TechnoTeam
Bildverarbeitung GmbH

AR/VR/MR test and
measurement software for
photometer/colorimeter

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

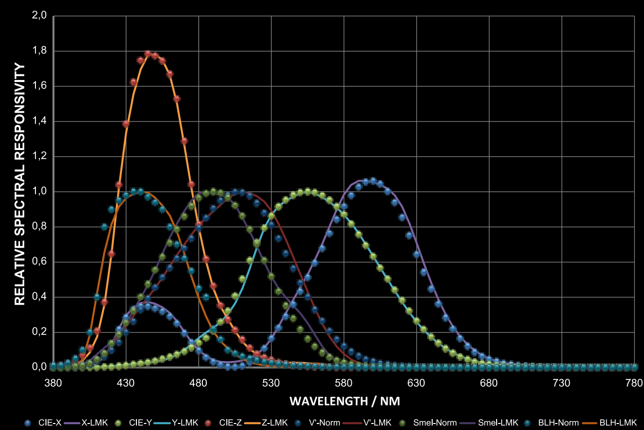
laboratory measurements, field measurements, industry automation

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.

NED lens type	TT NED 40 Autofocus Short	TT NED 40 Autofocus Long	TT NED 17 Autofocus Long
Focus operation	Electronically controlled focus		
Focal power	-5 dpt. to + 10 dpt.		
Entrance pupil position	First optical surface		
Entrance pupil diameter	2-6 mm (< 5 mm diffraction limited ±7.5° FOV)	2-6 mm (< 2.5 mm diffraction limited ±15° FOV)	2-6 mm (< 2.5 mm diffraction limited ±27° FOV)
FOV (diagonal)	30°		60°

- The resulting focal length of these special front lenses ranges from 35 mm to 60 mm.
- It provides a captured field of view of 20.7°–15.7° up to 35.1°– 26.6°.
- The lens offers compact dimensions with a diameter of only 36 mm.
- Features a manually adjustable focus range from 1.5 m to infinity.

- It provides a captured FOV of 120 (circular)
- The diameter of the entrance pupil (EP) is 1mm
- Comparing to the smaller/old Conoscopic lens the imaging curvature is improved
- Comparing to the smaller/old Conoscopic lens the MTF is improved

Near Eye Display Measurement

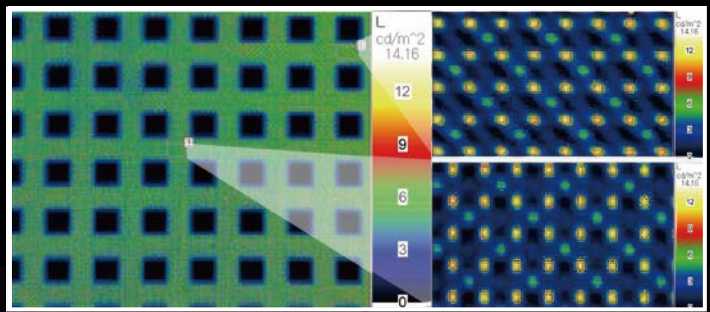
Imaging Luminance and Color Measuring Devices (ILMD / ICMD) in combination with adapted measuring lenses provide effective one-shot solutions to evaluate modern Near Eye Displays (NED). NED-suppliers asked for LMK-solutions adapted to their specific instrument structure. Here, the wide range of fields of view (FOV) and of NED-resolutions needs to be considered. On the basis of our experience in creating LMK's we offer a set of formulas to determine the basic parameters of lenses for different NED-concepts. We developed an optical system whose aperture-stop (respectively the NP (entrance pupil)) is in front of the optical surfaces. With two solutions – the conoscopic lens arrangement and special front stop lenses – we are able to offer solutions for NED measurement tasks. For highest accuracy we also can offer a robotic assisted precision aligning, scanning and rotating solution possible due to our compact camera-lens system.

Requirements of NED lenses

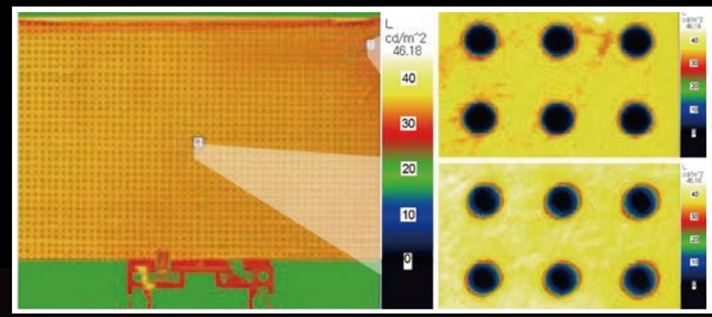
- ILMD entrance pupil has to be located inside the NED exit pupil
- ILMD entrance pupil has to be smaller than the NED exit pupil
- ILMD entrance pupil needs to be in front of the lens mechanics
- Compact luminance/color camera and lens design to enable robotic assisted precision aligning, scanning and rotation of the ILMD entrance pupil

