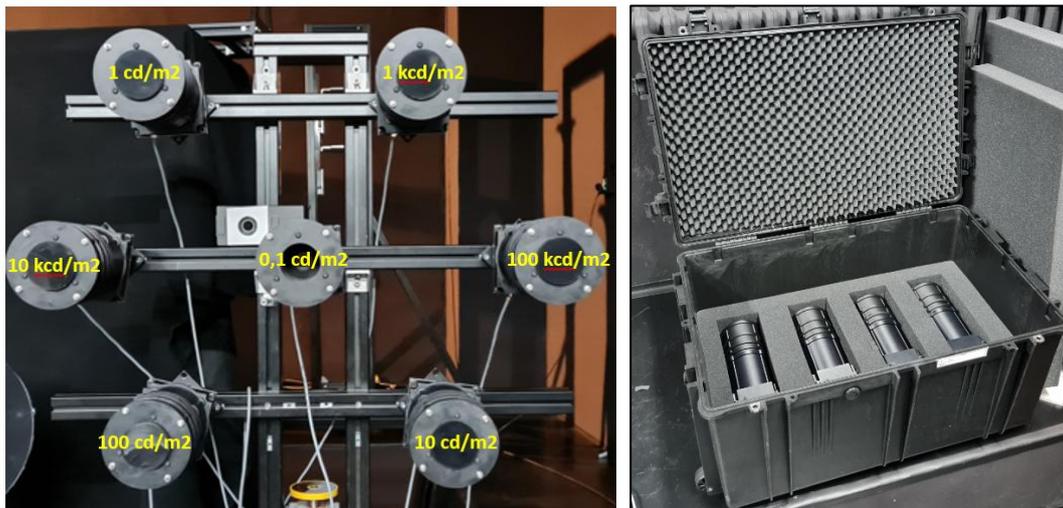


Figure 1: Photo of the developed Hidyni source in one of many possible configurations (left) and of the transport case (right)

### 4 Development of the source

In this chapter the scheme of the source module, its components and their assembly are described.

#### 4.1 Lighting module

The general design of a single Hidyni luminance module is shown in Figure 2. The body of the luminance module consists of the housing for the LED module, a mixing chamber (cone) ending with a diffuser and a set of the tubes and baffles. The original diffuser from the LED module was removed and installed at the end of the cone. The diffuser thus forms a luminous surface whose size is adjustable by the aperture behind it. All components were 3D printed using filaments ASA and PLA (black). The cone is finally coated on the inside with highly diffuse, reflective white paint. A commercially available tube dust cap (cover) can be fixed on the output aperture of the source to block the module's output without switching it off and thereby preserving its thermal equilibrium.

All the modules, regardless of the luminance level, have the same design. The aluminium base holds the LED module and is used as a cooler and mechanical interface between the LED module body and the angular joint. Each luminance module uses a combination of optical neutral density filters to reach the required luminance value (from  $0.1 \text{ cd/m}^2$  to  $100\,000 \text{ cd/m}^2$ ). The final adjustment to the nominal luminance level is reached by tuning the current supply to the LED by the module driver.

In the following, the detailed description of the different parts is given.

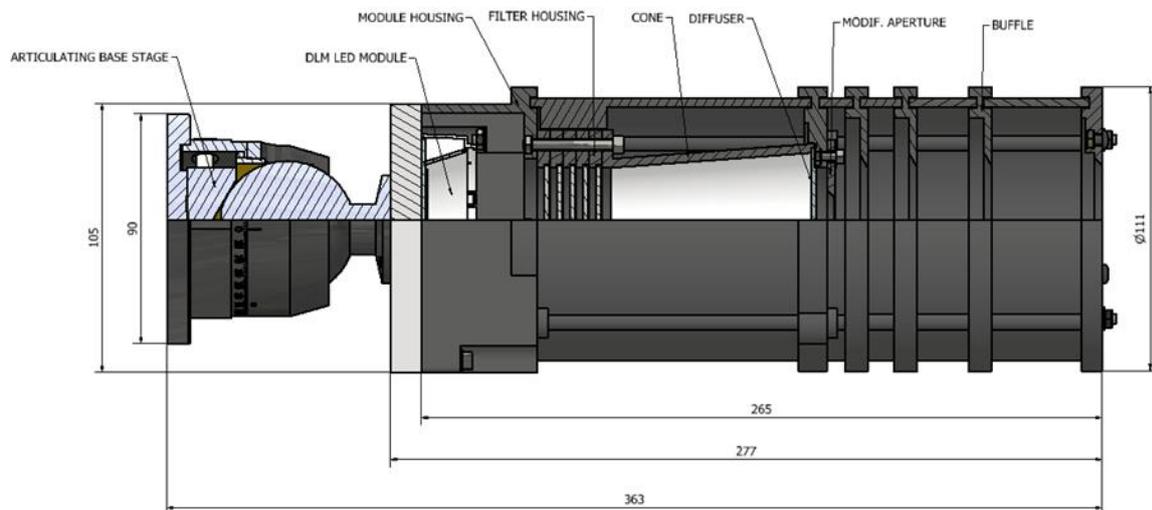


Figure 2: General design of a single lighting module.

## 4.2 Machined parts

The drawing of the aluminium base is reported below .

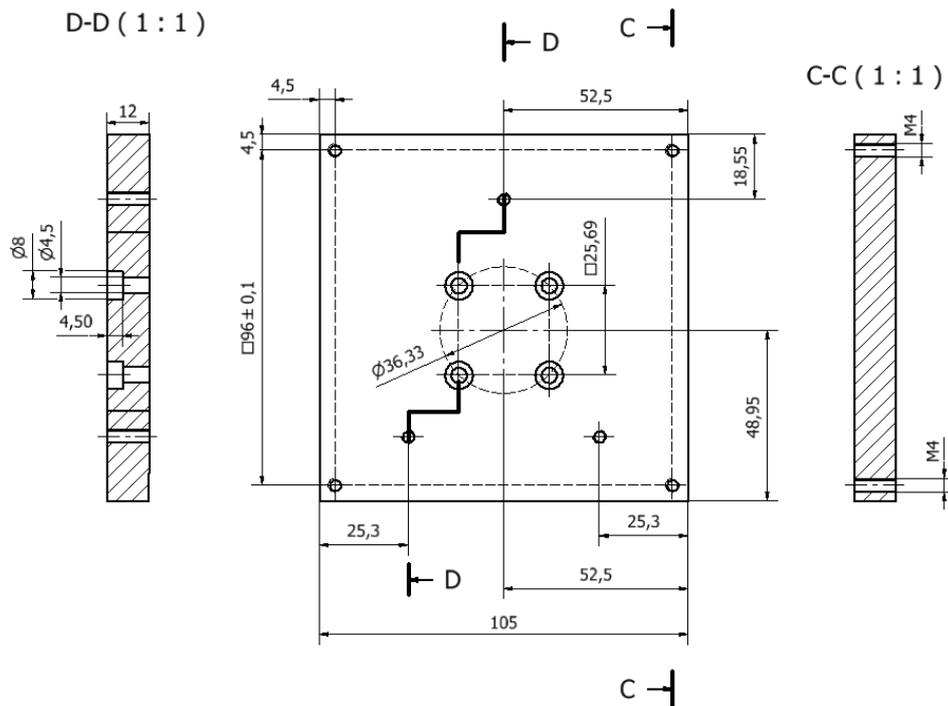


Figure 3: Drawing of the machined part for each module

### 4.3 3D printed parts

This Section gives the 3D files/3D printing schemes - description and the list of design files (see the following Tables).

Table 1: List of 3D printed parts of the high-contrast luminance source including its design file name.

| Part. | Name of the part        | Material (Vendor)          | STL file name                      |
|-------|-------------------------|----------------------------|------------------------------------|
| 1.    | HOUSING LED A1          | ASA (Filament PM)          | <i>HOUSING_LED_A1.stl</i>          |
| 2.    | FILTER FRAME            | ASA (Filament PM)          | <i>FILTER_FRAME.stl</i>            |
| 3.    | FILTER FRAME CONE short | ASA (Filament PM)          | <i>FILTER_FRAME_CONE_long.stl</i>  |
| 4.    | FILTER FRAME CONE long  | ASA (Filament PM)          | <i>FILTER_FRAME_CONE_short.stl</i> |
| 5.    | COVER TUBE              | ASA (Filament PM)          | <i>COVER_TUBE.stl</i>              |
| 6.    | BAFFLE DIFFUSER         | ASA (Filament PM)          | <i>BAFFLE_DIFFUSER.stl</i>         |
| 7.    | MODIFIED APERTURE 25    | ASA (Filament PM)          | <i>MODIFIED_APERTURE_25.stl</i>    |
| 8.    | DISTANCE Part A         | ASA (Filament PM)          | <i>DISTANCE_Part_A.ipt</i>         |
| 9.    | BAFFLE 47 mm            | REC-PLA (Print With Smile) | <i>BAFFLE_47_mm.stl</i>            |
| 10.   | DISTANCE Part B         | REC-PLA (Print With Smile) | <i>DISTANCE_Part_B.stl</i>         |
| 11.   | BAFFLE 48 mm            | REC-PLA (Print With Smile) | <i>BAFFLE_48_mm.stl</i>            |
| 12.   | DISTANCE Part C         | REC-PLA (Print With Smile) | <i>DISTANCE_Part_C.stl</i>         |
| 13.   | BAFFLE 49 mm            | REC-PLA (Print With Smile) | <i>BAFFLE_49_mm.stl</i>            |
| 14.   | DISTANCE Part D         | REC-PLA (Print With Smile) | <i>DISTANCE_Part_D.stl</i>         |
| 15.   | BAFFLE CAP 50           | REC-PLA (Print With Smile) | <i>BAFFLE_CAP_50.stl</i>           |

Table 2: General parameters of the printing process

|                       |   |
|-----------------------|---|
| Printer:              | BambuLab X1 Carbon Combo, software Bambu Studio   |
| Layer high:           | 0.2 mm  |
| Extruder:             | 0.4 – hardened steel  |
| Perimeters:           | 2   |
| Top and Bottom layers | 4 and 4   |
| Infill:               | 20% - gyroid  |
| Brim width:           | 10mm on Outside, for ASA mat. only  |
| Supports:             | Yes – AUTO + SNUG - top Z distance ASA 0.16 mm, PLA 0.2mm, pattern spacing 2.5 mm, 2 + 2 interface layers |

Table 3: ASA (Filament PM) printed parts specific parameters setting

|                                     |                                |
|-------------------------------------|--------------------------------|
| Filament:                           | 1.75 mm, Filament PM           |
| First layer temperature:            | 260°C – Nozzle temperature     |
| Temperature:                        | 275°C – Nozzle temperature     |
| Build plate temperature:            | 110°C (High Temperature Plate) |
| Chamber temperature:                | 50°C                           |
| Adhesive for FFF (FDM) 3D printing: | Dimafix Spray                  |
| Continuous cooling in the chamber:  | Approx. 2 hours                |

Table 4: REC-PLA (Print With Smile) printed parts specific parameters setting

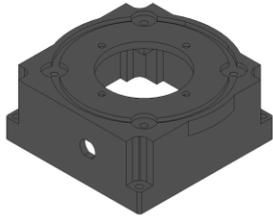
|                                     |  |
|-------------------------------------|--|
| Filament:                           | 1.75 mm, Print With Smile                      |
| First layer temperature:            | 230°C – Nozzle temperature                     |
| Temperature:                        | 235°C – Nozzle temperature                     |
| Build plate temperature:            | 35° C (Cool plate)                             |
| Cooling:                            | 100% + AUX Fan - 70%. First cooling layer off. |
| Adhesive for FFF (FDM) 3D printing: | 3Dlac Spray                                    |

An overview of the 3D-printed parts and its name declaration as used in this document is given in Figure 4.

HOUSING\_LED\_A1

FILTER\_FRAME

FILTER\_FRAME\_CONE\_long



FILTER\_FRAME\_CONE\_short



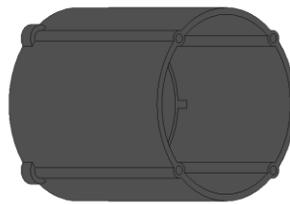
COVER\_TUBE



BAFFLE\_DIFFUSER



MODIFIED\_APERTURE\_25



DISTANCE\_Part\_A



BAFFLE\_47\_mm



DISTANCE\_Part\_B



BAFFLE\_48\_mm



DISTANCE\_Part\_C



BAFFLE\_49\_mm



DISTANCE\_Part\_D



BAFFLE\_CAP\_50

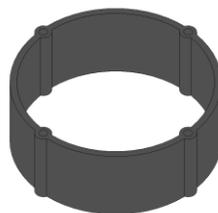


Figure 4: rendered view of all 3D printed parts for one module indicating its name

#### 4.4 Optical grey reflective filters (pre-attenuation)

Each lighting module uses combination of optical filters to reach the required luminance value. The filters were selected to reach a stable colour temperature at each luminance level. The filters are placed from the side of the LED source to the exit aperture with increasing optical density. The final adjustment to the nominal luminance level is reached by tuning the current fed to the LED by the module driver, see Table 6. The list of filters used for each luminance level is presented in Table 5. For more details see the list of materials in Section 4.7.

Table 5: List of neutral density filters to be implemented for each luminance level

| HiDyn source level | Nominal Luminance (cd/m <sup>2</sup> ) | Implemented optical ND filters |     |     |     |     |
|--------------------|--|--------------------------------|-----|-----|-----|-----|
|                    |  | Optical Density (-)            |     |     |     |     |
| I.                 | 0.1                                    | 0.7                            | 0.8 | 0.9 | 0.9 | 1.5 |
| II.                | 1                                      | 0.7                            | 0.8 | 0.9 | 0.9 | 1.5 |
| III.               | 10                                     | 0.7                            | 0.8 | 0.9 | 1.5 | -   |
| IV.                | 100                                    | 0.9                            | 0.9 | -   | -   | -   |
| V.                 | 1 000                                  | 0.9                            | 0.9 | -   | -   | -   |
| VI.                | 10 000                                 | 0.7                            | -   | -   | -   | -   |
| VII.               | 100 000                                | -                              | -   | -   | -   | -   |

## 4.5 LED Source and electronics

### 4.5.1 LED modules

The LED module is a white LEDs on PCB and diffuser model FORTIMO LED DLM FLEX 5000/840 GEN2 produced by Philips. The diameter of LED module is about 60 mm. The correlated colour temperature of the light emitted by the LED module is about 4000 K. The specified value of the emitted luminous flux is 5 000 lm.

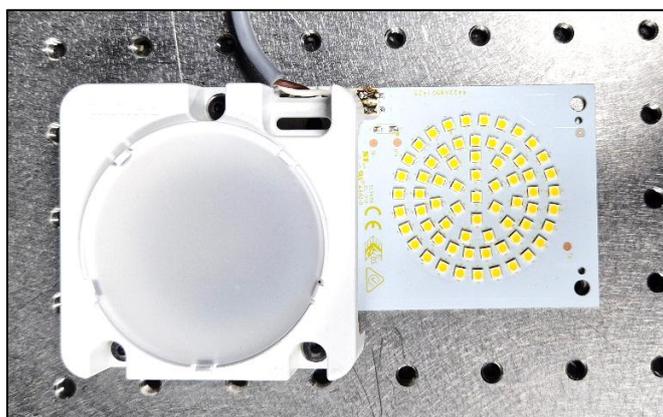


Figure 5: Photo of the LED housing (left) including diffuser and one LED module (right).

### 4.5.2 Drivers

The LED driver is a stabilized current source model XITANIUM 50W WH produced by Philips, see Figure 6. Every lighting module requires an independent current driver. The adjusted current levels correspondent to the luminance levels values are reported in the Table 6.



Figure 6: Photo of the LED driver

The drivers allow to adjust the LED driving current from 100% down to 1% with step of 1% by the integrated dimming capability. The flicker for all output levels was measured. For dimming levels lower than 27% a flicker higher than 1% occurs. To avoid flicker, an LC-filter was designed.

### 4.5.3 LC filter for flicker reduction

To minimize the source flicker namely in dimmed (adjusted) operation conditions, an LC circuit was implemented. The wiring diagram is shown in Figure 8 while the LC schematic is reported below in Figure 7. It is possible to solder the filter components in the air and install it in the box between the driver and the lighting module. With the insertion of this filter the residual flicker was found to be negligible.

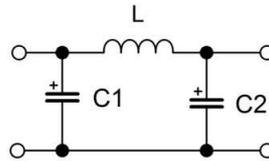


Figure 7: schematic of the LC filter circuit.

#### 4.5.4 Fine luminance level adjustment - Driver setting

To reach the required luminance levels each lighting module driver should be set for the particular Adjustable Light Output (%). Another way to fine tune the driver output is to set the current value, however this setting introduces the risk of damaging the LED module by using an excess current level. The exemplary values found for one Hidyni artefact are seen in Table 6. To set the driver one can use the MultiOne mobile application for Android OS produced by Signify. The mobile requirements are: Internal NFC, Android 10 or newer. For the details see the original manual for the application.

Table 6: Nominal luminance values and the exemplary Light Output level adjustment. The values are indicative for the CMI implementation of the source. METAS implementation used slightly different output levels due to slightly different driver model.

| HiDyn source level | Nominal Luminance (cd/m <sup>2</sup> ) | Adjustable Light Output (%) | LC filter needed for Flicker <1% |
|--------------------|--|-----------------------------|----------------------------------|
| I.                 | 0.1                                    | 3                           | Yes                              |
| II.                | 1                                      | 32                          |                                  |
| III.               | 10                                     | 57                          |                                  |
| IV.                | 100                                    | 5                           | Yes                              |
| V.                 | 1 000                                  | 47                          |                                  |
| VI.                | 10 000                                 | 46                          |                                  |
| VII.               | 100 000                                | 50                          |                                  |

#### 4.5.5 Wiring diagram

The driver must be connected to the mains using a power cord. To do this follow the original user guide from the driver producer. The LC filter is connected to the positive and negative pins of the driver output. The LED module is connected to the positive and negative poles of the LC filter output. For all connections a cable (2 cores with Cross Sectional Area of 0.5 mm<sup>2</sup>) was used. For recommended parts see the list of materials in Section 4.7. To connect the LED module is recommended to use a 2-pole connector included in the list of materials in Section 4.7. For the wiring diagram see Figure 8 below.

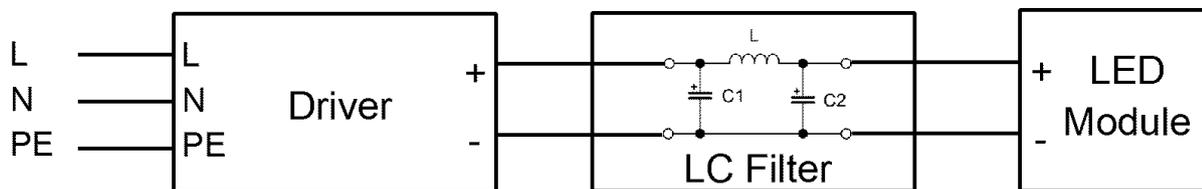


Figure 8: schematic wiring diagram of the driver, LC filter and LED module

#### 4.5.6 Light trap

A commercially available light trap KONICA MINOLTA CM-A23 was used as to get the luminance level of less than 0.01 cd/m<sup>2</sup>. Any other type of the trap with similar parameters can be used. For examples of alternative products see the Section 4.7.

The trap has been modified for better visibility in images of the high contrast scene. The entrance of the trap was surrounded by white square area made from sheet of paper.



Figure 9: photo of the light trap KONICA MINOLTA CM-A23 (left) and the modification (right)

## 4.6 Scene construction

To place the lighting modules to create the desired scene it is possible to connect them either to aluminium profiles or they can be mounted to tripods. A dark level of luminance lower than  $0.01 \text{ cd/m}^2$  was created using a commercially available light trap. In order to modify the geometrical configuration of the luminance modules, they can be connected either by aluminium profiles, or they can be mounted to tripods for more flexibility.

Three 80 cm long horizontal parallel profiles with a spacing of 30 cm were used to create a hexagonally arranged reference scene with dimensions of approximately 70 cm x 60 cm, see Section 0. for more details. These three profiles can be mounted for example on a wall. For the laboratory measurements made in this project a free-standing supporting structure holding the three profiles was constructed, see Figure 10. The commercially available aluminium profile system was used. Nuts and screws that are a common part of the aluminium profile system are used for mounting the Hidyni lighting modules. The articulating base of each module has four holes. Only two were used to mount the module to the profile. In the Figure 11 see the mounting of the articulating base and the profile (left), and whole module connected to the profile (right).

