TechnoTeam
Bildverarbeitung GmbH

Automotive lights test and measurement software for photometer/colorimeter

LMK position

APPLICATION OVERVIEW

Introduction

Imaging analysis of lighting scenarios and illuminated scenes are becoming more and more important. The complex analysis of various scenes requires the knowledge of the luminance distribution within the whole field of view or at least in many selected parts of it. Solving the necessary measuring tasks point by point either takes an enormous amount of time or is only possible within a coarse raster grid, if at all. Thus the development of spatially resolved radiation receivers has enabled the user to solve such measurement problems.

Some of the most important measurement tasks in which our applications are used and what one can measure with one of our LMK measurement systems are shown here:

Architectural lighting

- Luminance - Brightness level light pollution, glare sensation, visual perception
- Color, color appearance
- Luminous intensity distribution (LID), ray-data, BRDF data
- Non visual effect - blue light hazard, human melatonin suppression

Automotive lighting

- Exterior: head/tail lamps - luminance, color, luminous intensity distribution (LID)
- Interior: ambient and dashboard illumination - visibility, contrasts, visual and color appearance rating
- Display design - visual perception, glare sensation, contrast sensitivity

Lamp/Luminaire industry

- Luminance
- Color
- Luminous intensity distribution (LID) – ray data
- Non visuals – Blue light hazard

Display industry/metrology

- Luminance - brightness, uniformity, contrast ratio, image sticking, angular performance
- Color – color reproduction, color homogeneity
- Pixel defects and crosstalk
- Gamma determination and rating

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LMK position

LMK 6 & LMK 6 color

Sensor
[12 Bit digital, CMOS]

LMK 6-5 luminance/color
Sony IMX250 [2464 x 2046]

LMK 6-12 luminance/color
Sony IMX253 [4104 x 3008]

LMK 6-30 luminance/color
Sony IMX342 [6480 x 4860]

Dynamic range
Color High Dynamic measurement
[1:10.000.000 (~140 dB)]

Data transmission
Gigabit Ethernet Interface (GigE®)

Metrological specifications
V(λ) [$f_1' < 4\,\%$[1]]; X(λ) [$f_{1,E}' < 4\,\%$]
Z(λ) [$f_{1,E}' < 6\,\%$]; V´(λ) [$f_{1,E}' < 6\,\%$]

Measuring quantities
Luminance: L (cd/m²)
Chromaticity coordinates: (x,y)
Supported color spaces:
RGB, XYZ, sRGB, EBU-RGB, User, Lxy, Luv, Lu'v', L*u*v*, C*h*s*uv, L*a*b*, C*h*ab, HIS, HSV, HSL, WST[2]
Further measuring quantities can optionally be defined via scaling factors.

Measuring range[3]
Integration time from 100 µs to 15 s
1 ms ≈ 10000 cd/m²
3 s ≈ 3.3 cd/m²
The detection limit[4]($f_{3,0}$) in all measurement ranges is about 0.04 % relative to the highest measurement value in the range.
Higher luminances can be achieved using optional neutral density filters.

Calibration uncertainty[5]
fix focused lenses ΔL [< 2 %]
focusable lenses ΔL [< 2.5 %]

Repeatability[6]
ΔL [< 0.1 %]
Δx,y [< 0.0001]

Measuring accuracy
ΔL [< 3 % (for CIE standard illuminant A)]
Δx,y [< 0.0020 (for CIE standard illuminant A)]
Δx,y [< 0.0100 (set of test colors[7])]

Uniformity[4]
f_{21} [< 2 %]