Basic Laws of lens design

- Larger field angles require shorter focal lengths
- Larger image sensor dimensions ask for larger focal lengths to achieve a similar field angle
- High resolutions require a small field angle, or rather longer focal lengths and larger image sensors



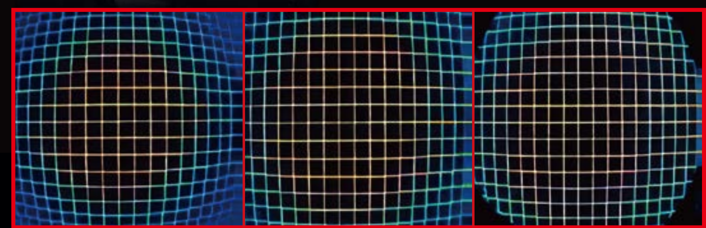
Left: High resolution measurement of crossed line pattern of an Oculus Rift using an 50 mm ocular based front stop lens Right: Magnification of Region 2 (Top) and Region 1 (Bottom)



Left: High resolution measurement of circular reference pattern using a 50 mm ocular based front stop lens Right: Magnification of Region 2 (Top) and Region 1 (Bottom)

High Field of View measurement of Oculus rift using a hypercentric lens

ILMD-NP position:



Too close | Correct | Too far

Special front-stop lenses

Ocular lens

With the existing conoscopic lens we offer a lens that has a virtual NP (appr. 2mm diameter) in front of the lens with a special front-stop. This lens works with a real intermediate image plane. The resulting focal length of these special front-stop lenses range from 8mm up to 16mm. It can realize a captured field of view (FOV) of ±30° down to ±15°. This field of view is smaller than the nominal field of most NED designs. An ideal device under test for this would be a monocular notifying that it realizes a field angle of maximal ±30°. The diameter of the NP can be changed from 2 - 7mm.

- High resolution measurements
- Measure NED resolution, NED distortion
- Determine the NED Modulation Transfer Function (MTF)
- Other ocular based lens designs for larger-field of views possible

Conoscopic lens arrangement

Hypercentric lens

Use of a conoscopic lens means that ray bundles from an entrance pupil (app. 2mm diameter) located 2 mm in front of the first lens create an image on the image sensor which is reversed in reference to a classical LMK-lens. The conoscopic lens arrangement offers a FOV up to 120° (circular image).

- Large Field of View measurements
- Measure luminance, chromaticity and other uniformity attributes with one / few measurements
- Measure eye box properties

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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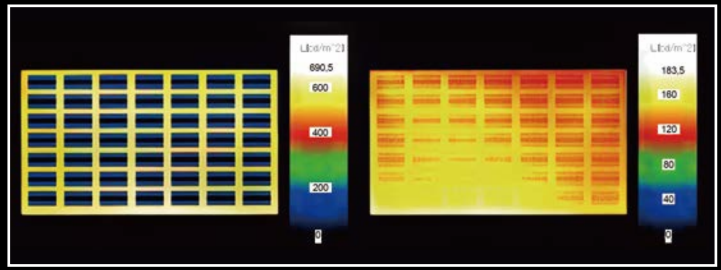
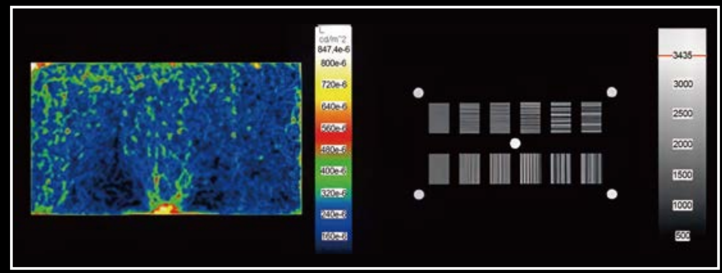
LMK Sticking image

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.