Any locally available aluminium profile system can be used to construct the holder. The specific dimensions of the holder depend on the specific requirements for the size of the constructed scene.

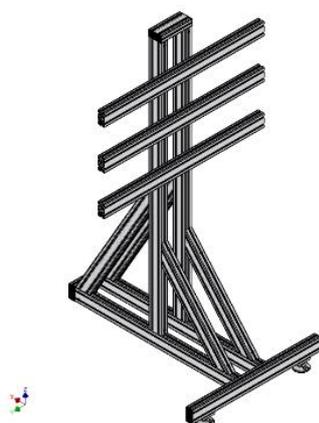


Figure 10: design view of the Hidyni holder made from aluminium profile system

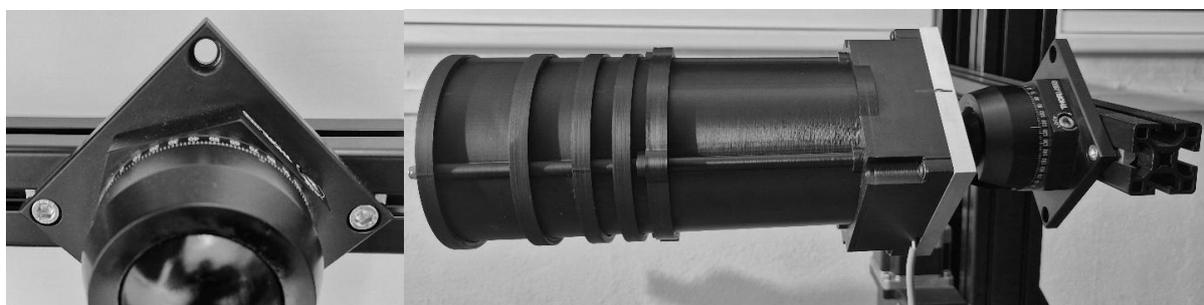


Figure 11: mounting of the articulating base and the profile (left), and whole module connected to the profile (right).

## 4.7 List of materials

This Section reports the list of materials for each luminance level lighting module.

Table 7: list of materials for the Module\_1 (0.1 cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 2    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTec s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | EDIH222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | Pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

Table 8: list of materials for the Module 2 (1 cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 2    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

Table 9: list of materials for the Module 3 (10 cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | M    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | Pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | Pc   |

Table 10: list of materials for the Module 4 (10<sup>2</sup> cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 2    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

Table 11: list of materials for the Module 5 ( $10^3$  cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 2    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

Table 12: list of materials for the Module 6 ( $10^4$  cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 1    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_long   | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

Table 13: list of materials for the Module 7 ( $10^5$  cd/m<sup>2</sup>)

| Part Nr. | Catalog Nr. / Order code | Product description  | Vendor                   | Qty. | Unit |
|----------|--------------------------|--|--------------------------|------|------|
| 1.       | SL20/M                   | Articulating Base Ball Stage, High Precision Ball              | Thorlabs                 | 1    | pc   |
| 2.       | ND207B                   | ND Filter, Optical Density: 0.7, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 3.       | ND208B                   | ND Filter, Optical Density: 0.8, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 4.       | ND209B                   | ND Filter, Optical Density: 0.9, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 5.       | ND215B                   | ND Filter, Optical Density: 1.5, 50 mm x 50 mm                 | Thorlabs                 | 0    | pc   |
| 6.       | 694793912134200          | Fortimo LED DLM Flex 5000/840 Gen2 (LED board)                 | Philips                  | 1    | pc   |
| 7.       | 871829179745600          | Fortimo LED DLM Flex Cover (Shallow housing)                   | Philips                  | 1    | pc   |
| 8.       | 929002862006             | Xitanium 50W WH 0.7-1.5A 54V TD/Is (Driver)                    | Philips                  | 1    | pc   |
| 9.       | W8S038                   | Washer (100 pack)  | Thorlabs                 | 23   | pc   |
| 10.      | ISO 4762 M3 x 10         | Bolt   | Shop/Market              | 3    | pc   |
| 11.      | ISO 4762 M4 x 12         | Bolt   | Shop/Market              | 7    | pc   |
| 12.      | ISO 4762 M4 x 25         | Bolt   | Shop/Market              | 4    | pc   |
| 13.      | ISO 4762 M4 x 35         | Bolt   | Shop/Market              | 4    | pc   |
| 14.      | ISO 4032 M3              | Nut  | Shop/Market              | 3    | pc   |
| 15.      | ISO 4032 M4              | Nut  | Shop/Market              | 20   | pc   |
| 16.      | DIN 985 M4               | Nut  | Shop/Market              | 4    | pc   |
| 17.      | Threaded bar M4x250      | Threaded bar   | Shop/Market              | 4    | pc   |
| 18.      | HOUSING_LED_A1           | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 19.      | FILTER_FRAME             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 5    | pc   |
| 20.      | FILTER_FRAME_CONE_short  | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 21.      | COVER_TUBE               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 22.      | BAFFLE_DIFFUSER          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 23.      | MODIFIED_APERTURE_25     | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 24.      | DISTANCE_Part_A          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 25.      | BAFFLE_48_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 26.      | DISTANCE_Part_B          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 27.      | BAFFLE_49_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 28.      | DISTANCE_Part_C          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 29.      | BAFFLE_50_mm             | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 30.      | DISTANCE_Part_E          | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 31.      | BAFFLE_CAP               | 3D printed part, additive manufacturing technique (FMD)        | 3Dtisk.PRO s.r.o.        | 1    | pc   |
| 32.      | COOLER_01.idw            | COOLER_01 material: Aluminium                                  | ProfmultiTee s.r.o.      | 1    | pc   |
| 33.      | GX12-2P Connector        | Connector  | Shop/Market              | 1    | pc   |
| 34.      | GX12-2P Socket           | Socket   | Shop/Market              | 1    | pc   |
| 35.      | ART 156366 DUPLI-COLOR   | EFFECT PRIMER-white color, spray (150 ml)                      | European Aerosols GmbH   | 1    | pc   |
| 36.      | ED1H222MNN1836; RoHS     | ESR;THT;2200uF;50VDC;Ø18x36mm                                  | Elite                    | 2    | pc   |
| 37.      | SSR21NH-M18164; RoHS     | THT;16,4mH;1,8A;210mΩ;-25÷120°C;250VAC                         | KEMET                    | 1    | pc   |
| 38.      | 775-6084                 | RS PRO 2 Core 0.5 mm <sup>2</sup> Mains Power Cable, 3 A 300 V | RS Components Sp. z o.o. | 4    | m    |
| 39.      | 490-245                  | RS PRO 3m Power Cable, Unterminated to CEE 7/3, 10 A, 250 V    | RS Components Sp. z o.o. | 3    | m    |
| 40.      | N/A                      | Hexagon Bolt Cover Cap Screw Caps Plastic Balck, M4            | Shop/Market              | 4    | pc   |
| 41.      | SM2EC2                   | TUBE_DUST_CAP Ø2"  | Thorlabs                 | 1    | pc   |

### Light trap

A commercially available light trap, for example:

- KONICA MINOLTA CM-A23 (Currently available model: Zero calibration box CM-A182).
- Acktar Tube Beam Dump LBD-T-30 (diameter 30 mm)
- Acktar Tube Beam Dump LBD-T-51 (diameter 51 mm)

#### 4.8 Instructions-to assemble the module

The 3D model of one of the assembled Hidyni module is shown in Figure 12. The construction of each of the 7 modules is very similar. A particular module is assembled from the components listed in the appropriate tables see the Section 4.7. In the following, information is given on how to assemble a module step-by-step.

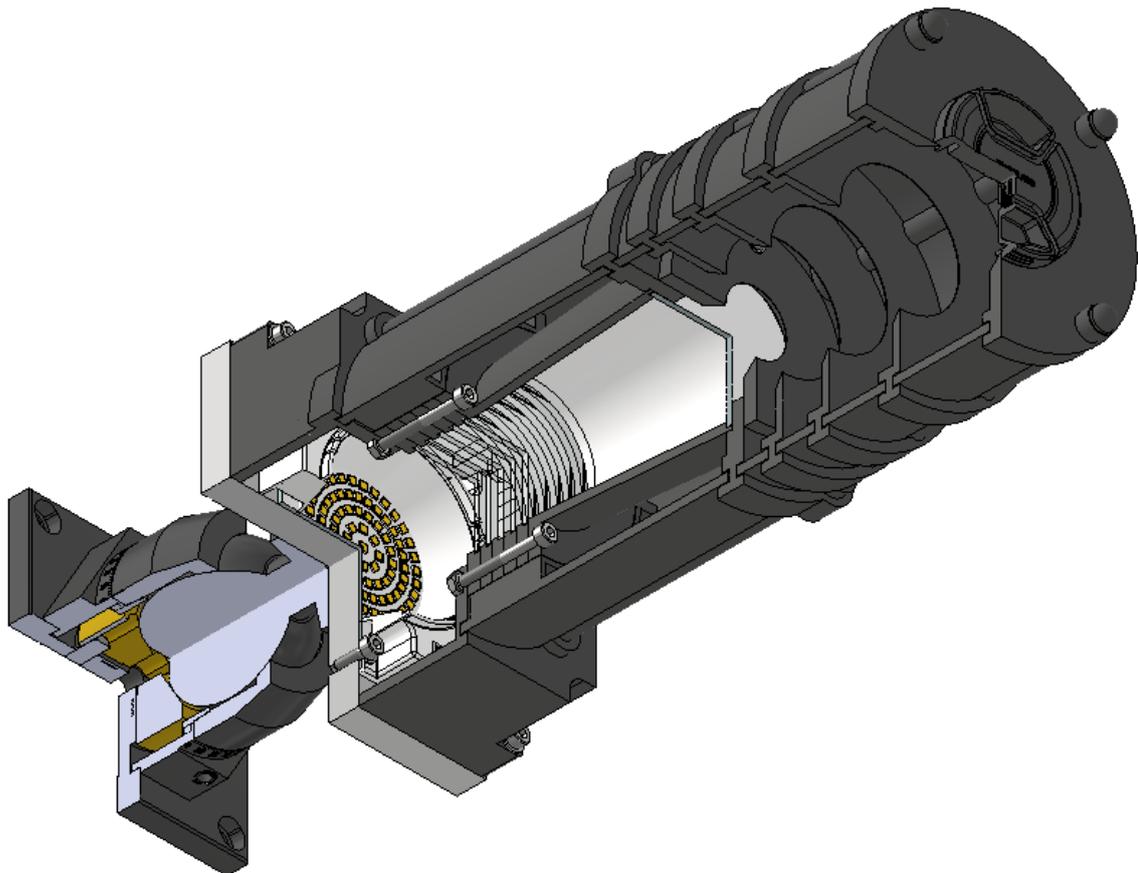


Figure 12: rendering of the 3D model of one assembled Hidyni module with cover cap

Step 1: Fasten the Cooler to the Articulating base by four screws.

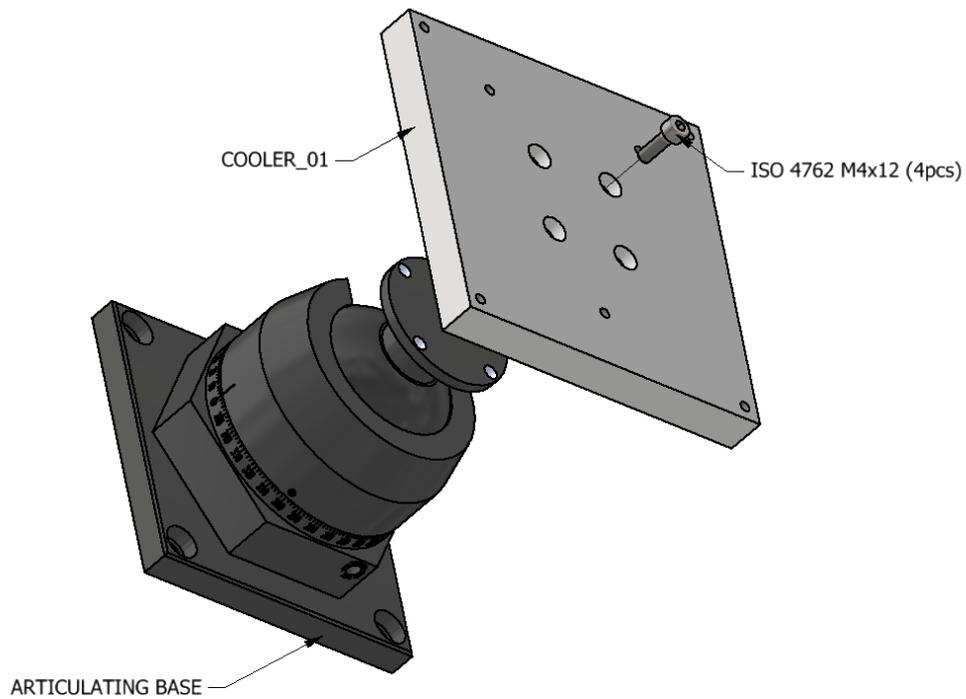


Figure 13: rendering of assembling Step 1

Table 14: Parts for Step 1

| Parts Description            | Qty. |
|------------------------------|------|
| Articulating Base Ball Stage | 1    |
| COOLER_01                    | 1    |
| ISO 4762 M4x12               | 4    |

Step 2: Prepare the LED board and the Shallow housing.

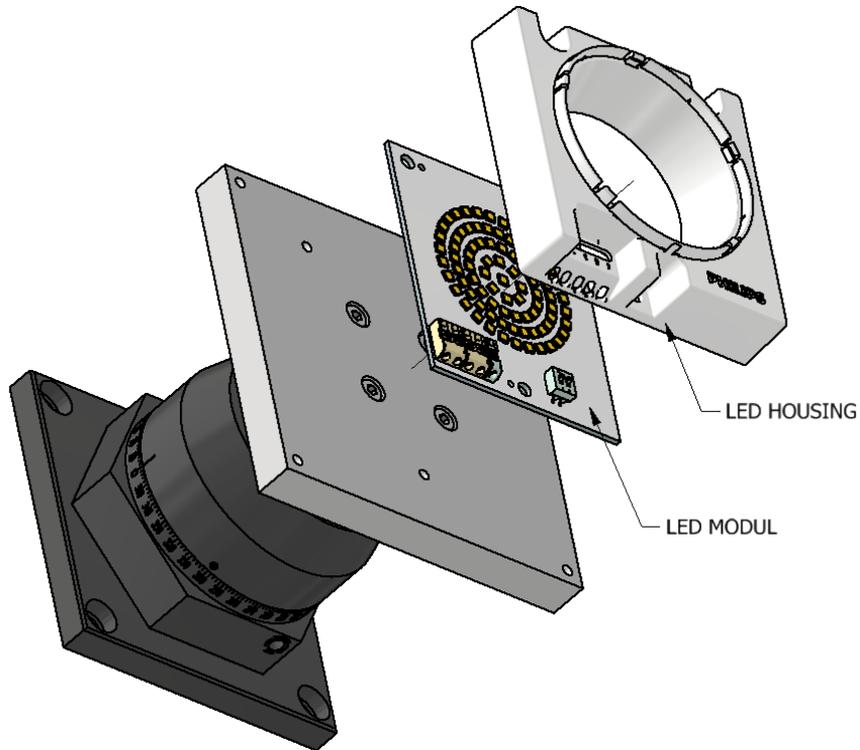


Figure 14: rendering of assembling Step 2

Table 15: Parts for Step 2

| Parts Description                              | Qty. |
|--|------|
| Fortimo LED DLM Flex 5000/840 Gen2 (LED board) | 1    |
| Fortimo LED DLM Flex Cover (Shallow housing)   | 1    |

Step 3: Mount the LED board and the Shallow housing to the COOLER.

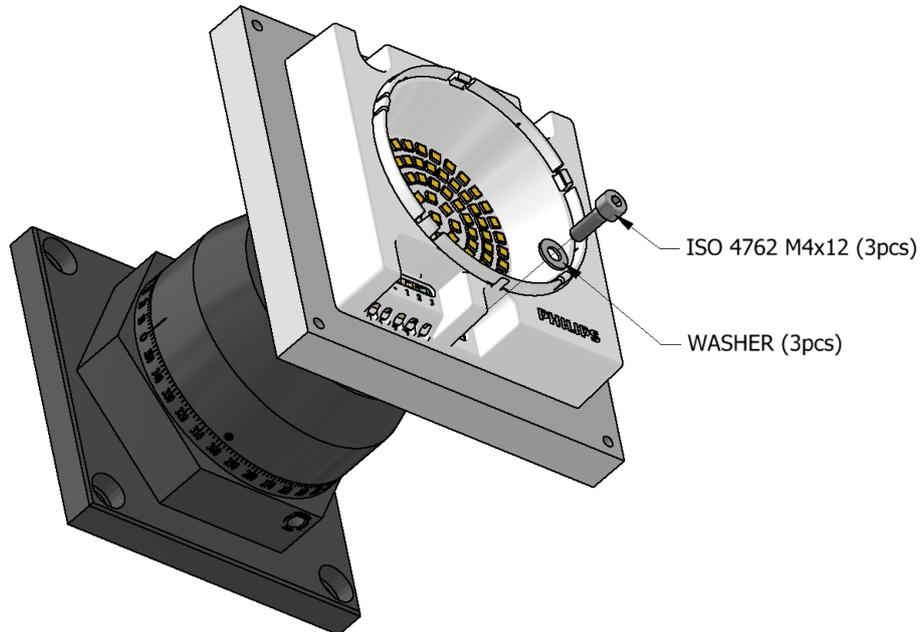


Figure 15: rendering of assembling Step 3

Table 16: Parts for Step 3

| Parts Description         | Qty. |
|---------------------------|------|
| Washer, W8S038 - Thorlabs | 3    |
| ISO 4762 M4x12            | 3    |

Step 4: Mount the connector into the HOUSING\_LED and insert the nuts into their positions .

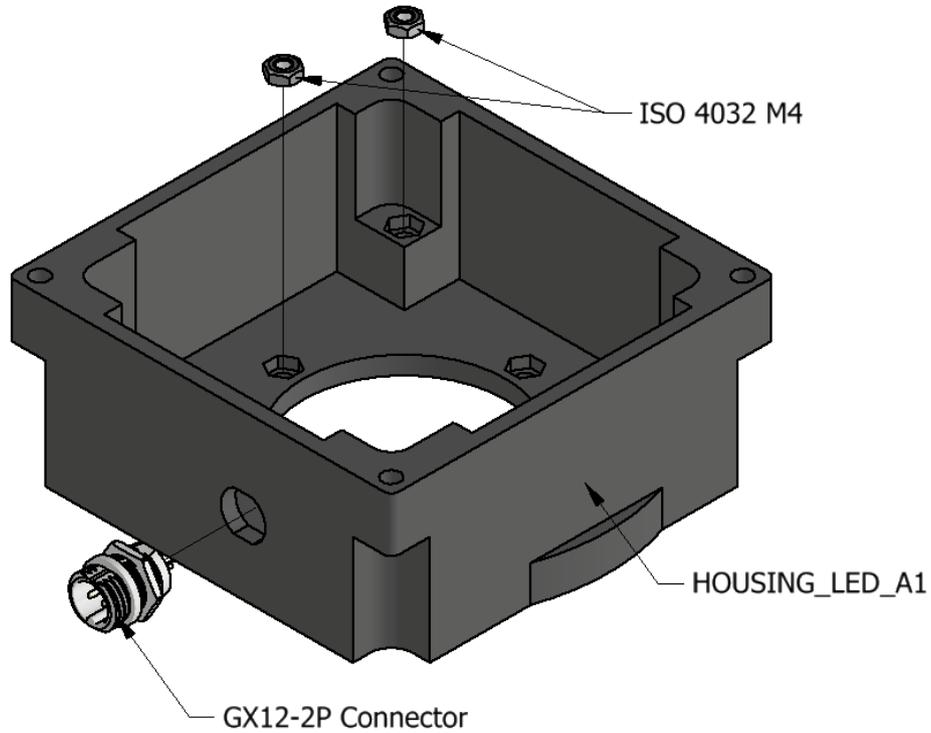


Figure 16: rendering of assembling Step 4

Table 17: Parts for Step 4

| Parts Description | Qty. |
|-------------------|------|
| HOUSING_LED_A1    | 1    |
| ISO 4032 M4       | 8    |
| GX12-2P Connector | 1    |

Step 5: Mount the Threaded bars.