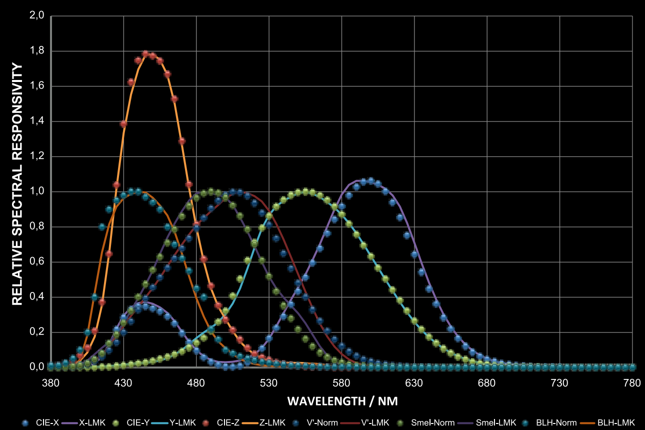
Fields of application
laboratory measurements, field measurements, industry automation

The **LMK** 6 features small dimensions, low weight at high sensor resolution, an optimized stray light, and high filter transmissions. In addition, it offers full sensor control for customized image sizes. This allows task-specific data transfer rates for high speeds while reducing data size. A special readout mode allows an image content based trigger for precise timing in dynamic scenarios.

LMK 6 luminance /color

The **LMK** 6 color equipped with an internal filter wheel offers a total number of six full glass filters. Four of them are used for color measurements according to the CIE-XYZ 2° standard observer. This allows to measure both luminance and color data. The remaining free slots on the filter wheel can be equipped with special filters:

- Scotopic filter V´(λ)
- Melanopic filter s_{mel}(λ) (ipRGC, acc. to CIE S 026:2018)
- Infrared filter (NIR range of 780 – 1100 nm)
- Blue light hazard filter (acc. to IEC 62471)
- BK7 glass filter to work with the spectral responsivity of the sensor directly



Spectral matching of the **LMK** 6 color

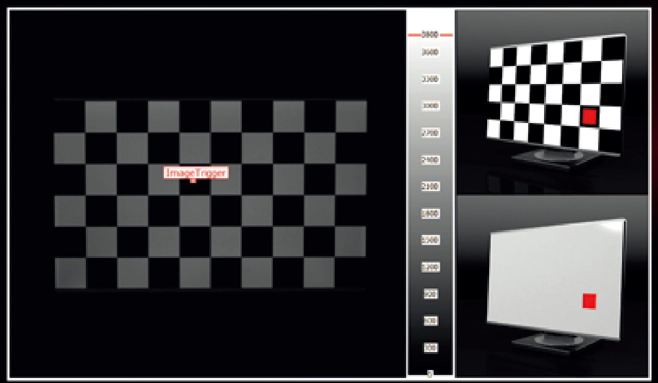
1 Measurements according to DIN 5032 Part 6 / ISO/CIE 19476:2014 (CIE S 023/E:2013) | 2 Dominant wavelength, saturation, correlated color temperature | 3 The luminance values represent the measuring range end values at the corresponding integration times. | 4 Definition and measurement according to CIE244:2021. | 5 Measurements according to CIE244:2021 using luminance standards traceable to the PTB (Physikalisch-Technische Bundesanstalt, the National Metrology Institute of Germany). | 6 Measurement performed on a stabilized white LED light source L = 100 cd/m². Standard deviation of the mean value over 100 pixel. | 7 Maximum difference of the measured value to the reference measurements using 12 LED-based luminance/color standards.

LMK position

LMK6
VIDEO PHOTOMETER

Triggered image capture

The **LMK** has different trigger methods for various applications. The different techniques can be used to trigger the **LMK** itself or to use the camera to trigger other objects, i.e., in production lines. One of the triggers can be the video image content itself. Here, the image content is constantly evaluated to trigger an image capture as soon as a change in brightness is detected. No additional devices are required for this method.

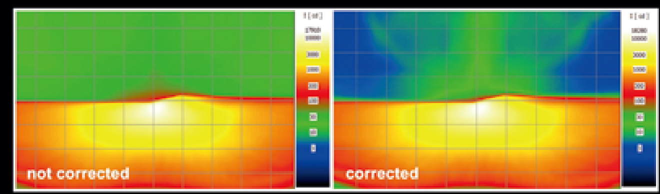


LMK color

LMK monochrome

High-contrast measurements

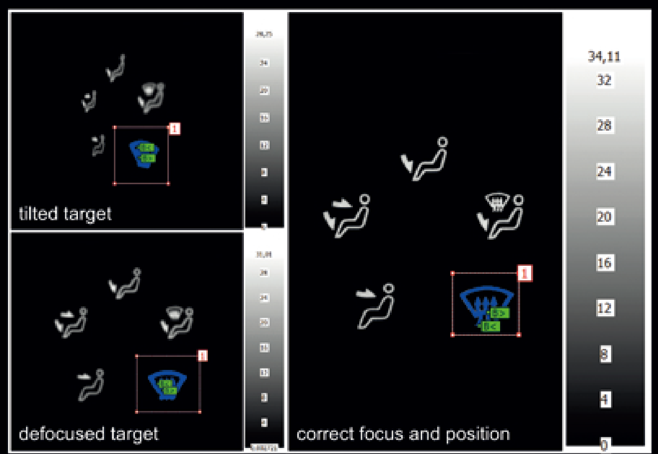
While dynamic means the light in different scenes, one speaks of contrast in the case of intensity differences within one image. Due to some constrictions, ILMDs can display much less contrast than the 1:10,000,000 dynamic range. Standard ILMDs achieve contrasts in the order of 1:1,500 at the bright-dark boundary (f_{25}). In the even more unfavorable scenario of negative contrast (f_{24}), they achieve contrasts of only 1:100 or less (see table). Such standard systems are unsuitable for applications where high contrasts must be measured, such as automotive headlamps or high-power shutter LEDs. For those measurement tasks, systems specially optimized for the application are needed. This is why the **LMK** can be delivered with an optional high-contrast calibration.



	Description	Standard system	High-contrast system[4]
f_{23}	Effect of surrounding field	1:1,000	1:2,000
f_{24}	Stray light influence for negative contrast	1:100	1:2,000
f_{25}	Edge function	1:1,500	1:15,000

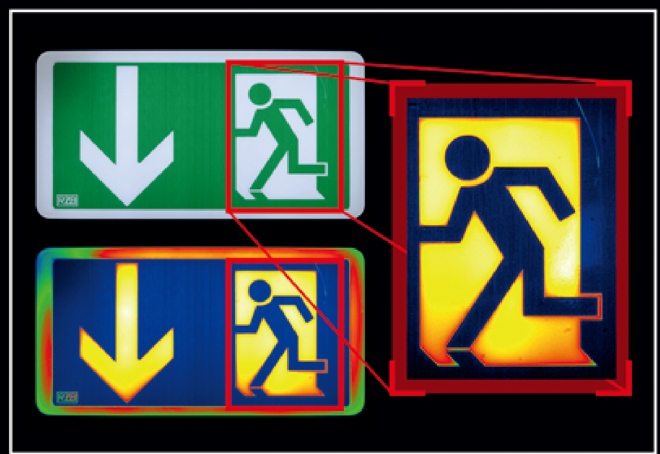
Smart live-view mode

With the live-view mode of the **LMK**, measuring setups can be quickly adjusted, and changes are seen in real time without the need for separate image capture. This mode allows the user to comfortably see the object to be measured, the exposure, the quality of the focus, temporal modulation effects, and moiré. The fast live-view mode is also guaranteed with high image resolutions.