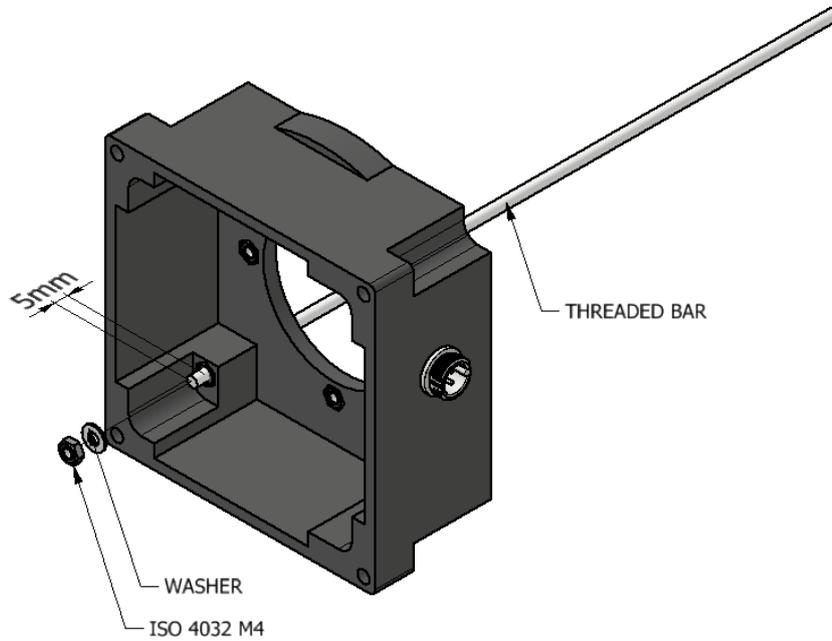


Figure 17: rendering of assembling Step 5

Table 18: Parts for Step 5

| Parts Description   | Qty. |
|---------------------|------|
| THREADED BAR M4X250 | 4    |
| ISO 4032 M4         | 4    |
| WASHER              | 4    |

Step 6: Fasten the Threaded bars to the LED housing.

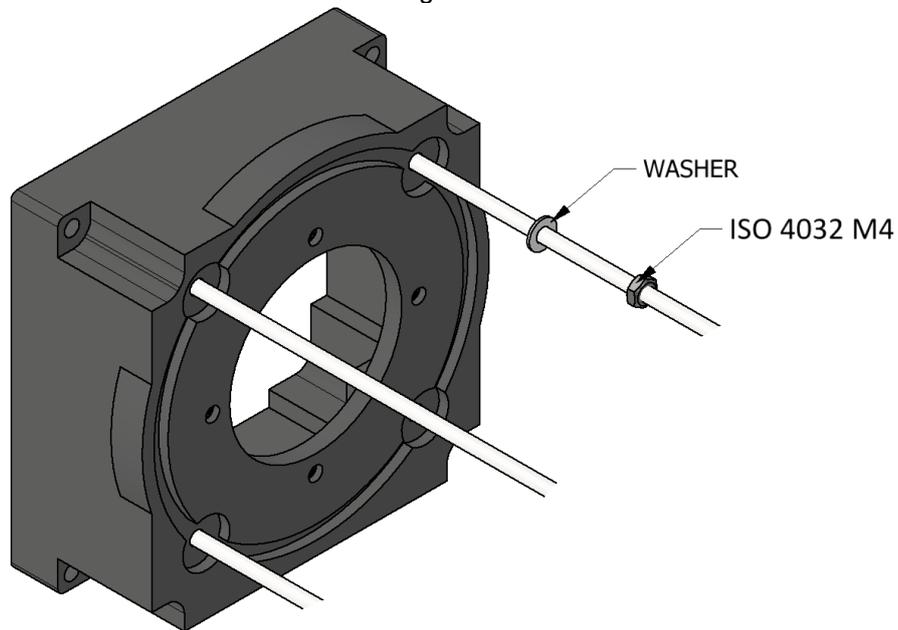


Figure 18: rendering of assembling Step 6

Table 19: Parts for Step 6

| Parts Description         | Qty. |
|---------------------------|------|
| Washer, W8S038 - Thorlabs | 4    |
| ISO 4032 M4               | 4    |

Step 7: Follow the figure below.

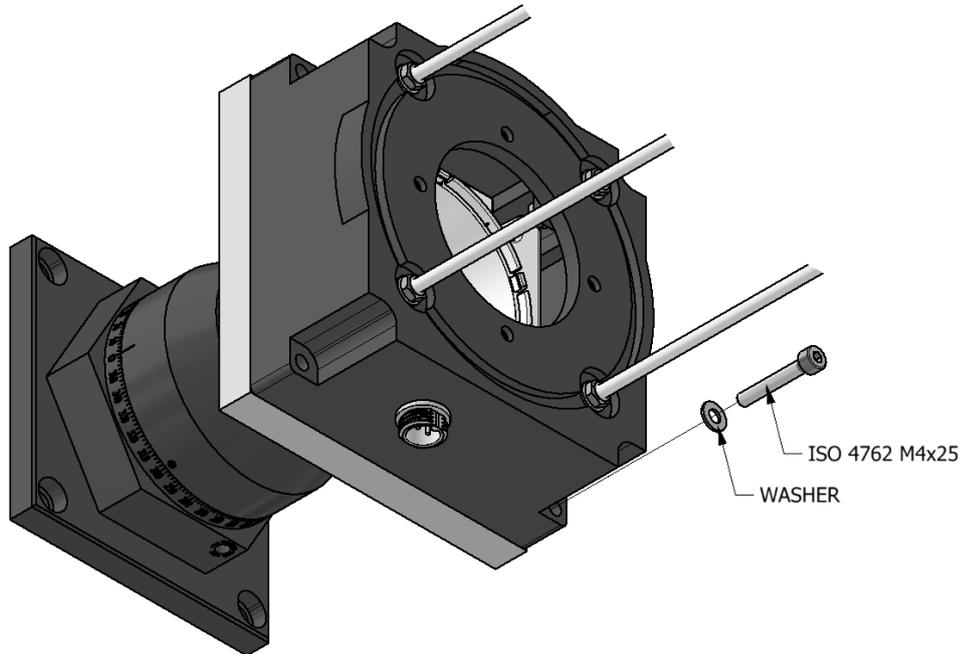


Figure 19: rendering of assembling Step 7

Table 20: Parts for Step 7

| Parts Description         | Qty. |
|---------------------------|------|
| Washer, W8S038 - Thorlabs | 4    |
| ISO 4762 M4X25            | 4    |

Step 8: Follow the figure below.

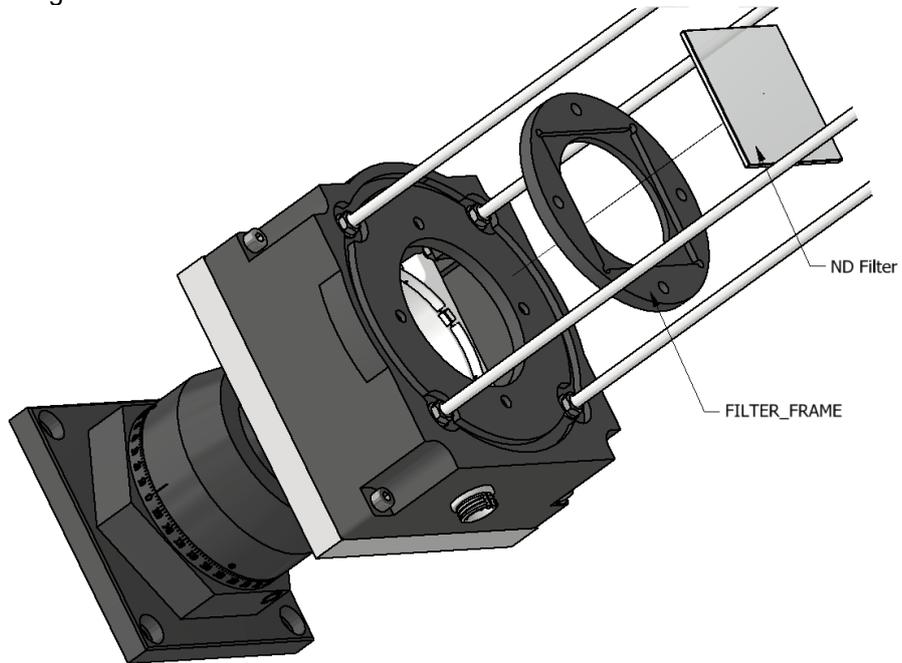


Figure 20: rendering of assembling Step 8

Table 21: Parts for Step 8

| Parts Description | Qty. |
|-------------------|------|
| FILTER_FRAME      | 5    |
| ND_Filter         | 5    |

Step 9: Follow the figure below.

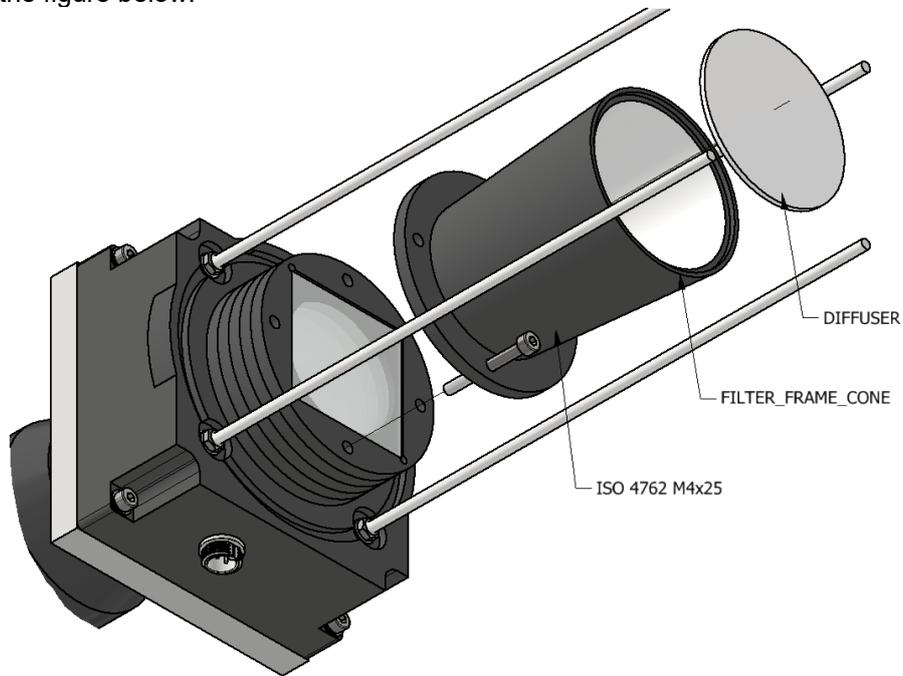


Figure 21: rendering of assembling Step 9

Table 22: Parts for Step 9

| Parts Description | Qty. |
|-------------------|------|
| DIFFUSER          | 1    |
| FILTER_FRAME_CONE | 1    |
| ISO 4762 M4x25    | 4    |

Step10: Follow the figure below.

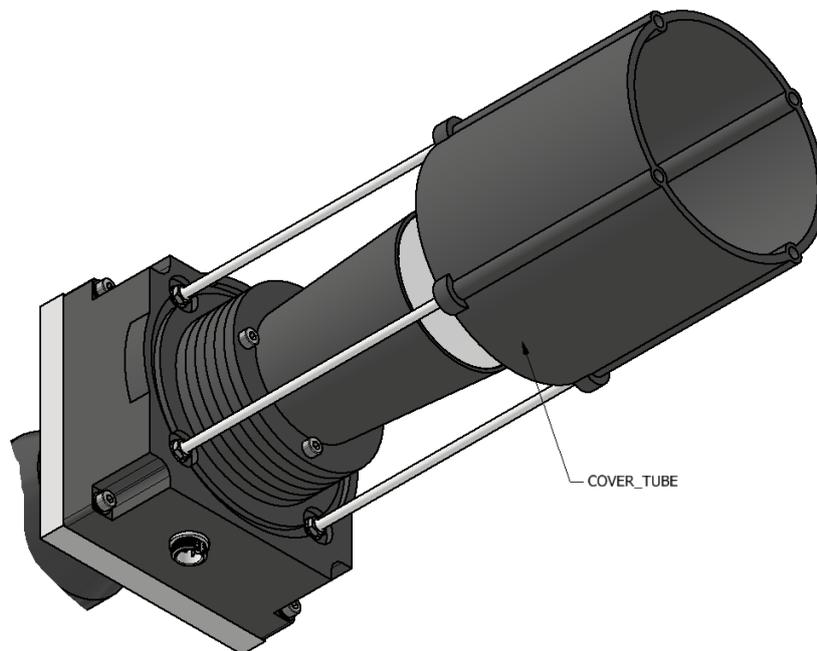


Figure 22: rendering of assembling Step 10

Table 23: Parts for Step 10

| Parts Description | Qty. |
|-------------------|------|
| COVER_TUBE        | 1    |

Step 11: Insert the nuts into their positions in the Baffle\_Diffuser and mount it.

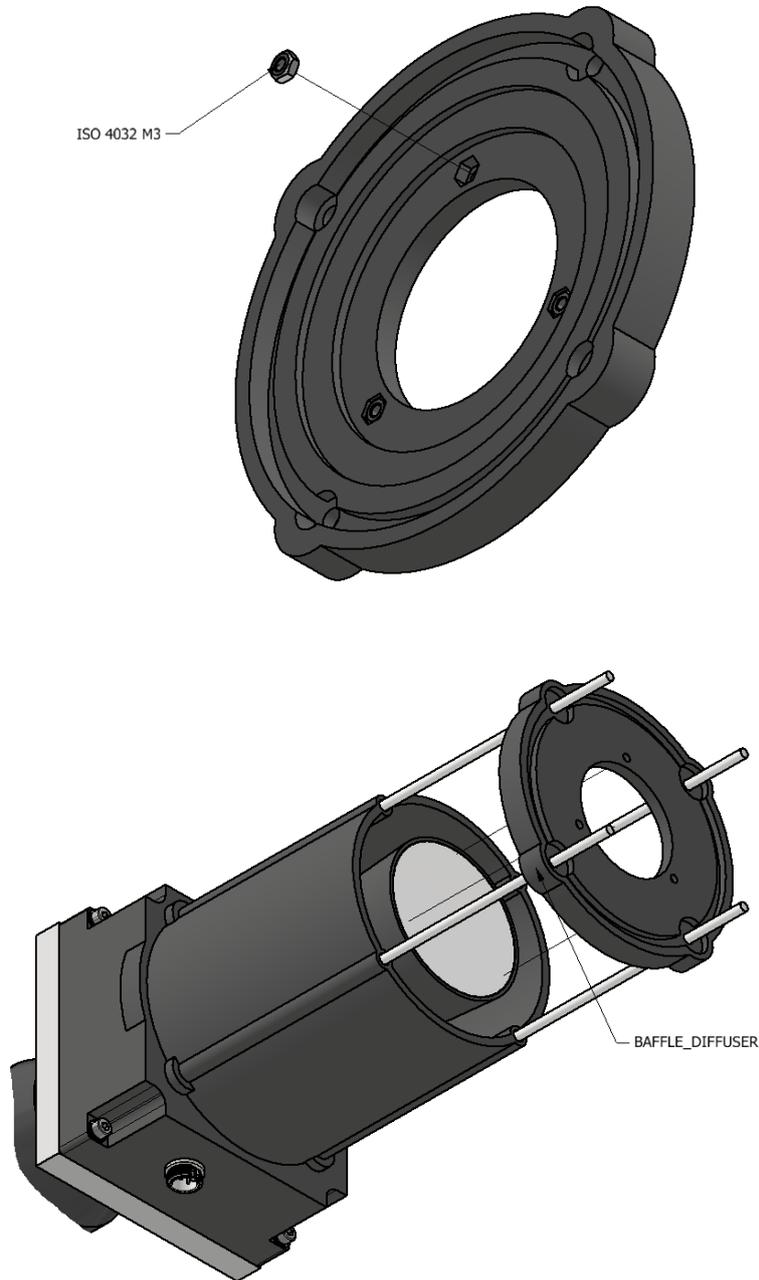


Figure 23: rendering of assembling Step 11

Table 24: Parts for Step 11

| Parts Description | Qty. |
|-------------------|------|
| BAFFLE_DIFFUSER   | 1    |
| ISO 4032 M3       | 3    |

Step 12: Follow the figure below.

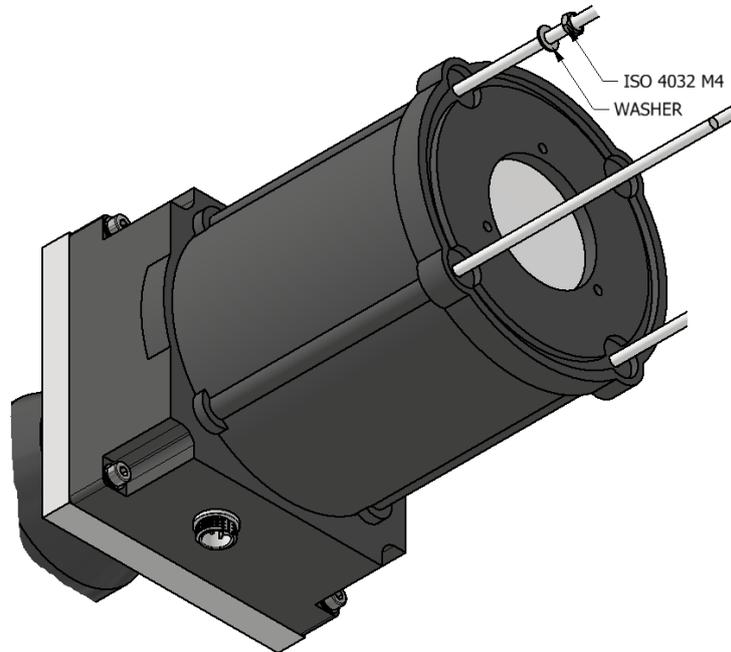


Figure 24: rendering of assembling Step 12

Table 25: Parts for Step 12

| Parts Description | Qty. |
|-------------------|------|
| WASHER            | 4    |
| ISO 4032 M4       | 4    |

Step 13: Follow the figure below.

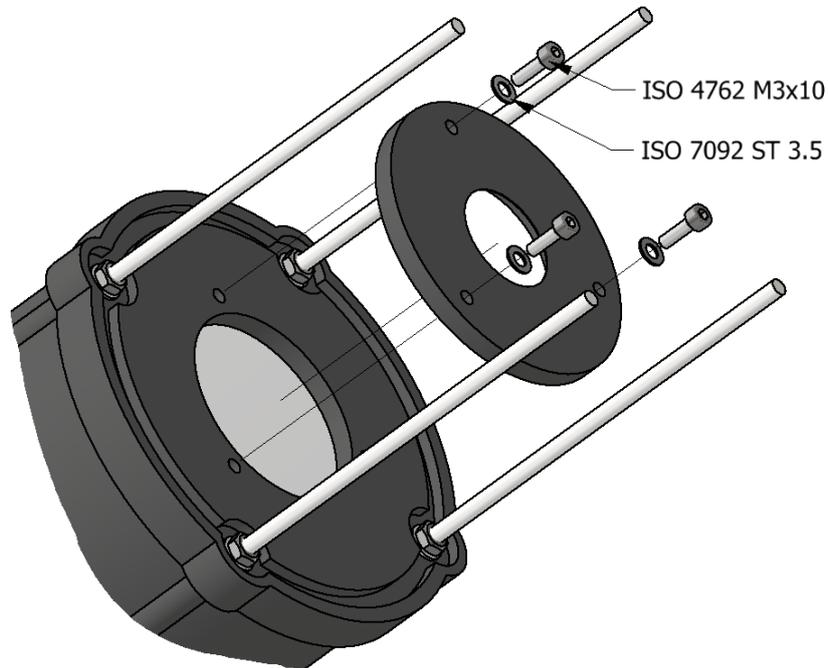


Figure 25: rendering of assembling Step 13

Table 26: Parts for Step 13

| Parts Description    | Qty. |
|----------------------|------|
| MODIFIED_APERTURE_25 | 1    |
| ISO 7092 ST 3.5      | 3    |
| ISO 4762 M3x10       | 3    |

Step 14: Follow the figure below.