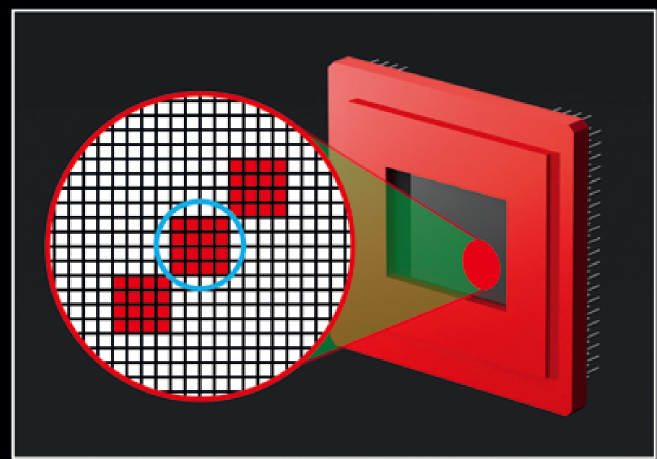
Sensor-level image region cropping

The **LMK's** ability to capture and transmit downsized images ensures faster image transmission and processing. The user can intuitively define the image section needed with the help of the live-view mode of the **LMK**.



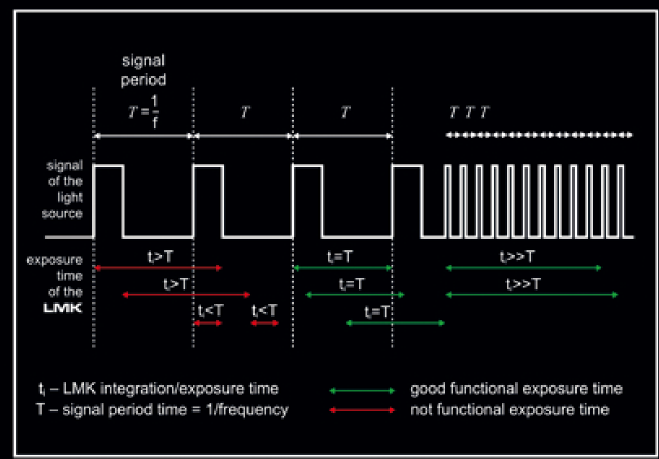
Binning

By combining individual pixels into pixel blocks (macro pixels), the sensitivity at the sensor level can be adapted to various lighting situations. This method provides an easy and intuitive way to adjust the sensitivity to light of the **LMK** by up to 16 times. This function requires an optional calibration.



Determination of modulation frequency

The **LMK** can determine the temporal modulation frequency of DUTs through targeted and intelligent changes in exposure time. This function makes it possible, for example, to detect the pulse-width modulation (PWM) of LED light sources.



LMK display

Display characterization is a broad field that encompasses many different metrology concepts. These concepts use a variety of light measurement devices such as Imaging Luminance and Color Measurement Devices (ILMD/ICMD) for measurement tasks based on luminance, contrast, and color. Even more so, ILMDs are particularly effective for all measurement tasks requiring simultaneous inspection of all display pixels and where high-resolution images are needed. Examples include defect and uniformity analysis, as well as resolution measurements that require accurate absolute luminance data and high image quality at the same time. The high-resolution LMK 6-12 and 6-30 combined with the LMKdisplay package fulfill these measurement tasks in three main aspects:

- Correlation to human perception
- Fast measurements
- Reproducible measurements

These are ensured by maintaining and continuously improving the high quality of our absolutely calibrated high transmission filter-based LMK luminance cameras, our certified calibration and QM processes, and by constantly developing innovative methods and metrology concepts. Our stray light correction (SLC) for high-contrast measurements, our image trigger for simple and accurate temporal alignment, or our phase compensation DeMOIRÉ are only a few examples. Each system is configured and calibrated with selected manual or autofocus standard lenses. The range of display metrology tasks covered is further extended by our own lens developments, such as conoscopic, macroscopic, microscopic, and NED lenses. In addition, we offer customer-specific lens developments.

Various software packages such as the LMK LabSoft are optimized for laboratory measurement tasks and come with over 400 SDK functions to support customer R&D. Other software packages such as the LightChecker offer an ideal solution for fast and precise easy to parametrize in-line inspection tasks. TechnoTeam software covers free updates over the complete product's lifetime, including newly developed display metrology concepts.

Further, TechnoTeam actively contributes to national and international standardization in photometry (CIE, DIN), display metrology (DFF, DKE, IEC, ICDM) as well as national and international conferences and scientific journals, with more than 20 contributions on display metrology in the past three years.