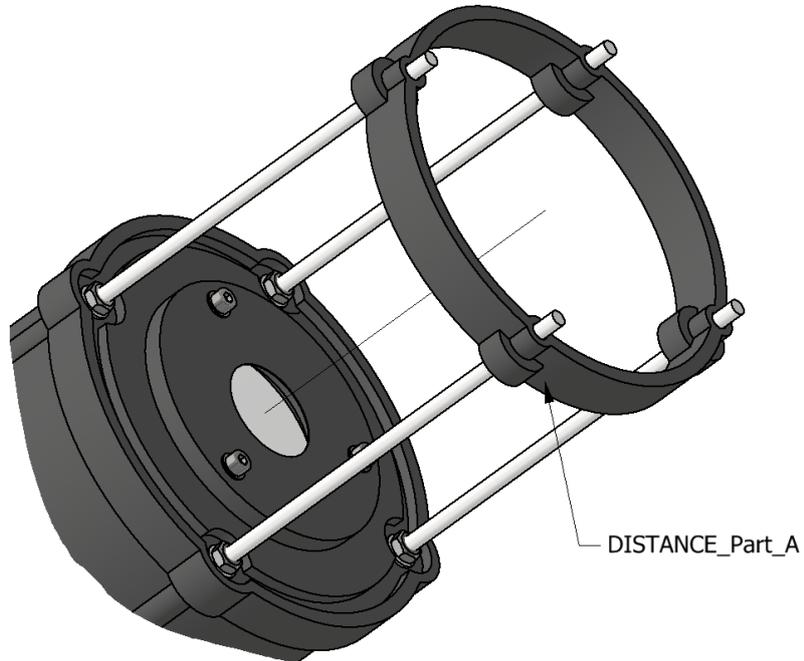


Figure 26: rendering of assembling Step 14

Table 27: Parts for Step 14

| Parts Description | Qty. |
|-------------------|------|
| DISTANCE_Part_A   | 1    |

Step15: Follow the figure below.

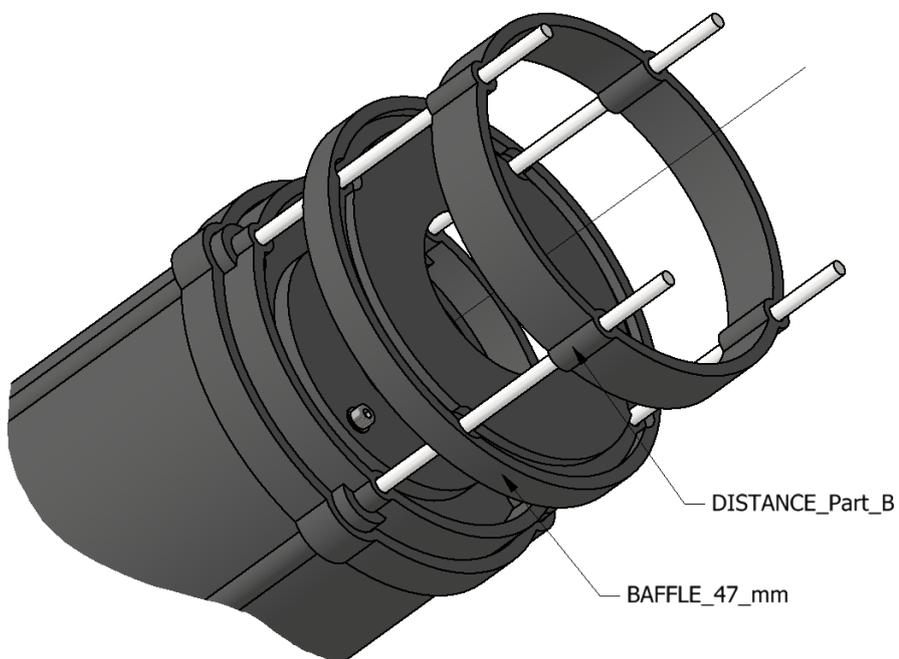


Figure 27: rendering of assembling Step 15

Table 28: Parts for Step 15

| Parts Description | Qty. |
|-------------------|------|
| BAFFLE_47_mm      | 1    |
| DISTANCE_Part_B   | 1    |

Step16: Follow the figure below.

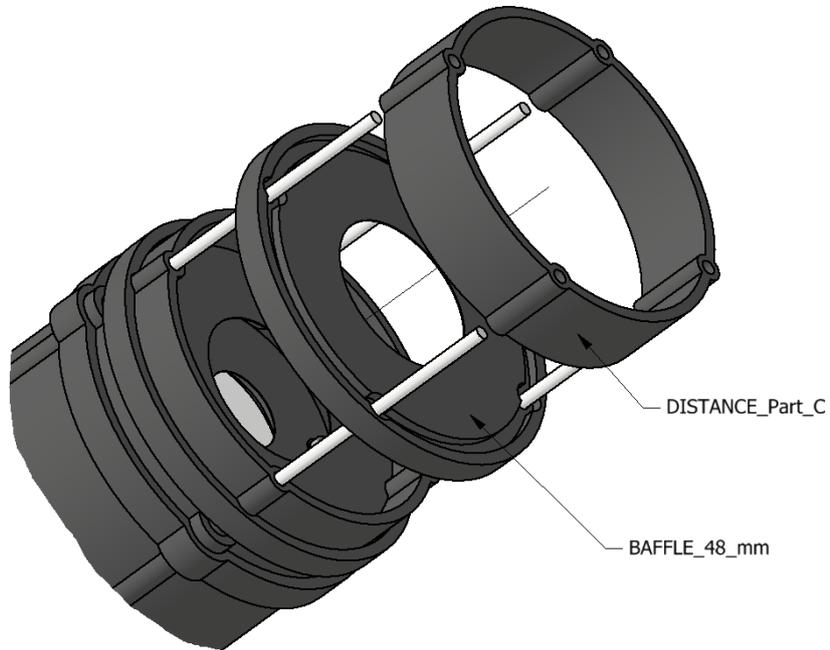


Figure 28: rendering of assembling Step 16

Table 29: Parts for Step 16

| Parts Description | Qty. |
|-------------------|------|
| BAFFLE_48_mm      | 1    |
| DISTANCE_Part_C   | 1    |

Step17: Follow the figure below.

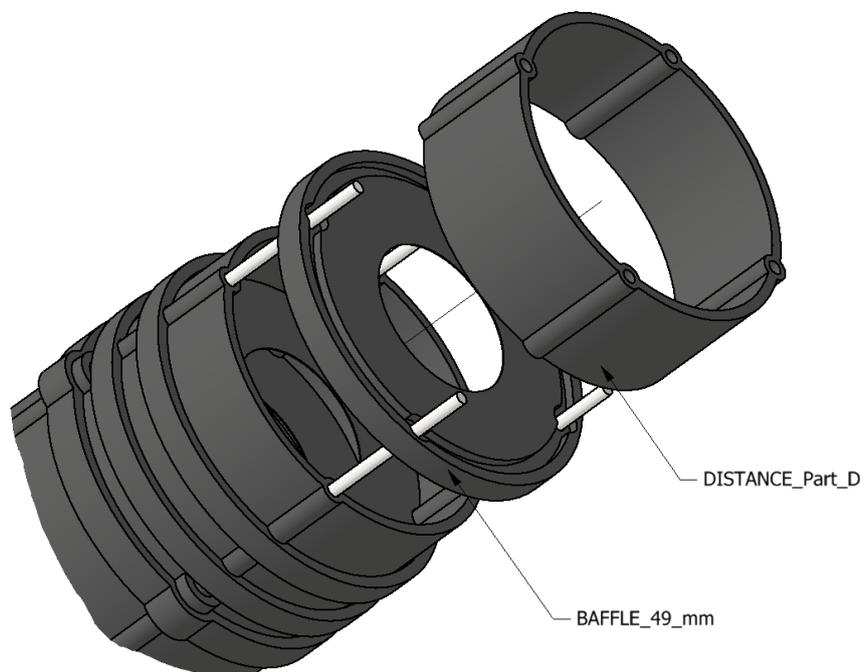


Figure 29: rendering of assembling Step 17

Table 30: Parts for Step 17

| Parts Description | Qty. |
|-------------------|------|
| BAFFLE_49_mm      | 1    |
| DISTANCE_Part_D   | 1    |

Step18: Follow the figure below.

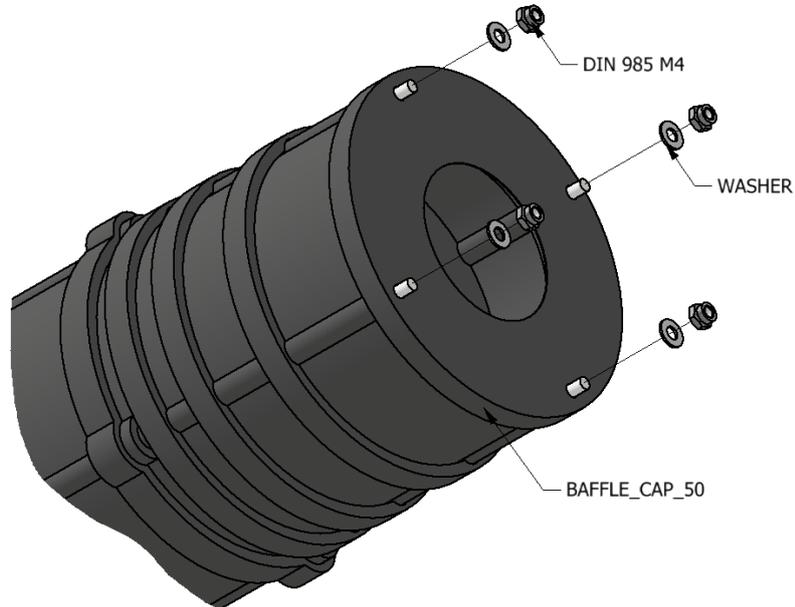


Figure 30: rendering of assembling Step 18

Table 31: Parts for Step 18

| Parts Description | Qty. |
|-------------------|------|
| BAFFLE_CAP_50     | 1    |
| WASHER            | 4    |
| ISO 4032 M4       | 4    |

Step19: Follow the figure below.

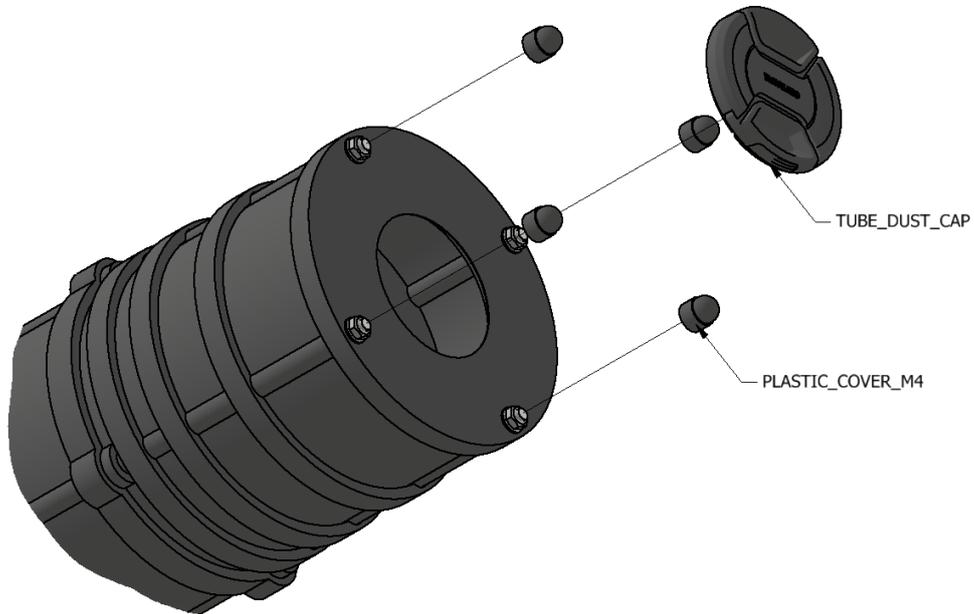


Figure 31: rendering of assembling Step 19

Table 32: Parts for Step 19

| Parts Description | Qty. |
|-------------------|------|
| PLASTIC_COVER_M4  | 4    |
| TUBE_DUST_CAP     | 1    |

## 5 Technical specification of the source

The exemplary Hidyni source was fully characterised. The luminance was measured and characterised regarding its temperature sensitivity, warming up time, temporal stability (the long-term operating stability (on/off cycling) and short-term operating stability (operating time of approximately 1 and 14 hours)). In addition, the spectral power distribution and correlated colour temperature, the average luminance (by an initial calibration and a recalibration one year later), cross-talk between modules and the uniformity of the luminous area of each module was determined. This was done for a source aperture of 25 mm.

### 5.1 Spectral power distributions

The relative spectral radiance distribution and the correlated colour temperature (CCT) of the source was measured using a reference tele-spectro-radiometer (Minolta CS-2000). The measured spectra of the seven lighting modules is given in Figure 32. The measured correlated colour temperature for each Hidyni module is listed in the Table 33.

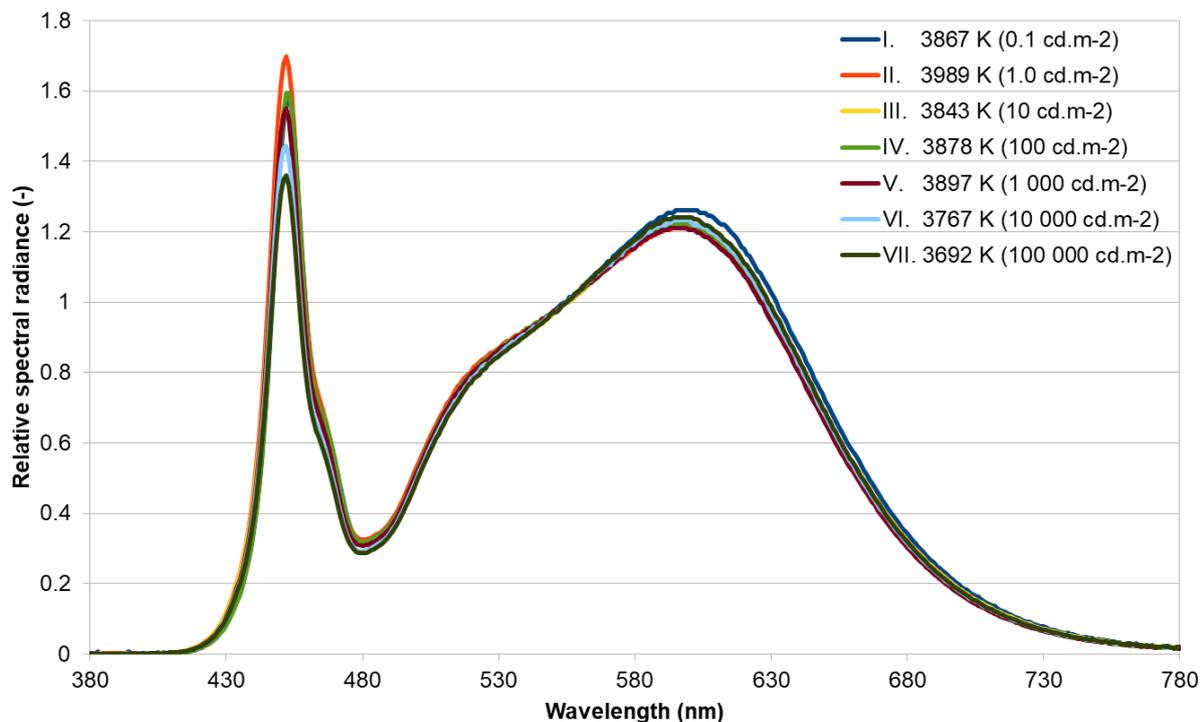


Figure 32: Spectral power distributions of the Hidyni source

Table 33: Correlated colour temperature of the Hidyni source

| Hidyni source level | Nominal Luminance (cd/m <sup>2</sup> ) | Measured CCT (K) |
|---------------------|--|------------------|
| I.                  | 0.1                                    | 3867             |
| II.                 | 1                                      | 3989             |
| III.                | 10                                     | 3843             |
| IV.                 | 100                                    | 3878             |
| V.                  | 1 000                                  | 3897             |
| VI.                 | 10 000                                 | 3767             |
| VII.                | 100 000                                | 3692             |

The quality index  $I_{SM}$  was calculated according to CIE 251:2023 from the measured relative spectral power distribution.

$$I_{SM}(S_T) = \int_{\lambda_{min}}^{\lambda_{max}} \left| \frac{S_T(\lambda) \cdot V(\lambda)}{\int_{360\text{ nm}}^{830\text{ nm}} S_T(\lambda) \cdot V(\lambda) d\lambda} - \frac{S_R(\lambda) \cdot V(\lambda)}{\int_{360\text{ nm}}^{830\text{ nm}} S_R(\lambda) \cdot V(\lambda) d\lambda} \right| d\lambda$$

$S_R$  ... reference spectrum CIE reference illuminant L41 [CIE 251:2023]

$S_T$  ... test spectrum (the spectrum of Hidyni luminance module)

$V(\lambda)$  ... luminous efficiency function

Table 34: Quality index  $I_{SM}$  according to CIE 251:2023 of the Hidyni source modules

| Hidyni source level | Nominal Luminance (cd/m <sup>2</sup> ) | Quality index $I_{SM}(S_T)$ (-) |
|---------------------|--|---------------------------------|
| I.                  | 0.1                                    | 0.055                           |
| II.                 | 1                                      | 0.033                           |
| III.                | 10                                     | 0.042                           |
| IV.                 | 100                                    | 0.037                           |
| V.                  | 1 000                                  | 0.034                           |
| VI.                 | 10 000                                 | 0.044                           |
| VII.                | 100 000                                | 0.050                           |

## 5.2 Luminance

The average luminance of each Hidyni luminance module was calibrated using a well-established method with reference to a calibrated spot-photometer. The measurement was done in a dark laboratory on the photometric bench. See the photo of the measurement setup in Figure 33.

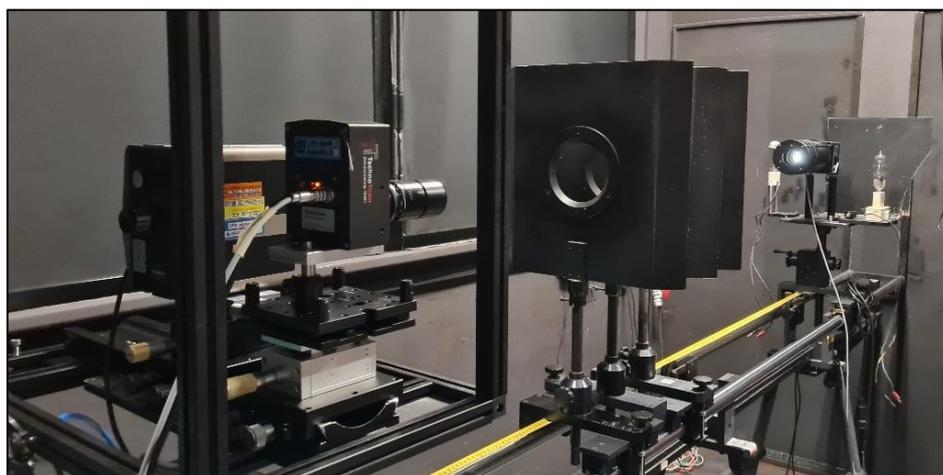


Figure 33: photo of the measurement setup used for luminance calibration of one module

The measurement of the average luminance was done in a diameter of 23 mm - slightly smaller than the full size of the Hidyni module aperture (25 mm). The diameter was reduced to allow alignment of the reference spot-photometer for reliable results and with respect to ILMD calibration conditions. The diameter of the measured area is supposed to be about 2 mm smaller (generally about 90% of the full size of the Hidyni module aperture) than the diameter of the Hidyni module aperture and aligned concentric to the luminous area, see Figure 34 .