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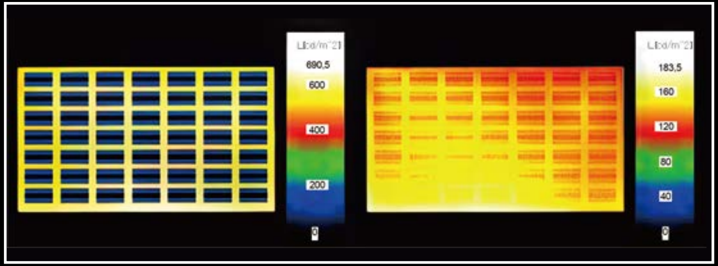
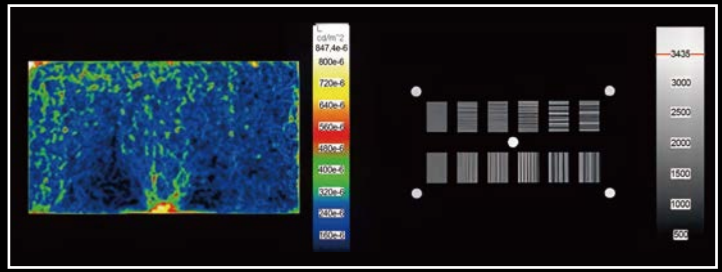
LMK Sticking image

Analyzes display sensitivity to static content through rapid luminance measurement series. The software package includes evaluations according to the three-level and two-level methods with both local and temporal corrections for highly accurate image sticking results. Exact timing is ensured by LMK 6 image trigger technology.



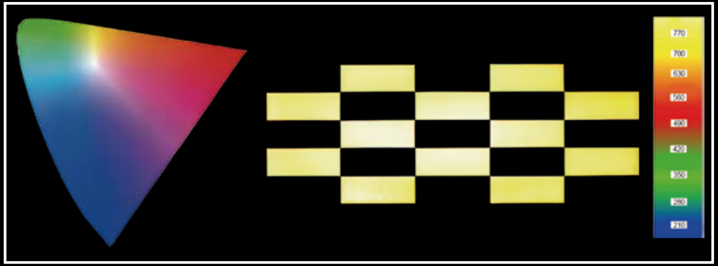
LMK BlackMURA

Analyzes the bright and black-level uniformity of displays, taking into account the full area luminance distribution and its gradients based on human perception. Short-distance evaluations for large displays are possible using by applying correction models. The software allows adjustments to the viewing conditions with presets for automotive displays according to the DFF.



LMK Basic

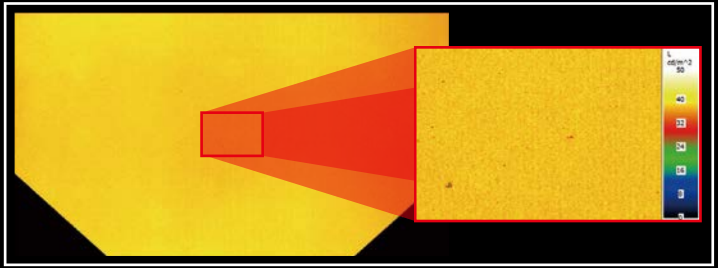
Allows evaluations of display quality such as luminance, uniformity, contrast, halo, color, etc. The optional SLC correction ensures a higher precision for high dynamic range images as required for checkerboard contrast or halo.



LMK Lenses

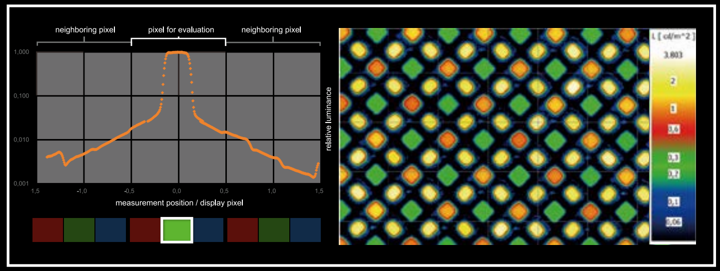
LMK DeMURA

Enables precise single capture measurements for the fast acquisition of pixel-level luminance data required to correct single-pixel emitters or to identify and localize defects. The software is based on an advanced pixel registration concept (APR) and highly precise DeMOIRÉ technique by phase compensation.



LMK Resolution

Evaluates the luminance distribution of individual subpixels and determines the perceived display resolution. The method is based on measurements with high-resolution macroscopic and microscopic lenses. The optional SLC correction ensures high precision and contrast.



LMK for automotive display metrology

Over the past 30 years, TechnoTeam gained extensive knowledge in photometry and colorimetry for automotive exterior and interior, including measuring displays of all shapes and sizes. Examples include passenger displays, central information displays, cluster elements or pillar-to-pillar displays, curved and s-shaped displays based on LCD and OLED technology, as well as head-up displays, camera-monitor-systems, and many more. Customers trust and choose the LMK to ensure the optical quality of automotive displays because of the expected high quality of metrology and support. Another reason is that many of our developments improve automotive display metrology in terms of reproducibility and speed.

One example is the LMK Position system. It is a combination of a 6-axis robot with an LMK and was developed to improve the reproducibility and effectivity of automotive BlackMURA measurements. It allows image stitching of large pillar-to pillar displays and easy, fast and reproducible alignment of the LMK at the driver and passenger vantage points, even for complex 3D curved and freeform displays. Another example is the short-distance BlackMURA concept. It allows production measurements of large displays at reasonable measurement distances.

Finally, most of our measurement concepts are the result of joint research projects with our Automotive OEM, Tier 1 and Tier 2 industry partners. Successful development projects include:

- The uniformity measurement BlackMURA (OEM Working Group, DFF)
- The uniformity measurement Sparkle (Volkswagen and Elektrobit Automotive)
- The display resolution measurement Pixel Cross Talk (Porsche)
- The defect analysis Sticking Image 2 Level (Mercedes)
- The defect analysis Sticking Image 3 level (Johnson Controls and Visteon, DFF)
- The angular contrast evaluation region in the CCM (OEM Working Group)

LMK position

CALIBRATION PROC ESS

An ILMD/ICMD (short IxMD) system consists of a digital camera, optical filters for the spectral matching, (changeable) lenses and additional neutral density filters. The aim is to measure the two-dimensional projection of the luminance / color distribution of a device under test (DUT) with or without a geometrical calibration.

For accurate data evaluation, all non-ideal properties of the system need to be corrected in relation to international agreed standards (e.g. luminance) typically using calibration factors. For this purpose, the software controlling the IxMD, needs a model and model parameters. The estimation of the model parameter is the aim of the individual adjustment of a measuring system. With the additional calibration the success of the adjustment will be checked and stated including the associated measurement uncertainty verified by the measurement of defined index values.

Most of the following measurements to estimate model parameter are made individually for every system and lens. Only viewing measurements are system specific only and can be done once for a system type.

All characterizations described with red index values are performed individually. Some other characterizations described with black index values can be created system specific in most cases.

This description is valid for an LMK COLOR camera with a focusable lens and neutral density filters.

For every measurement the adjustments made by the measurement before are taken into account.

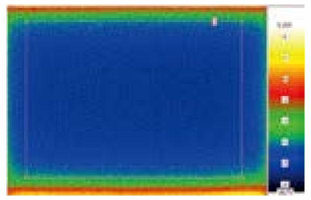
If no other reference is given all tests and characterizations are done according to DIN5032-10:2019 / CIE TC2-59 CD:2019

The way to a calibrated ILMD/ICMD system

$f_{3,0}$

Dark signal properties

Measurement and characterization of the dark signal properties of a system including dark signal, dark signal non-uniformity and faulty pixels.