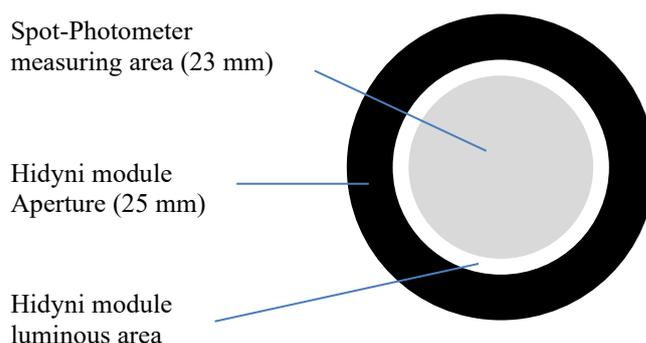


Figure 34 Scheme of the luminance calibration condition (Spot-photometer and Hidyni source - alignment, for easier visualization not to scale)

The uncertainty of the diameter setting during the calibration by the reference spot-photometer was 1 mm. The uncertainty contribution caused by the Hidyni luminance module nonuniformity was determined experimentally during the calibration and it is ranging from 0.15 % up to 0.26 % ( $k=1$ ) depending on the Hidyni module and is included into the uncertainty budget. The main contribution to the combined measurement uncertainty is the calibration of the reference spot-photometer, which was 0.65 % for the levels 0.1  $\text{cd/m}^2$  up to 1000  $\text{cd/m}^2$  and 0.60 % for the levels 10  $\text{kcd/m}^2$  and 100  $\text{kcd/m}^2$ . The uncertainty budget was prepared for each Hidyni luminance module. In the table below see an example for the Module III with a nominal luminance of 10  $\text{cd/m}^2$ .

Table 35: uncertainty budget for the calibration of average luminance of Hidyni luminance module 10 cd/m<sup>2</sup>

| Source of the uncertainty           | Uncertainty (%) |
|-------------------------------------|-----------------|
| Spot-photometer calibration         | 0.65            |
| Aging of the Spot-photometer        | 0.20            |
| Resolution of digital indication    | 0.028           |
| Source nonuniformity                | 0.20            |
| Long term operating stability       | 0.020           |
| Temperature sensitivity             | 0.040           |
| Repeatability                       | 0.20            |
| Combined uncertainty (k=1)          | 0.74            |
| <b>Expanded uncertainty (k = 2)</b> | <b>1.5</b>      |

The result of the calibration of the average luminance of seven Hidyni luminance modules accompanied by the uncertainty of the measurement are given in Table 36. **Remark:** the uncertainty of the relative contrast is much lower as the absolute traceability of the spot-photometer (its calibration and aging), which dominates the absolute luminance calibrations but is strongly correlated between two measurements, will be reduced to its non-linearity (inter- and intra-range), resulting in an expanded uncertainty (k=2) of about 0.91% up to 1.8% for the ratio between two sources.

Table 36: Calibrated average luminance of seven Hidyni luminance modules. (Calibrated in May 2025.)

| Nominal<br>$L_v$ (cd/m <sup>2</sup> ) | Measured<br>$L_v$ (cd/m <sup>2</sup> ) | (k=2)<br>$U_{rel}(L_v)/\%$ |
|---------------------------------------|--|----------------------------|
| 0.1                                   | 1.02E-01                               | 1.9                        |
| 1                                     | 1.026E+00                              | 1.5                        |
| 10                                    | 1.037E+01                              | 1.5                        |
| 100                                   | 1.128E+02                              | 1.4                        |
| 1 000                                 | 1.017E+03                              | 1.4                        |
| 10 000                                | 9.96E+03                               | 1.3                        |
| 100 000                               | 1.021E+05                              | 1.3                        |

## 5.3 Stability

### 5.3.1 Temperature sensitivity

The Hidyni source was designed to operate primarily under laboratory conditions. The absolute calibration of the average luminance of each module was carried out in a photometry laboratory, where the ambient temperature is maintained at 25.0 °C ± 0.5 °C. The sensitivity for the temperature was measured in a climate chamber. The temperature was stabilized at five levels from 10 °C up to 50°C. For each temperature the level of light output was measured. A linear dependence corresponding to a constant sensitivity was observed, see the graph in Figure 35. The temperature sensitivity was determined to be -0.07 % / °C.

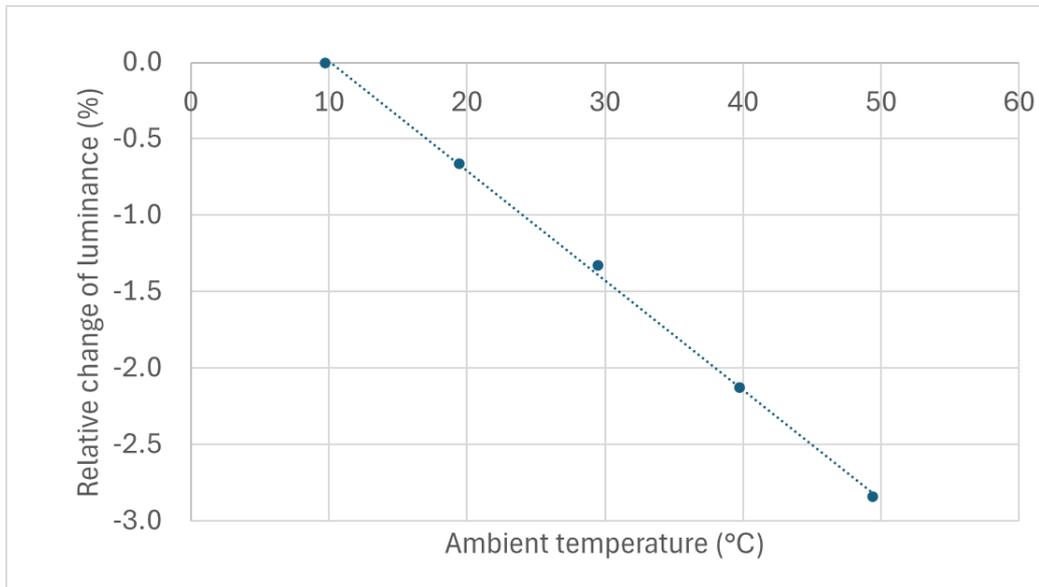


Figure 35: Ambient temperature dependence of one module (reference temperature 10 °C)

### 5.3.2 Temporal stability

Before characterisation of the temporal stability, each module was preaged for 300 hours of operating time. Then the warming-up time was measured. All modules reached a stabilised value in maximum time of 35 minutes. An example of the output signal of the 10 cd/m<sup>2</sup> Hidyni luminance module recorded in one second intervals after turning on is presented in Figure 36.

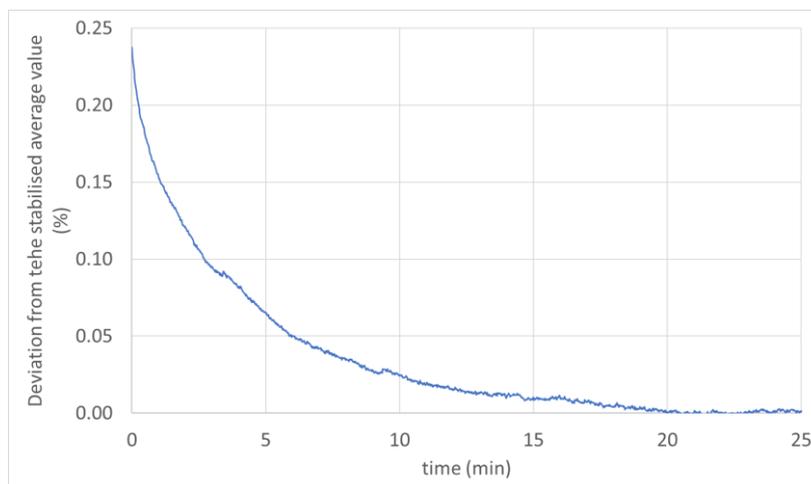


Figure 36: Measurement of the warming up time of the Hidyni luminance module III (with 10 cd/m<sup>2</sup>)

The long-term operating stability was measured in 20 cycles: 2 hours operation time (1.75 hours warm up and 0.25 hours of averaging the cycle luminance for each of the 20 cycles), 1 hour cooling down. The stability was evaluated as follows. From last 15 minutes of operation the average cycle luminance and its standard deviation was calculated for each cycle. The cycle luminance deviation from the averaged luminance was calculated for each cycle. The averaged luminance was calculated as the mean of 20 average cycle luminances. The maximum deviation from the averaged luminance presents the measured long-term stability. An example of the record of the measurement for Hidyni luminance module VII with a nominal luminance of 100 kcd/m<sup>2</sup> is shown in Figure 37

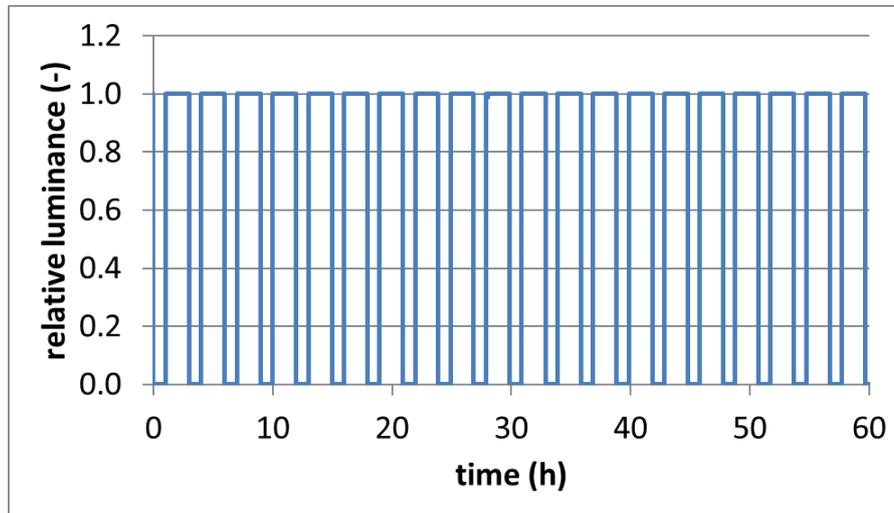


Figure 37: Relative luminance measurement (On/Off cycling) of Module VII (with a nominal luminance of 100 kcd/m<sup>2</sup>).

The evaluated data are presented in Figure 38. The dots are the deviations of the average cycle luminance from averaged luminance and the bars represents the Standard deviations of each average cycle luminance. As seen from the graph the long-term operating stability was in these 20 cycles better than 0.02%.

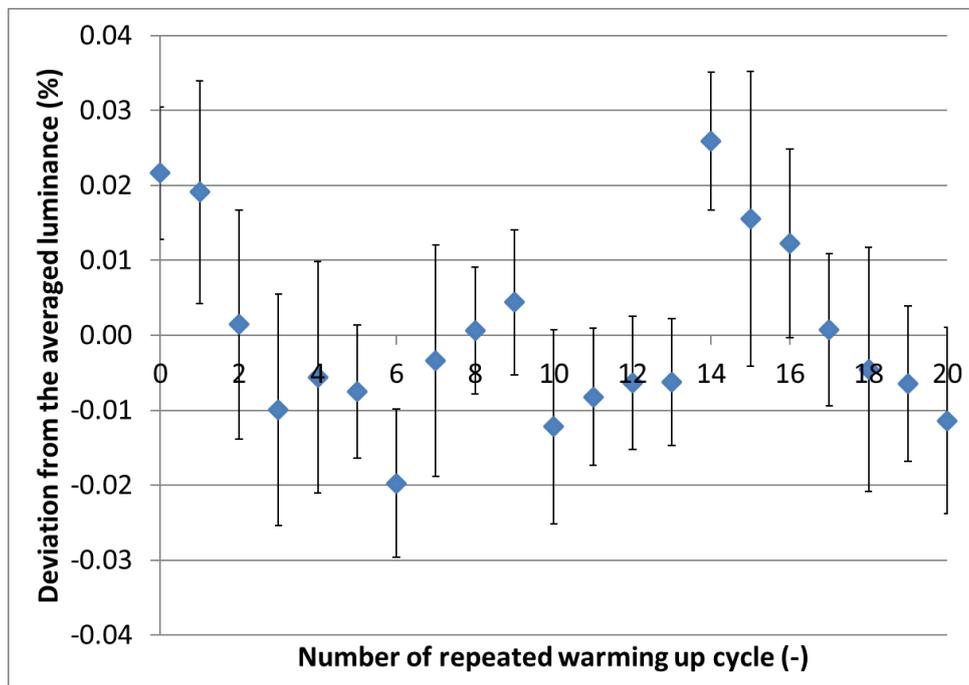


Figure 38: deviation of the average cycle illuminance from the averaged illuminance

The short-term operating stability was measured after 2-hour warm-up. The stability was evaluated by the maximum deviation from the mean value measured over periods of 1 and of 14 hours. Temporal stability was determined as  $\pm 0,04$  % in 14 hours and  $\pm 0,02$  % in 1 hour period. See Figure 39 and Figure 40.

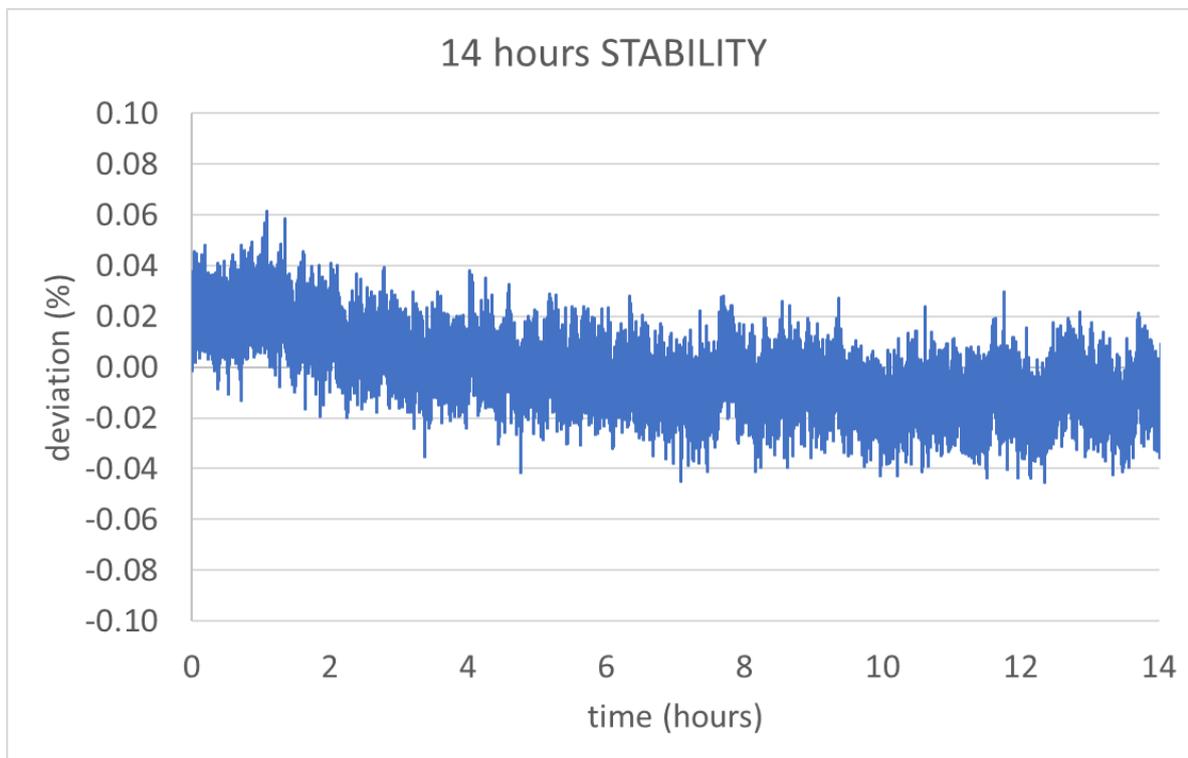


Figure 39: short-term lumiance stability of Module II (nominal luminance of 10 cd/m<sup>2</sup>) over 14 hours

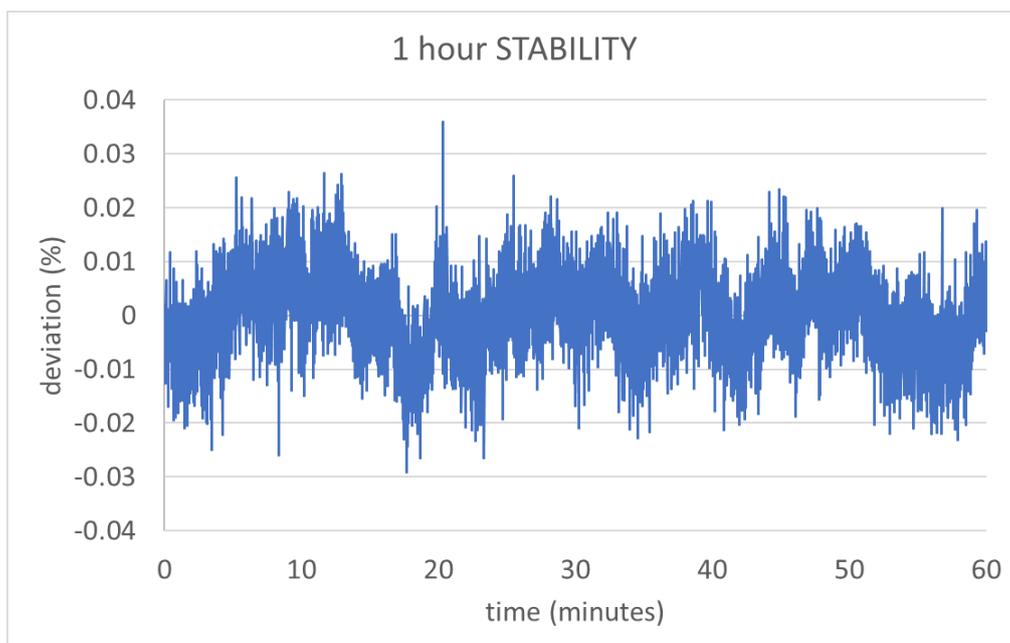


Figure 40: short-term lumiance stability of Module II (nominal luminance of 10 cd/m<sup>2</sup>) over 1 hour

### 5.3.3 Aging of the Hidyni source

The initial calibration of the luminance of exemplary modules was performed in 2024, see Table 36, and a recalibration was carried out one year later. Table 37 presents the relative deviation between the two calibrations for each module. The deviations of the calibrated luminance values range from -0.8 % to +0.5 % which are below the uncertainty of the luminance calibration, ranging from 1.3 % to 1.9 %. For greater clarity, the data are also presented graphically in Figure 41.

Table 37: deviation of the calibrated average luminance of seven Hidyni modules

| Nominal Luminance<br>$L_v$ (cd/m <sup>2</sup> ) | Deviation<br>2025 - 2024<br>% | Uncertainty<br>(k=2)<br>$U_{rel}(L_v)/\%$ |
|---|-------------------------------|---|
| 0.1   | -0.6                          | 1.9                                       |
| 1   | 0.5                           | 1.5                                       |
| 10  | 0.3                           | 1.5                                       |
| 100   | -0.2                          | 1.4                                       |
| 1 000   | -0.7                          | 1.4                                       |
| 10 000  | -0.8                          | 1.3                                       |
| 100 000   | -0.8                          | 1.3                                       |

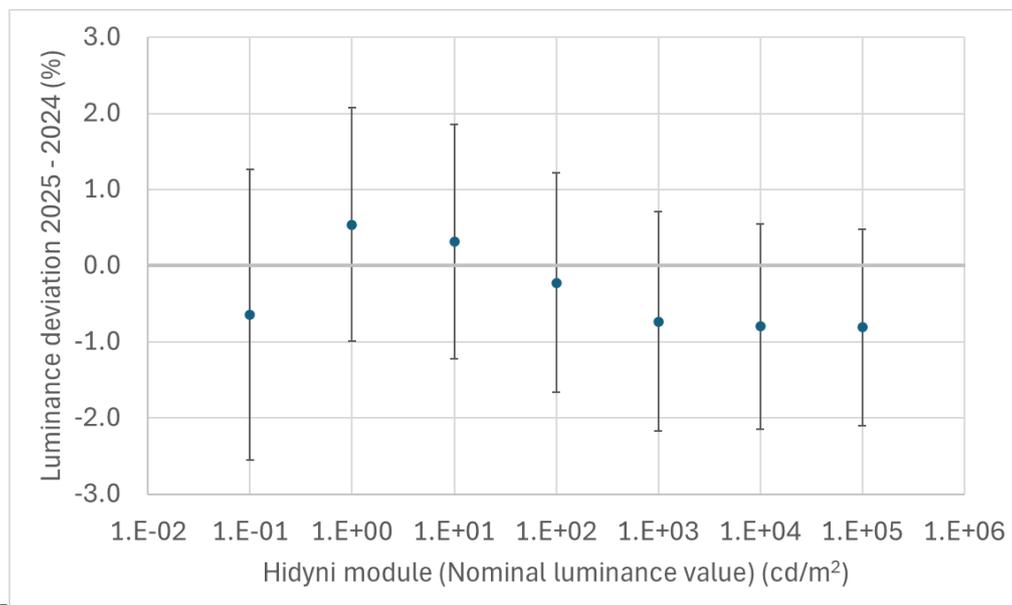


Figure 41: relative luminance deviation between the two calibrations performed one year apart.