Dark signal non-uniformity (of the system without correction) at 5s integration time and 25°C ambient temperature.

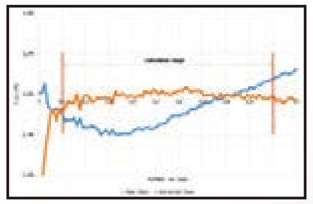
Apply all the dark signal properties for correction and calculate the detection limit (relative or using a common calibration factor).

$f_{3,1}$

Basic camera and sensor data

Measurement of basic camera and sensor data (not related to lenses) using the Photon Transfer Method (PTM) to estimate the system transfer factor k_{sys}, the basic noise σ_0 and the full well capacity Q_r.

The non-linearity over different integration times with selected luminance values is measured and used for correction later on.

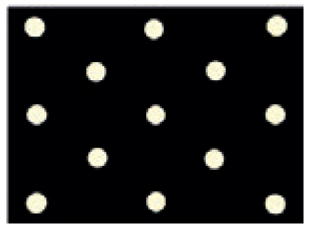


Measurement with and without correction of the non-linearity for a system.

f_{21}, f_{22}

Lens shading

Flat field measurements with large homogenous objects using specialized integrating spheres and raster measurements using small homogenous objects and a rotation stage.

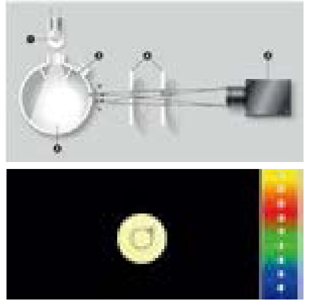


Example: Raster measurement for the characterization of the lens shading to measure the f_{22} uniformity index after using all measured corrections.

f_{Adj}

Adjustment

Measure the calibration factor for every color filter and use the luminance for standard illuminant A as the reference value.



Measurement setup according to DIN5032-10 for the luminance adjustment of an ILMD.

ΔC

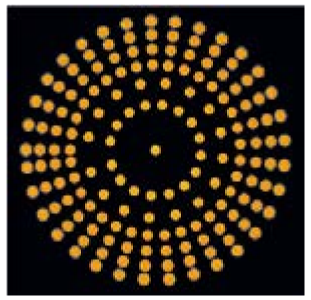
Color calibration

Measure different known light sources (LED based L³ STANDARDs or other references) and calculate a transformation matrix for the camera color space (4 to 8 filters) to the standard color space of the 2° CIE standard observer.

Multi-Color calibration with different L³ STANDARDs. Apply the transformation, perform test measurements and calculate color differences ΔC.

Lens and filter distortion correction

Measure the distortion caused by the color filters and/or lenses and calculate correction information.

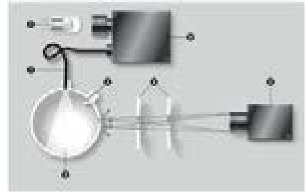


Example of a measurement grid for a sky lens (fisheye lens) to calculate the angular positions for every pixel e.g. necessary for UGR evaluation.

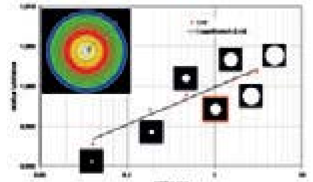
f_1' $f_{6,T}$ f_{12} f_{23} f_{24} f_{25} f_{29}

Further characterization

After finishing all the measurements used for correction multiple characterizations are necessary to check the calibrated system:



Measurement setup according to DIN5032-10 for the spectral responsivity measurement of an ILMD e.g. to state f_1'.