## 5.4 Geometry

The Hidyni source was designed as a modular system to support the characterisation of ILMDs with various measurement fields (e.g. different focal lengths), using freely adjustable mounting positions for seven independent luminance modules. The source consists of seven independent luminance modules that cover six orders of magnitude of luminance, ranging from 0.1 cd/m<sup>2</sup> to 100 000 cd/m<sup>2</sup>. The modules can be used simultaneously or separately in any geometrical arrangement. The Hidyni source comprises a light trap for background evaluation.

The geometry of the Hidyni source is defined by the size of the build scene and by the positioning of the modules in the scene. The modules can be organised in various reference scenes. The different sizes of the reference scenes can be built so the Hidyni source can be adapted to different FOVs. The luminous area shape of each luminance module is circular. The size of the luminous area of each module has nominal diameter of 25 mm. It is easy to modify it by modifying the diameter of the exchangeable aperture, see the “MODIF. APERTURE” in Figure 2. The maximum diameter of the aperture is 40 mm. In case of using the diameters larger than 25 mm, the significant deterioration of homogeneity should be taken into consideration. It is caused by the decline in brightness toward the diffuser edges.

In order to modify the geometrical configuration of the luminance modules, they can be connected either by aluminium profiles, or they can be mounted to tripods. The prototype of a holder made from aluminium profiles was designed and built, see the Section 4.6. The holder allowed to create a hexagonally arranged reference scene, with maximum dimensions of approximately 70 cm × 60 cm which is recommended in another document of this joint research project (Deliverable D2: Good practice guide describing the characterisation of different HDR imaging instruments, such as ILMDs and RGB matrix sensor cameras, based on the recommendations stated in CIE 232:2019 and CIE 244:2021). The schematic illustration of the hexagonally arranged Hidyni source is shown in Figure 42. The red frame represents the FOV of ILMD according to the document D2.

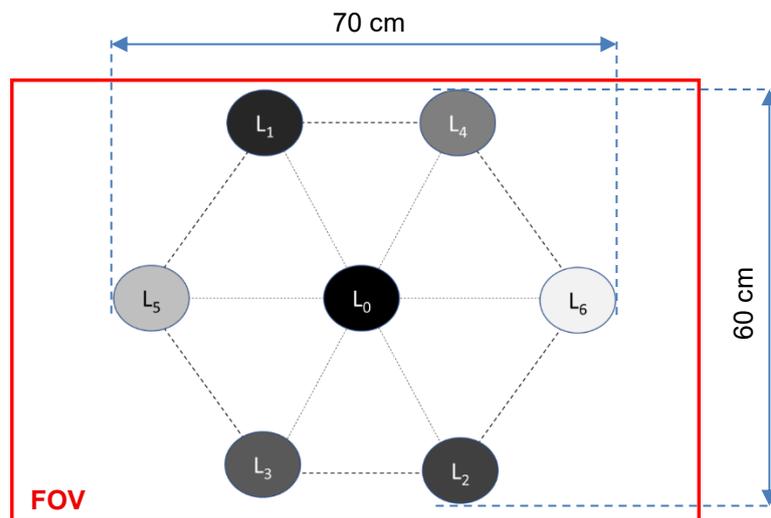


Figure 42: scheme for a hexagonal arrangement of Hidyni source in the FOV of ILMD

The photo of Hidyni source modified for such a reference scene is shown in Figure 43. There is a trap mounted in the middle of the scene (white rectangle target round the trap entrance which helps better finding of the position of the trap in the picture when the high-contrast scene is measured by an HDR-ILMD.)



Figure 43: Photo of the Hidyni source arranged for creating a reference scene of dimension 70 cm x 60 cm (hexagonal arrangement of the luminance modules).

The Hidyni modules intentionally have a directional characteristic. The luminous intensity distribution was measured using a mirror goniophotometer at distance 15 m see Figure 44. The full beam angle is about 23° which helps to reduce parasitic stray light in the laboratory.

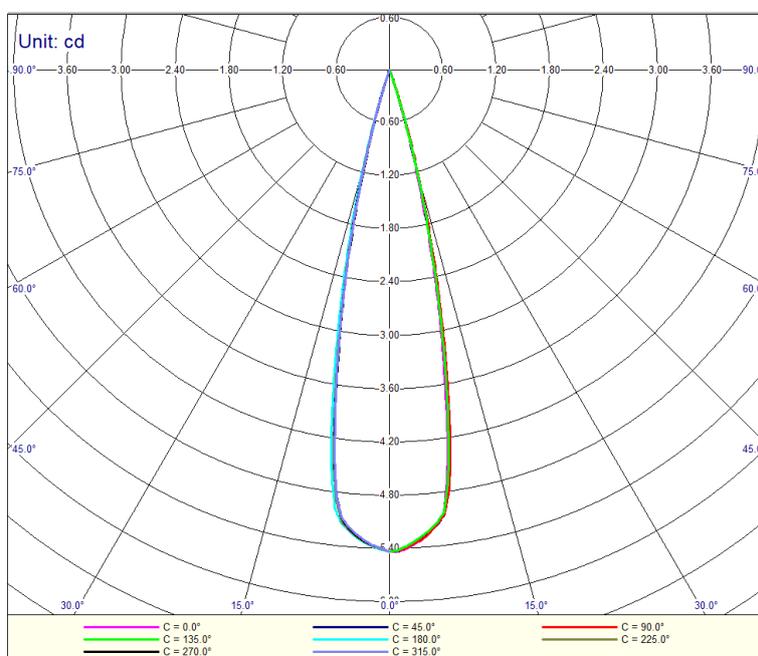


Figure 44: luminous intensity distribution of one Hidyni luminance module

## 5.5 Uniformity

The uniformity across the luminous area with a diameter of 25 mm was measured using a reference ILMD, averaged over 10 acquisitions to reduce the influence of photon noise. The uniformity was evaluated as the standard deviation of all measured points lying in the evaluated area. The measured uniformities are listed in Table 38. The example of the measured uniformity for the module 0.1 cd/m<sup>2</sup> is shown in Figure 45.

Table 38: measured uniformities of the Hidyni luminance modules

| Hidyni source level | Nominal Luminance (cd/m <sup>2</sup> ) | Measured uniformity StdDev (%) |
|---------------------|--|--------------------------------|
| I.                  | 0.1                                    | 3.3                            |
| II.                 | 1                                      | 2.7                            |
| III.                | 10                                     | 2.8                            |
| IV.                 | 100                                    | 2.6                            |
| V.                  | 1 000                                  | 2.8                            |
| VI.                 | 10 000                                 | 2.4                            |
| VII.                | 100 000                                | 2.4                            |

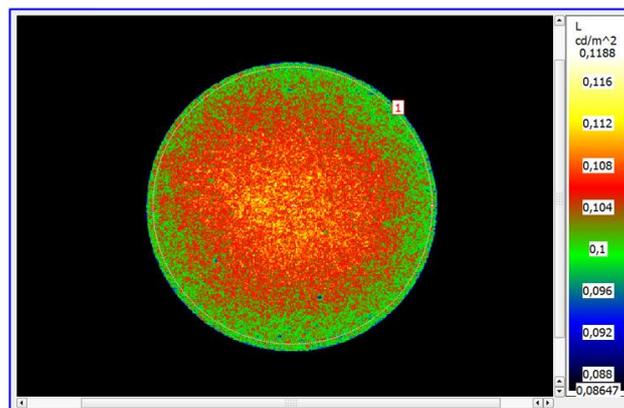


Figure 45: measured luminance image showing the uniformity of the Hidyni module I (0.1 cd/m<sup>2</sup>)

## 5.6 Cross-talk between modules analysis

The cross-talk among the constituent Hidyni luminance modules was characterised. The luminance of the middle 0.1 cd/m<sup>2</sup> Hidyni luminance module was measured using a spot-photometer in a configuration see the photo in Figure 46.

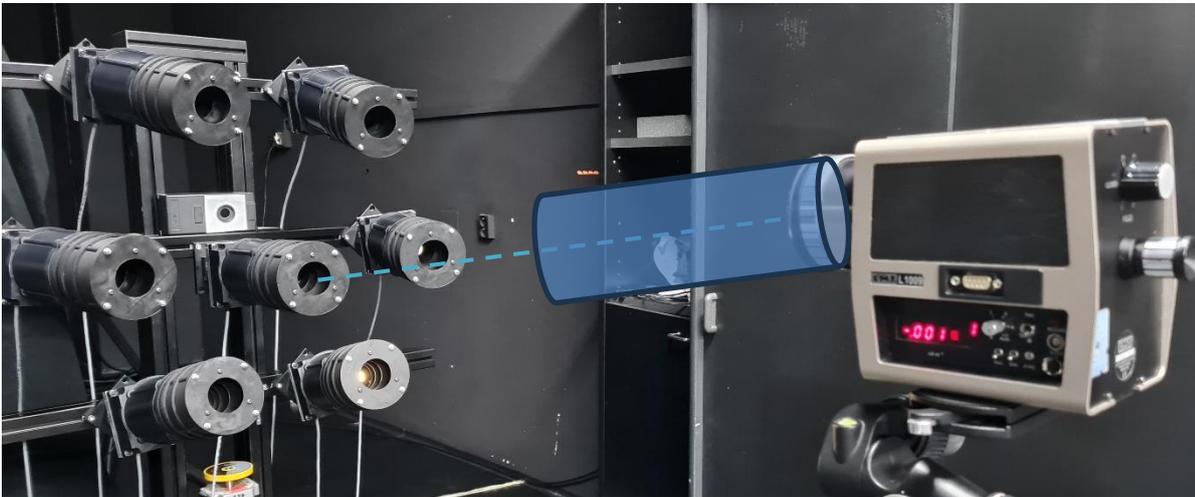


Figure 46: photo of the cross-talk measurement setup

The illustrated image shows a tube mounted on the spot-photometer lens, which was necessary during the measurement to minimize stray parasitic light reaching the lens. The worst-case cross-talk scenario was identified when the module with the lowest luminance ( $0.1 \text{ cd/m}^2$ ) was affected by the presence of higher-luminance modules. The first measured value corresponds to the luminance of the  $0.1 \text{ cd/m}^2$  module, with only this module turned on while all other modules were switched off. Subsequently, the  $0.1 \text{ cd/m}^2$  module remained on, and one additional module was turned on at a time to observe the effect. Finally, the  $0.1 \text{ cd/m}^2$  module was measured while all other modules were turned on simultaneously.

Cross-talk was evaluated as the relative deviation between the luminance measured on the  $0.1 \text{ cd/m}^2$  module when only this module was turned on, and the luminance measured on the same module when additional light sources were also turned on.

Table 39: measured uniformities of the Hidyni luminance modules

| Hidyni module turned on                 | Hidyni module I measured Luminance ( $\text{cd/m}^2$ ) | Cross-talk (%) |
|---|--|----------------|
| I. (0.1)                                | 0.102  | 0              |
| I.+ II. (1)                             | 0.102  | 0              |
| I. + III. (10)                          | 0.102  | 0              |
| I. + IV. (100)                          | 0.102  | 0              |
| I. + V. (1000)                          | 0.102  | 0              |
| I. + VI. (10 000)                       | 0.103  | 1              |
| I. + VII. (100 000)                     | 0.108  | 6              |
| I. + II. + III. + IV. + V. + VI. + VII. | 0.110  | 7              |

This example demonstrates how the luminance of one module might be affected by the signals from the others, i.e. with a contribution of about  $7 \cdot 10^{-8}$  for each source. The cross-talk between modules should be taken into consideration when evaluating the measurement results. For the investigated setup and with respect to the targeted uncertainty of 1% one can expect that cross-talk is insignificant regarding a contrast of up to  $10^{-4}$ . The level of the cross-talk might depend on the specific measurement configuration, including also properties of the room and ILMD - Hidyni distance, as well as on the measuring instrument. i.e. reflections from the ILMD under characterization back into the

scene. To reduce the crosstalk some corrections in alignment are recommended in another document of this joint research project (Deliverable **D2**: Good practice guide describing the characterisation of different HDR imaging instruments, such as ILMDs and RGB matrix sensor cameras, based on the recommendations stated in CIE 232:2019 and CIE 244:2021.)

## 5.7 Hidyni alignment setup for ILMD characterisation

The Hidyni source was designed for characterisation of ILMD devices. Figure 47 shows the photo of the Hidyni source and the graphical output of the ILMD measurement result.

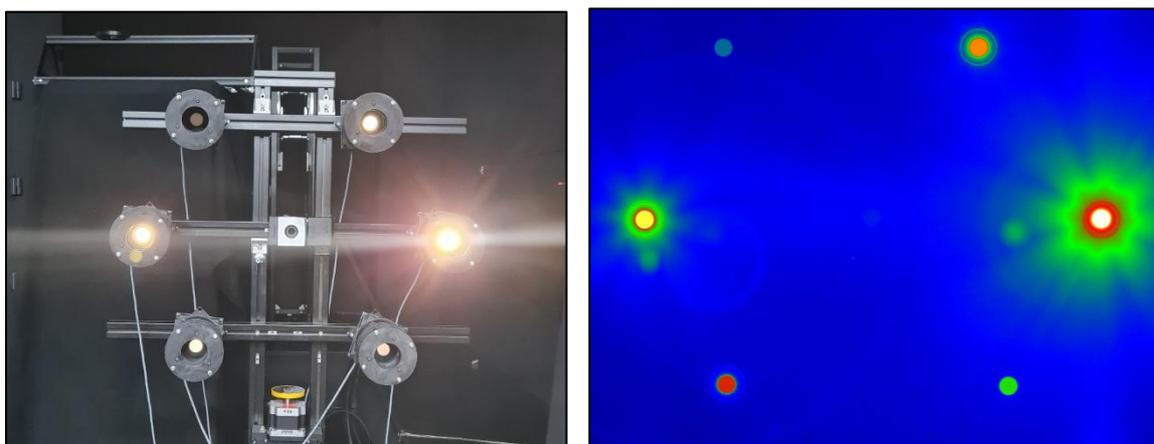


Figure 47: photo of the Hidyni source (left) and the graphical output of the ILMD measurement result

Each Hidyni module features a lockable, adjustable platform to align the light source with the camera. In the basic alignment procedure, the module's output should face directly toward the lens of the ILMD, and both the light source and the ILMD lens axes should be parallel. To ensure this the luminous circular area of the luminance module should appear centred in the larger output aperture, as shown in the ILMD image in Figure 48. If this is not the case, minor adjustments are required: loosen the joint, realign the module, and then securely tighten it again.



Figure 48: photo of the luminous area of the luminance module appearing centred in the output aperture

If specific conditions do not allow for the standard alignment procedure, it is recommended to use a laser to assist with alignment. The laser must be precisely aligned so that its beam is perpendicular to its mounting base. Place the laser at the front aperture of the module and aim it at the ILMD lens. Repeat this procedure for all lighting modules. For the final alignment, again ensure that all modules are correctly aimed at the ILMD see Figure 49.

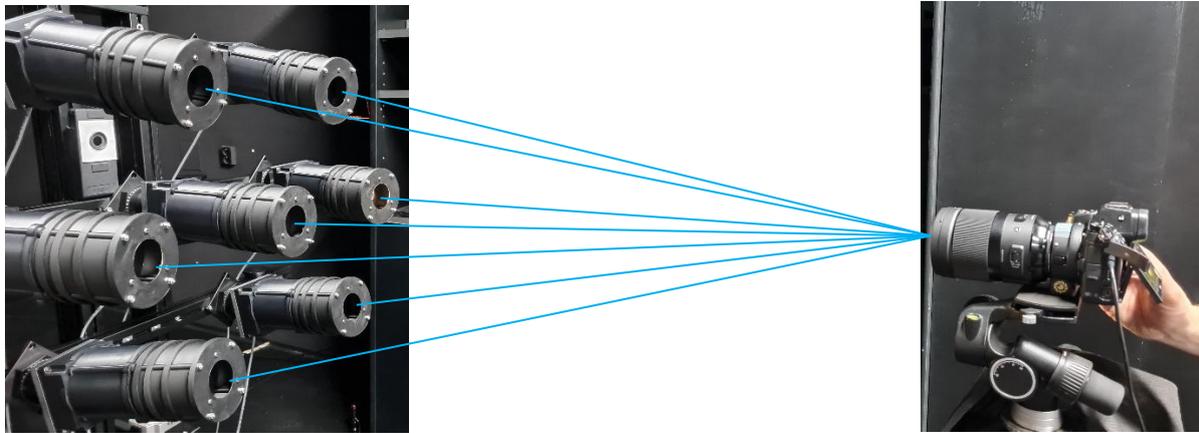


Figure 49: photo of the final alignment of the Hidyni source modules with an ILMD

## 6 Exemplarily Hidyni reproduction

To verify the applicability of this design guide the Hidyni was reproduced by the partner METAS on the basis of a technical guide provided by the partner CMI as given in the previous chapters of this document. The goal was to verify that this guide is detailed enough to be published on the project website for open-access as a reference design guide. For the sake of the verification, the replication was performed by technical personnel that had no previous information about the source nor contributed to its design. The following sections will describe the experience gained during assembly and first testing, recommendations and describes minor changes by add-on features as potential improvements.

### 6.1 Assembly

All seven sources are built from the same parts. The only difference is the number of ND filters inserted in the holder. This approach was found very efficient to print the 3D parts and assemble the sources in parallel.

As the luminance output of the LED sources are highly dependent on the temperature thermal gap pad (see Figure 51, DISTRELEC part number 1745693, specification: 2W/mK 280mW/°C) was used on the aluminium plate which is working as a heat sink. When the threaded bars are mounted on the LED housing, the nut shall be fixed very well because all the following parts are attached to this bar. However, the 3D printed parts are flexible and will bend when the screws are tightened too strong. The fully assembled sources are shown in Figure 52 right. Each source has a magnetic protection cover.

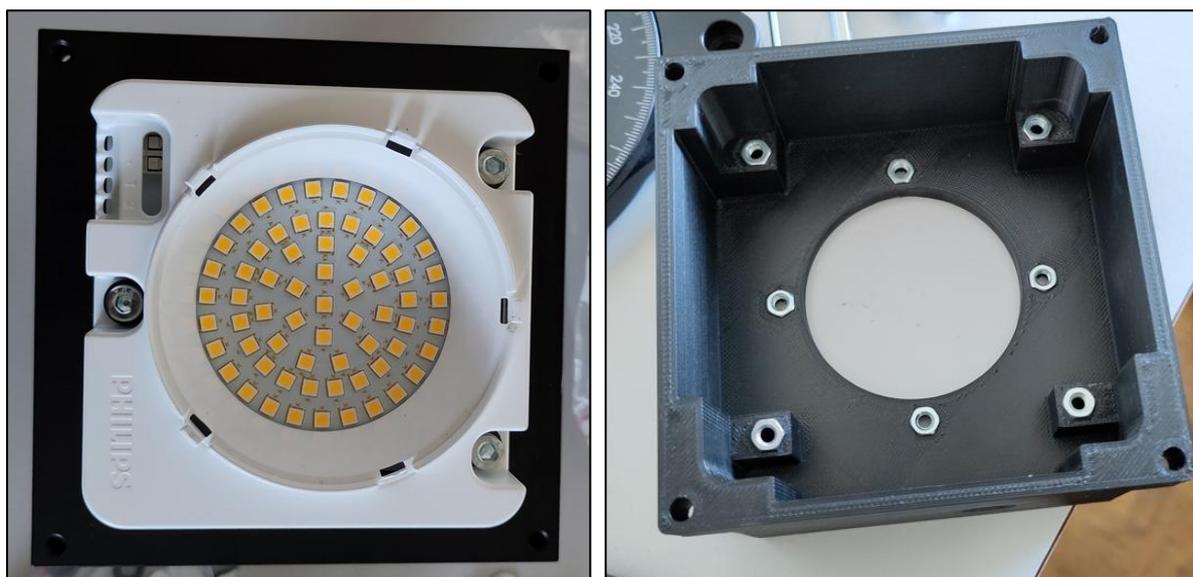


Figure 50: Photo of the LED module on aluminium plate (left) and of the housing (right).

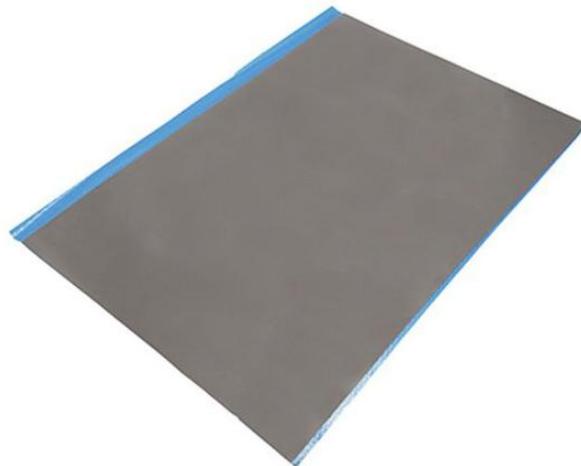


Figure 51: Photo of the thermal Gap Pad used to join the LED module and the aluminium plate.

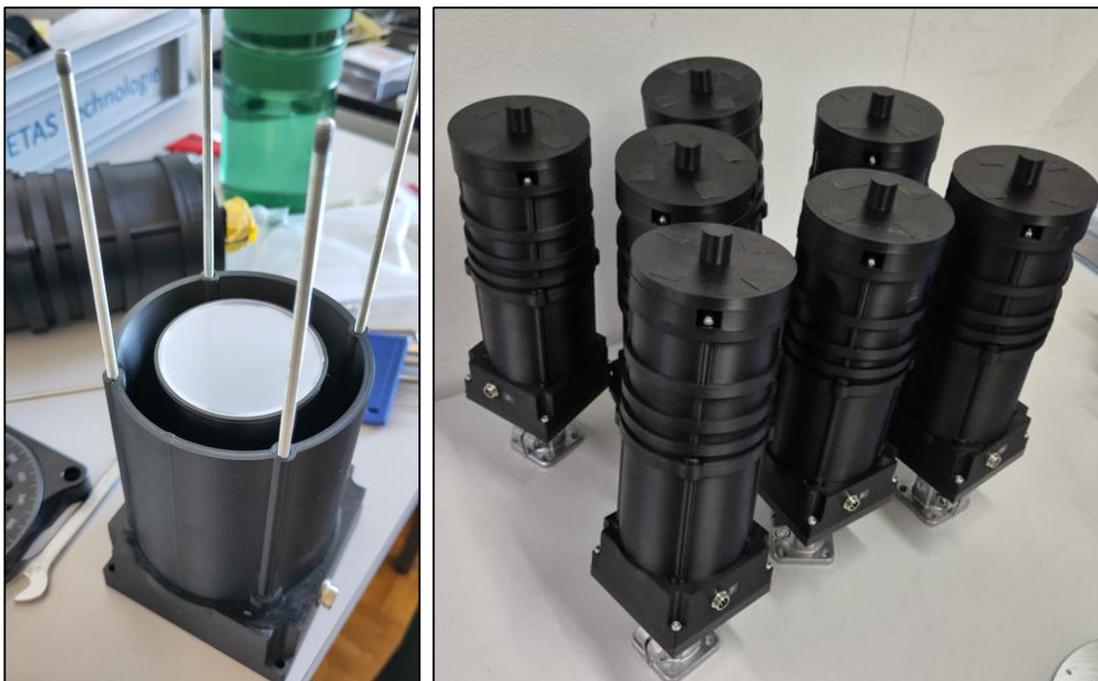


Figure 52: Photo of one luminance source during integration (left) and of all seven sources fully assembled with protective cover (right)

METAS selected a simpler yet cheaper alternative ball joint compared to the original design guide (see Figure 13). The new joint costed less than half the price of the original proposed (around €80). This part was found via Norelem with part number "29010-5301"



Figure 53: Photo of the alternative ball joint used by METAS for the 7 light sources

The aperture diameter was measured with a TCM 100 Microscope before assembly. The diameter of each of the 7 apertures are stated in Table 40. The dimension of the aperture can be used in case one needs to calibrate the source to its average luminance by measuring the illuminance at a known distance and calculating the luminance of the full aperture. However, such calibration introduces difficulties in real practice e.g., that straylight from the baffle tube contributes to the illuminance measurement and that the selection of the full area of the aperture on a luminance image is mandatory in order to use the calibration value. But as the sources and thus the straylight are similar to another the relative ratio (contrast) is not significantly affected by these.

Table 40: Luminance source aperture measurement

| Aperture      | 1      | 2      | 3      | 4      | 5      | 6      | 7      |
|---------------|--------|--------|--------|--------|--------|--------|--------|
| Diameter [mm] | 25.256 | 25.185 | 25.263 | 25.203 | 25.241 | 25.191 | 25.247 |
| stdev [mm]    | 0.0122 | 0.0179 | 0.0120 | 0.0083 | 0.0248 | 0.0084 | 0.0256 |

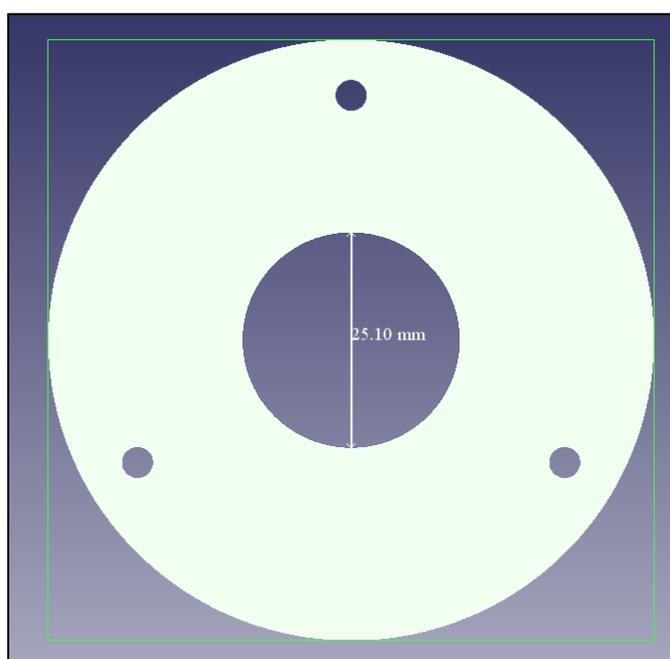


Figure 54: Aperture diameter in the CAD file (MODIFIED\_APERTURE\_25.stl)

## 6.2 Driver settings

Each source has its dedicated set of driver and LC filter. The MultiOne mobile application was used to adjust (fine tune) the driver level in order to achieve the nominal luminance level. The protection cover was replaced with redesigned front cap with magnets and a laser pointer in order to align the source correctly to the luminance meter (Figure 55 right). The driver settings found by this adjustment are summarized in Table 41. The embedded laser pointer that was use was an APC Laser Module LC-LMP-635 series from LASER COMPONENTS (See, Figure 56).

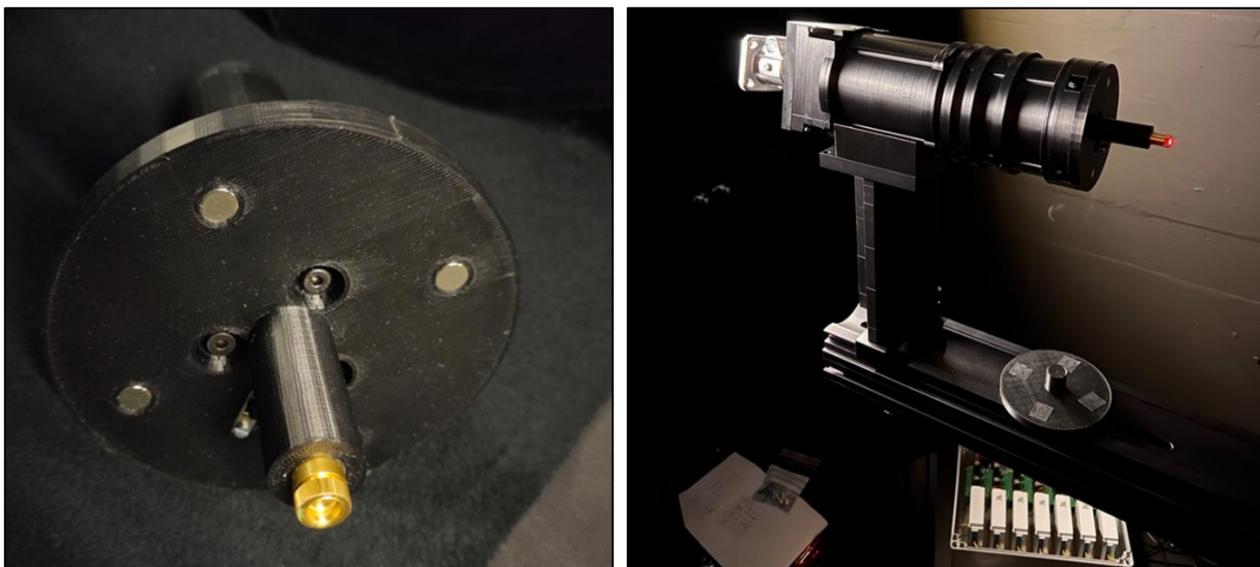


Figure 55: Photo of the alignment laser inside the cover (left) and attached to the source module (right)

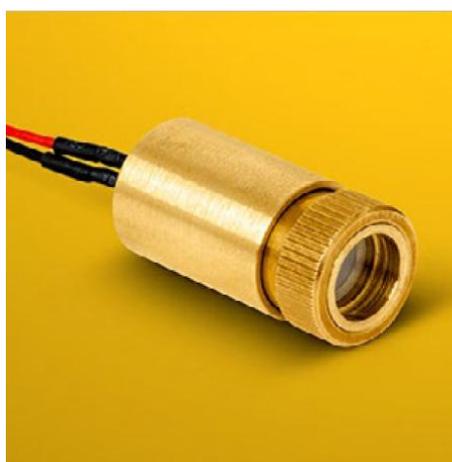


Figure 56: Photo of the laser module embedded in the modified magnetic lens cap (LASER COMPONENTS)

Table 41: Driver setting and ND filters used for each source

| Source | Driver level / % | Implemented optical ND filters / OD |     |     |     |     | Nominal luminance / $\text{cd/m}^2$ |
|--------|------------------|-------------------------------------|-----|-----|-----|-----|-------------------------------------|
|        |                  |                                     |     |     |     |     |                                     |
| 1      | 3                | 0.7                                 | 0.8 | 0.9 | 0.9 | 1.5 | 0.1                                 |
| 2      | 24               | 0.7                                 | 0.8 | 0.9 | 0.9 | 1.5 | 1                                   |
| 3      | 60               | 0.7                                 | 0.8 | 0.9 | 1.5 |     | 10                                  |
| 4      | 5                | 0.9                                 | 0.9 |     |     |     | 100                                 |
| 5      | 42               | 0.9                                 | 0.9 |     |     |     | 1'000                               |
| 6      | 42               | 0.7                                 |     |     |     |     | 10'000                              |
| 7      | 80               |                                     |     |     |     |     | 100'000                             |

### 6.3 Homogeneity test

The homogeneity of each source was measured with and ILDM and the results are shown in Figure 57 and Table 42.

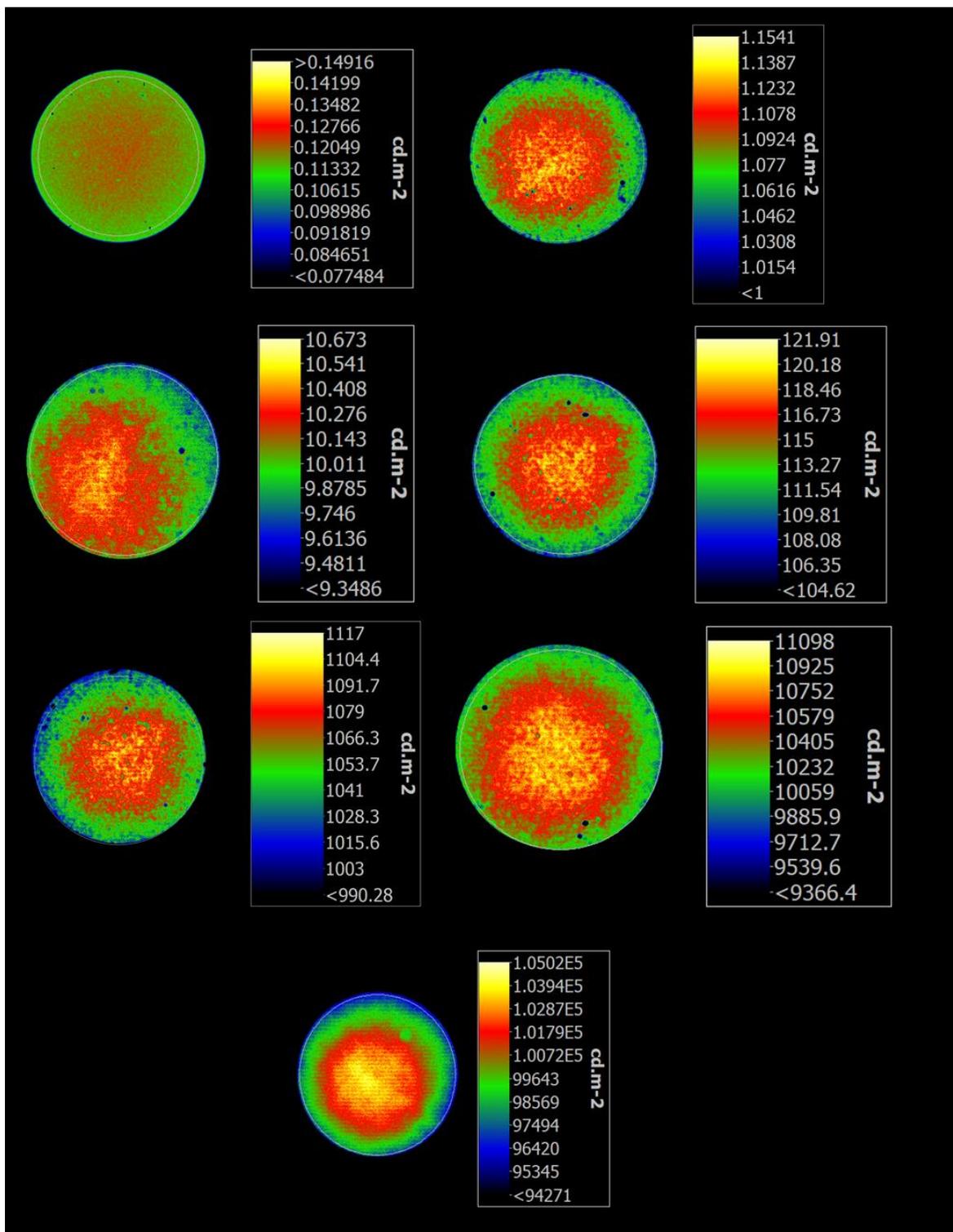


Figure 57: Luminance images used for the homogeneity measurement

Table 42: Homogeneity measurement data

| Module         | S1        | S2        | S3        | S4        | S5        | S6        | S7        |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $L_{av}$       | 1.180E-01 | 1.098E+00 | 1.018E+01 | 1.157E+02 | 1.067E+03 | 1.059E+04 | 1.015E+05 |
| $L_{min}$      | 1.082E-01 | 1.016E+00 | 9.465E+00 | 1.087E+02 | 1.014E+03 | 1.004E+04 | 9.691E+04 |
| $U_o$          | 92%       | 93%       | 93%       | 94%       | 95%       | 95%       | 96%       |
| Contrast to S7 | 1.163E-06 | 1.082E-5  | 1.003E-4  | 1.140E-3  | 1.051E-2  | 1.043E-1  | 1.000E+0  |

### 6.4 Installation and alignment

After the characterization of the sources, the sources were mounted on the Kanya profiles "heptaopus" and connected to the driver box (Figure 58). In this configuration all sources are switched on simultaneously. The magnetic protection covers are used to close the source in case only a subset of sources is needed for a test. The ILMD was fixed on the optical bench, and the sources were orientated towards the ILMD with the help of the alignment laser, see Figure 59.

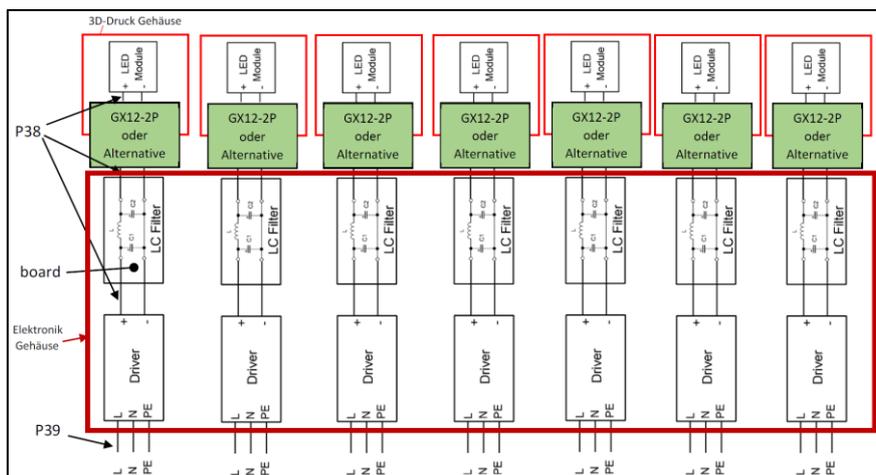
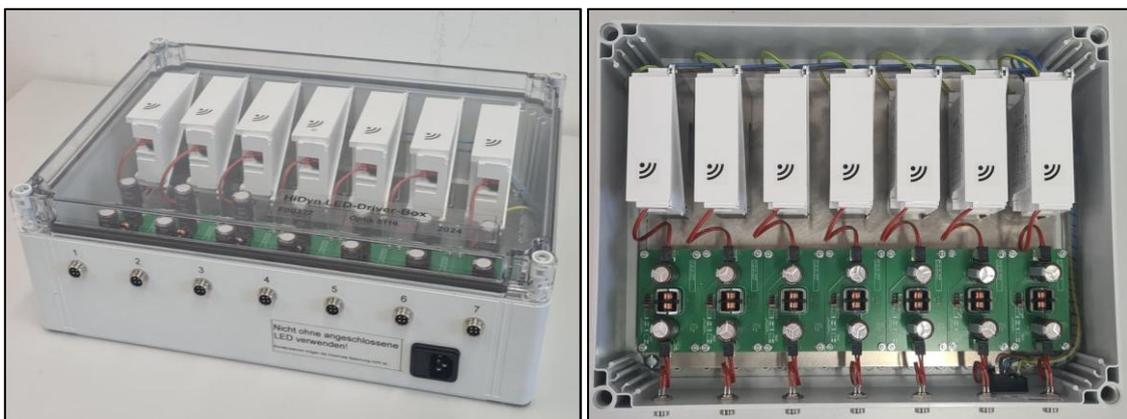


Figure 58: Photos and electrical schematic of the driver box



Figure 59: Photo of the Hidyni sources during the alignment process

Figure 60 shows the final configuration of METAS Hidyni and Figure 61 shows the first ILMD image taken from these sources. In addition to the 7 sources two light traps were added.