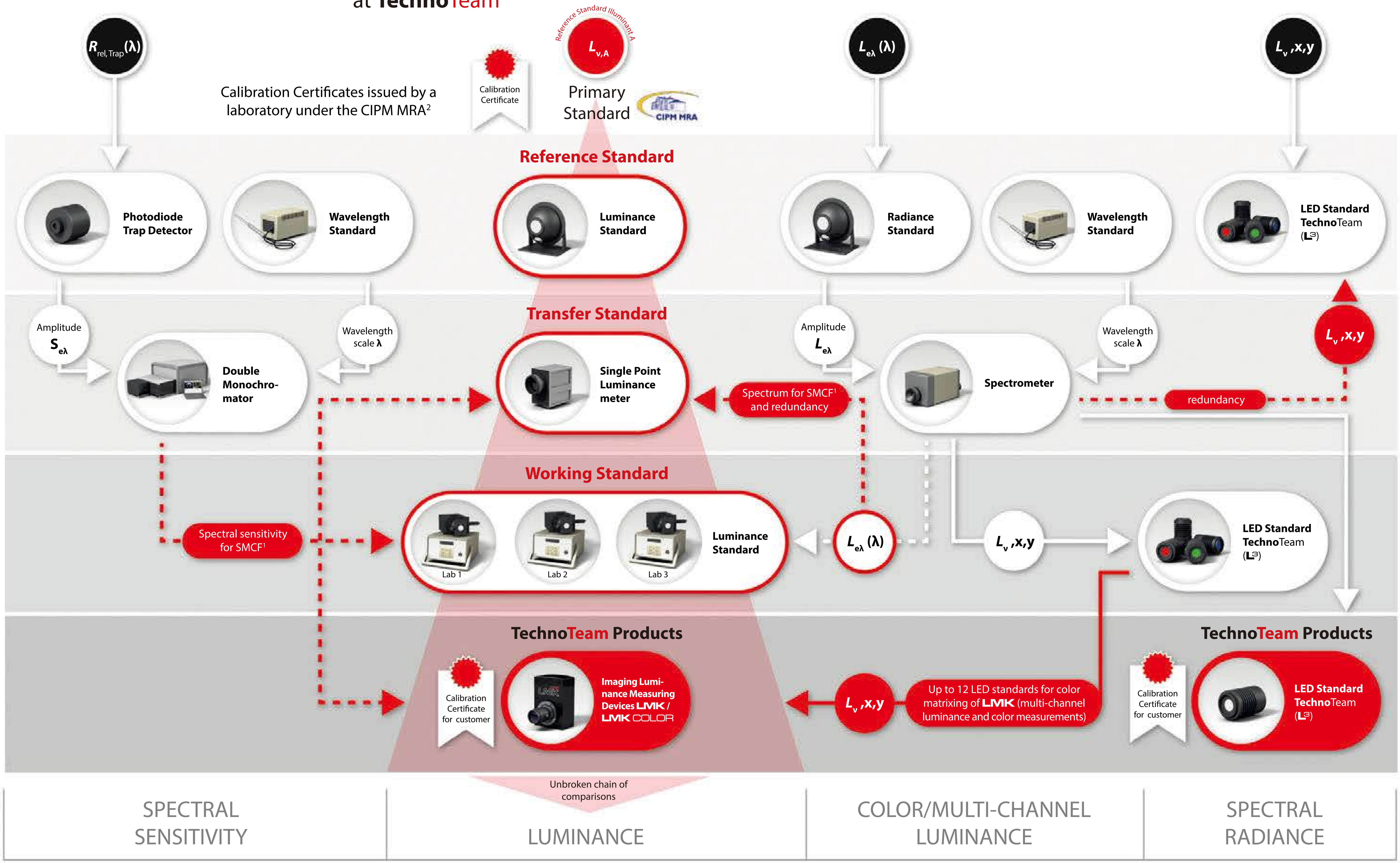


Example measurements results for the Size-Of-Source effect stated with the characteristic value f_{29}

LMK position

TRACEABILITY

at TechnoTeam



1 SMCF – spectral missmatch correction factor | 2 The CIPM MRA has been signed by the representatives of 105 institutes – from 59 Member States, 42 Associates of the CGPM, and 4 international organizations – and covers a further 157 institutes designated by the signatory bodies. The most important institutes for us are PTB and METAS actually.

MEMO

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