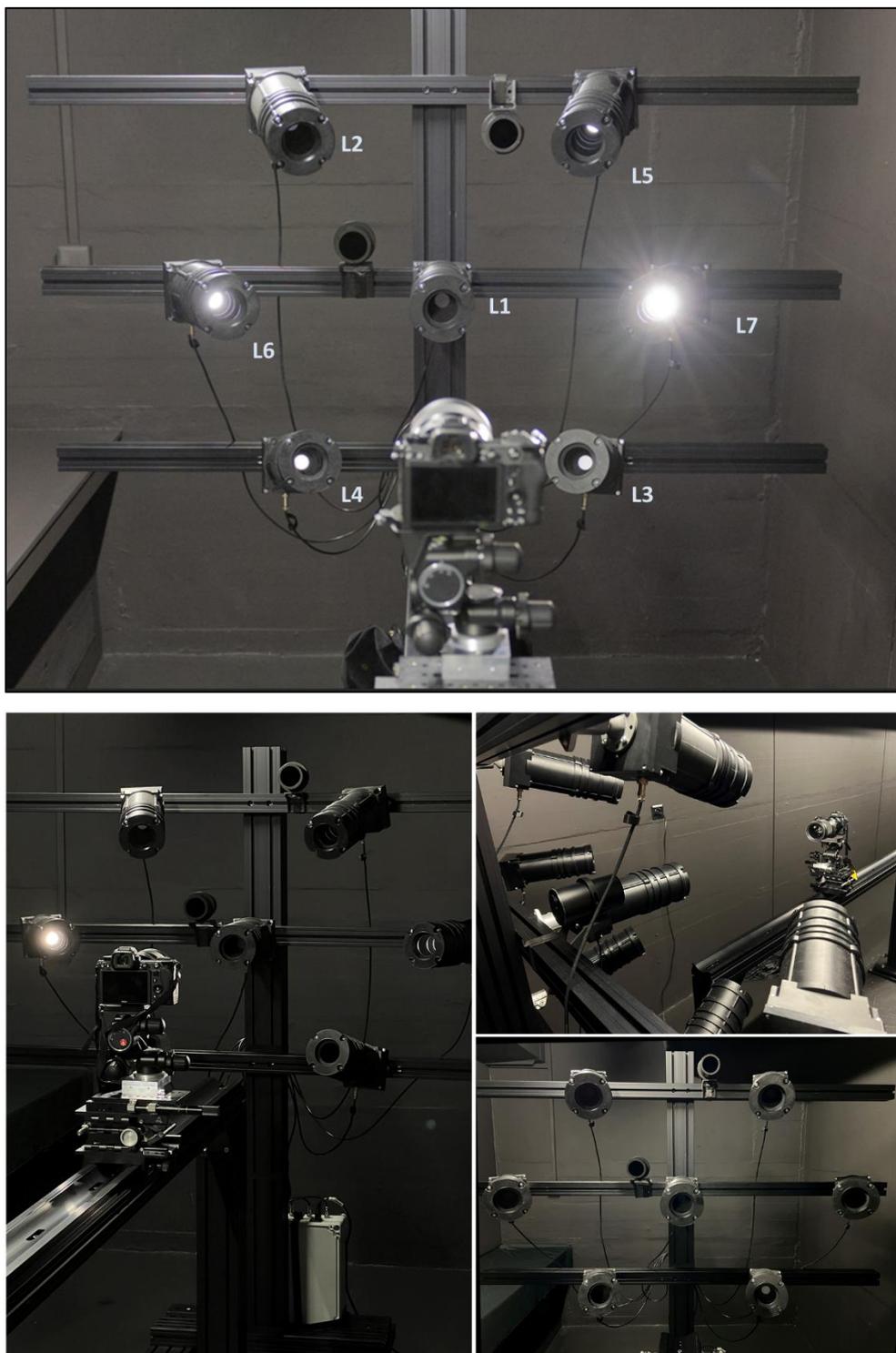


Figure 60: Photos of the fully assembled METAS Hidyn source

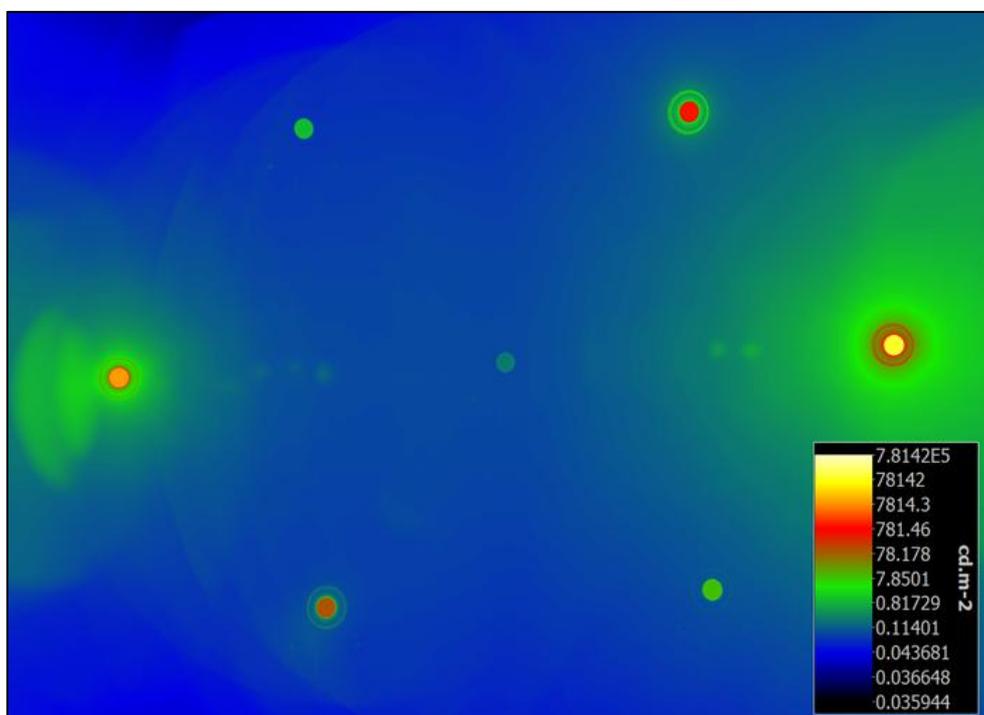


Figure 61: luminance image of the fully assembled METAS Hidyni source

## 6.5 Temperature test

The relative luminance drift with temperature of the sources was tested with a LMT spot luminance meter (Figure 62 left and Figure 63).



Figure 62: Photo of the luminance meter mounted in front of source L7 (left) and of the temperature sensors at the back of the source modules aluminium plate (right)

The output voltage of the luminance meter was logged, see Figure 64. This value is proportional to the luminance value of the source. As only a relative measurement was performed the conversion to  $\text{cd/m}^2$  is not presented here. All sources reached a stable in luminance output within 60 minutes. The relative luminance drift in % was calculated from the luminance value obtained 120 minutes after switching the source on.

Table 43: Test equipment

| Equipment                  | Manufacturer              | Description                         | Messmittel no. |
|----------------------------|---------------------------|-------------------------------------|----------------|
| Spot luminance meter       | LMT Lichtmesstechnik GmbH | Serie L1000                         | 2333           |
| Luminance voltage DAQ      | National instruments      | USB-6212                            | 8291           |
| Luminance measurement SW   |                           | Labview: NI USB-6211<br>Messverlauf | -              |
| Temperature logging        | Almemo                    | 2290-8                              | 4907           |
| Temperature sensors        | Almemo                    | NTC                                 | 3075           |
| Temperature measurement SW | Almemo                    | AMR WinControl9                     | -              |

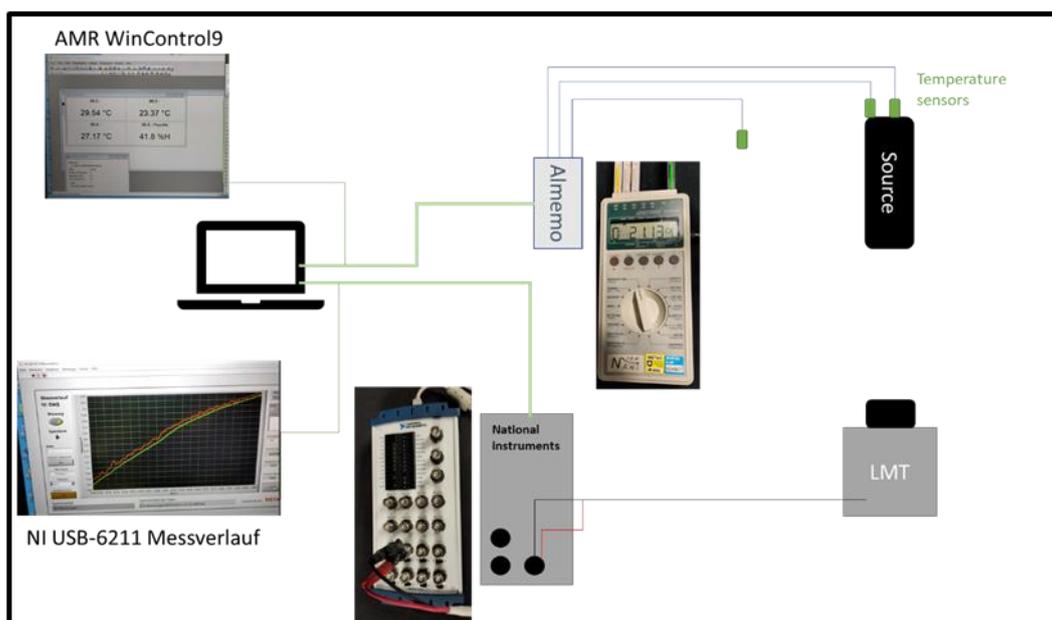


Figure 63: Sketch of test setup scheme

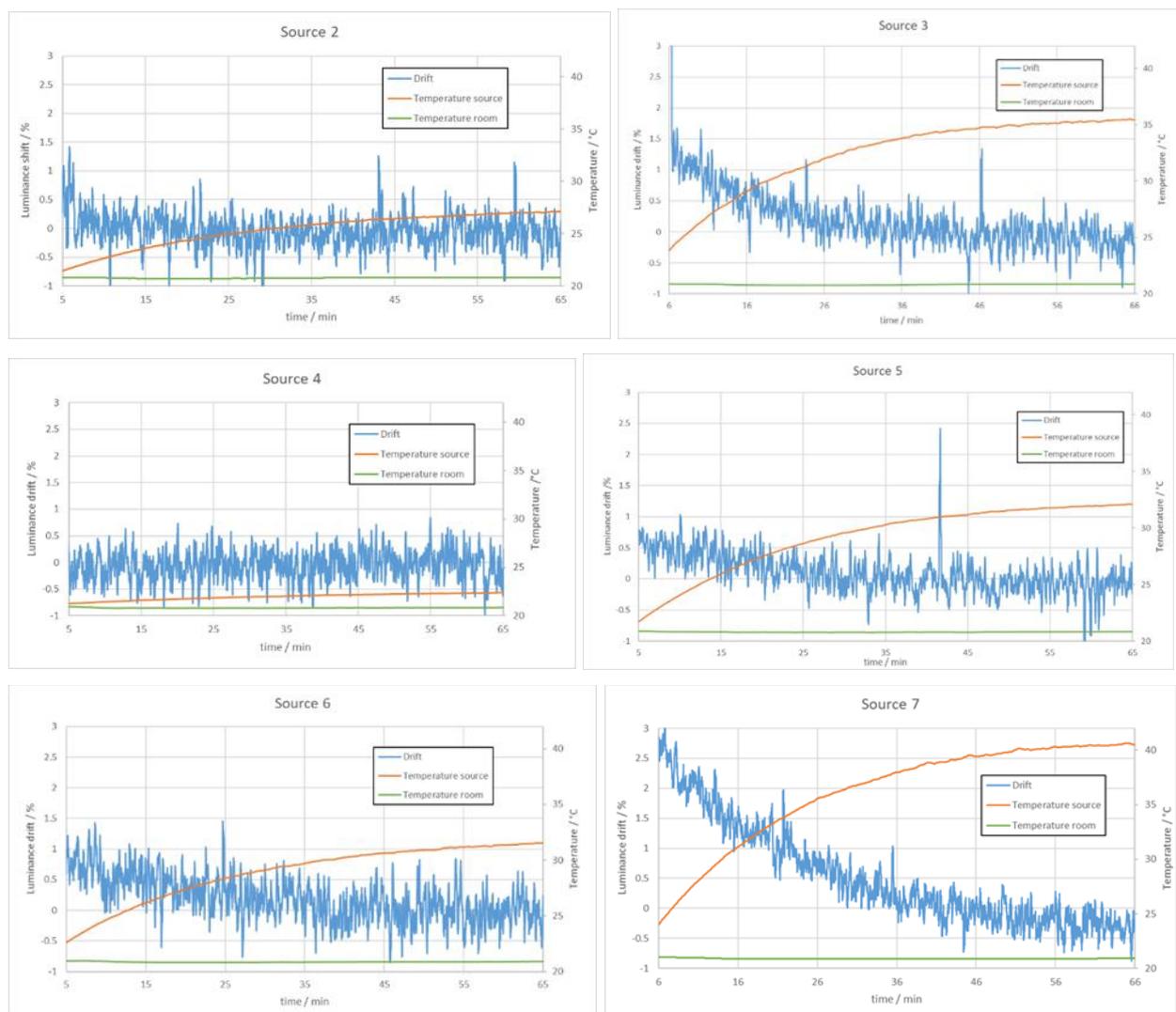


Figure 64: temperature change and luminance drift of sources with different luminance value after switch-on

The luminance and temperature drift for different dimming levels is shown in Figure 64. The size of the blue bubbles in Figure 65 shows the optical density filter transmission (the larger the bubble, the bigger the transmission).

Observations:

- The higher the driver level (smaller dimming) the warmer gets the source
- The luminance decreases with increasing temperature
- Sources 5 & 6 have the same dimming level, however source 5 gets slightly warmer. The cause could be that source 5 has stronger optical filter absorbing more light from the source and thus heating up more.
- Sources 4 & 5 have the same filter but different dimming level. The temperature and luminance drift are much larger on the brighter source no.5.

Table 44: Source characteristics

| Source | ND Filter Transmission % | Driver level % | Δ Temperature after 60 min | Δ Luminance after 60min |
|--------|--------------------------|----------------|----------------------------|-------------------------|
| 2      | 0.002                    | 24             | 5.5                        | - 0.4 %                 |
| 3      | 0.013                    | 60             | 11.6                       | - 1.4 %                 |
| 4      | 1.585                    | 5              | 1.13                       | +0.2 %                  |
| 5      | 1.585                    | 42             | 10.2                       | - 0.7 %                 |
| 6      | 19.953                   | 42             | 8.9                        | - 1.0 %                 |
| 7      | 100.000                  | 80             | 16.7                       | - 3.1 %                 |

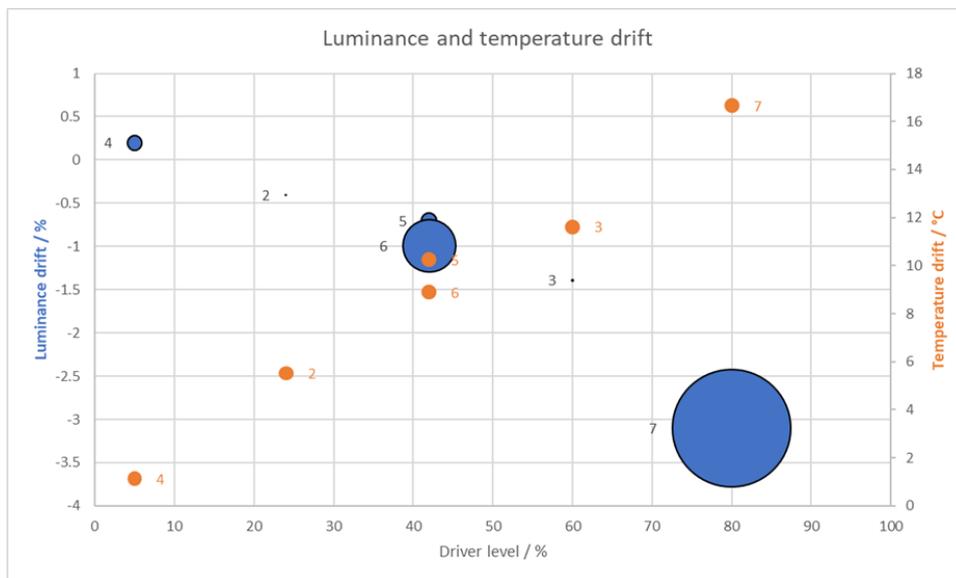


Figure 65: Luminance and temperature drift for different dimming levels (the blue bubble size indicates the optical density filter transmission)

The found relative change of the flux versus the temperature increase corresponds well with the data shown in the specification sheet of the LED sources (Philips Fortimo LED systems DLM Flex 5000lm Gen2 Datasheet). In both cases the negative slope is about -0.2%/K (Figure 66).

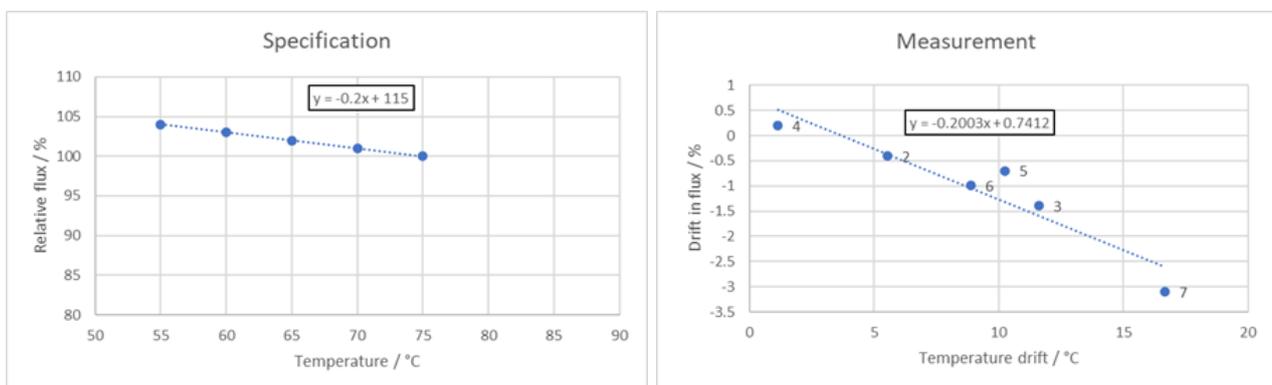


Figure 66: Flux drift vs temperature: Comparison specification to measurement

## 7 Conclusions

A high contrast luminance reference source (Hidyni) was developed, as part of HiDyn project at Czech metrology institute (CMI) in collaboration with Agencia Estatal Consejo Superior de Investigaciones Cientificas (CSIC), and successfully replicated by METAS. This source provides a reference for the characterization Imaging Luminance Measurement Devices (ILMD) or other imaging-based measurement devices dedicated to the evaluation of indoor or outdoor lighting conditions. The Hidyni was designed to cover the characterization of ILMDs with various measurement fields using freely adjustable mounting positions for seven independent luminance modules. The luminance levels of the modules are graduated with decimal steps from 0.1 cd/m<sup>2</sup> to 100 kcd/m<sup>2</sup> and a light trap providing a value lower than 0.01 cd/m<sup>2</sup> is included. The Hidyni was designed as a modular system to be maximally flexible. The luminance levels of each module can be easily modified as well as the size of their luminous area. Various reference scenes of different sizes can be built, to match different measurement fields. Each luminance module can be easily turned off and on, but caps are available too. All these features make Hidyni very suitable for ILMD's characterisation procedures.

The source was fully characterized, and the average luminance of each luminance module was calibrated. The source achieves very good time stability and low nonuniformity required for ILMD's characterizations. In terms of uniformity, the current design reaches the technological limits of the LED module used. The uniformity of the source, as currently constructed, could be improved by using custom-made diffusers or by employing a sphere-based design for the luminance modules. To maintain the same module size in such a configuration, a more powerful and compact LED light source would be necessary. However, the main goal of the source development was to achieve the required high dynamic range from 0.1 cd to 100 kcd/m<sup>2</sup>, making it suitable for the characterization of the high-dynamic-range of ILMD's. The residual luminance nonuniformity of about 2.8% has a negligible effect on the results of the ILMD high dynamic range characterization. This is because the ILMD measures the average luminance of the non-uniform surface, and the spatial distribution of luminance remains very similar across all luminance levels due to the consistent design of each luminance module. As a result, when the ratio between luminance levels is evaluated, the impact of non-uniformity is effectively minimized. Furthermore, thanks to the selected technology and the construction of the source, it can achieve luminance levels of up to 200 kcd/m<sup>2</sup> when operated at full driver current, if necessary.

The expanded uncertainty of the demonstrated absolute luminance calibration of the seven source modules is ranging from 1.3 % for the brightest module up to 1.9 % for the dimmest module. This fulfils the target of an expanded uncertainty no larger than 2 % for the dimmest source, but not the target of an expanded uncertainty no larger than 1 % for the brightest source. Based on the results of numerous characterization measurements performed within this project using various types of ILMD instruments, it was found that the achieved calibration uncertainty of the brightest sources fully complies with the current requirements for the intended application of the source. Regarding the contrast between to source modules relative to another, which is of much more relevance regarding HDR imaging, an expanded uncertainty (k=2) of about 0.91% (between two of the brightest source modules) up to 1.8% (between two of the dimmest source modules) is estimated, cf. Section 5.2. For all other contrasts, the uncertainties remain within these limits. In this scope the target of 1 % up to 2 % is considered fulfilled regarding the most relevant use of the high-contrast reference source.

The design of the Hidyni uses off-the-shelf products and 3D printed body with special attention on its simple reproducibility in the conditions of calibration and testing laboratories. The modular design of the source allows easy portability. This guide to the realization of the Hidyni was written to enable reproducibility by independent producers.