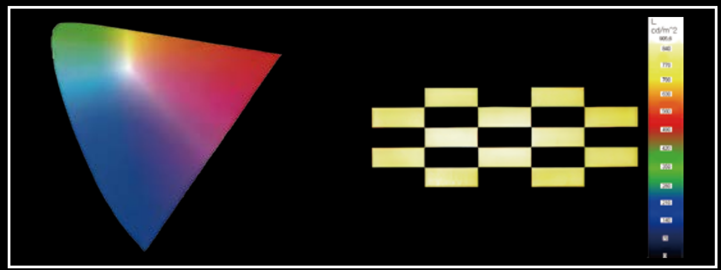
LMK BlackMURA

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

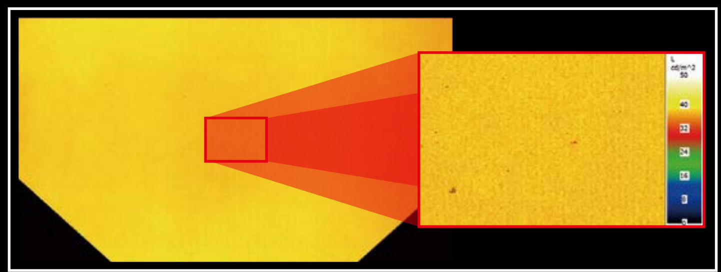
Allows evaluations of display quality such as luminance, uniformity, contrast, halo, color, etc. The optional SLC correction ensures a higher precision for high dynamic range images as required for checkerboard contrast or halo.



LMK Lenses

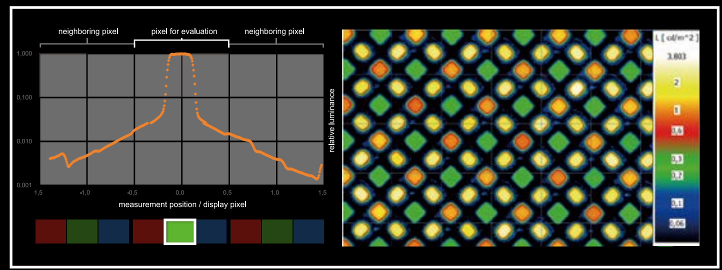
LMK DeMURA

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 AR/VR display metrology

Over the past 30 years, TechnoTeam gained extensive knowledge in photometry and colorimetry for AR/VR display technology, including measuring displays of all shapes and sizes. Examples include head-mounted displays (HMDs), augmented reality (AR) glasses, virtual reality (VR) headsets, and mixed reality (MR) devices. Customers trust and choose the LMK to ensure the optical quality of AR/VR displays because of the expected high quality of metrology and support. Another reason is that many of our developments improve AR/VR 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 AR/VR display measurements. It allows image stitching of large displays and easy, fast, and reproducible alignment of the LMK at various viewing points, even for complex curved and freeform displays. Another example is the short-distance concept for measuring AR/VR display quality. 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 AR/VR 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 PROCESS

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.

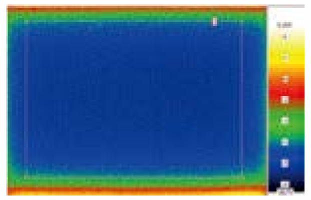
For every measurement the adjustments made by the measurement before are taken into account.

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.



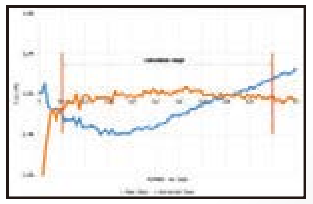
Dark signal non-uniformity (of the system without correction) at 5s integration time and 25°C ambient temperature.

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.

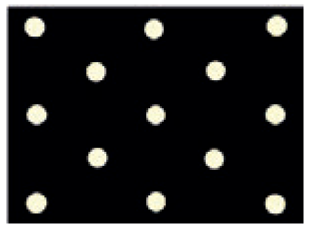
The non-linearity over different integration times with selected luminance values is measured and used for correction later on.



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

f_{21}, f_{22} Lens shading

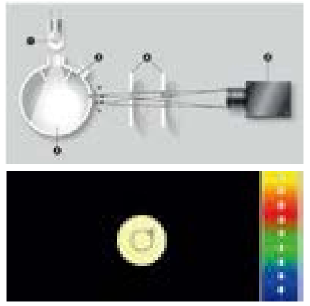
Flat field measurements with large homogenous objects using specialized integrating spheres and raster measurements using small homogenous objects and a rotation stage.



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.

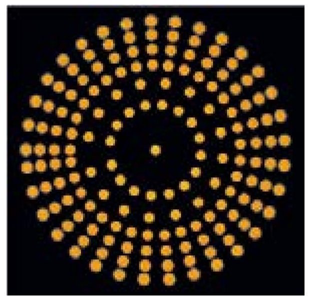
ΔC Color calibration

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

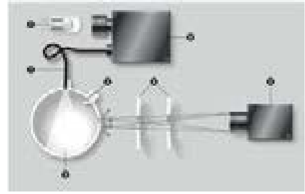
Measure the distortion caused by the color filters and/or lenses and calculate correction information.



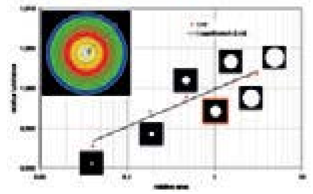
Example of a measurement grid for a sky lens (fisheye lens) to calculate the angular positions for every pixel e.g. necessary for UGR evaluation.

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:

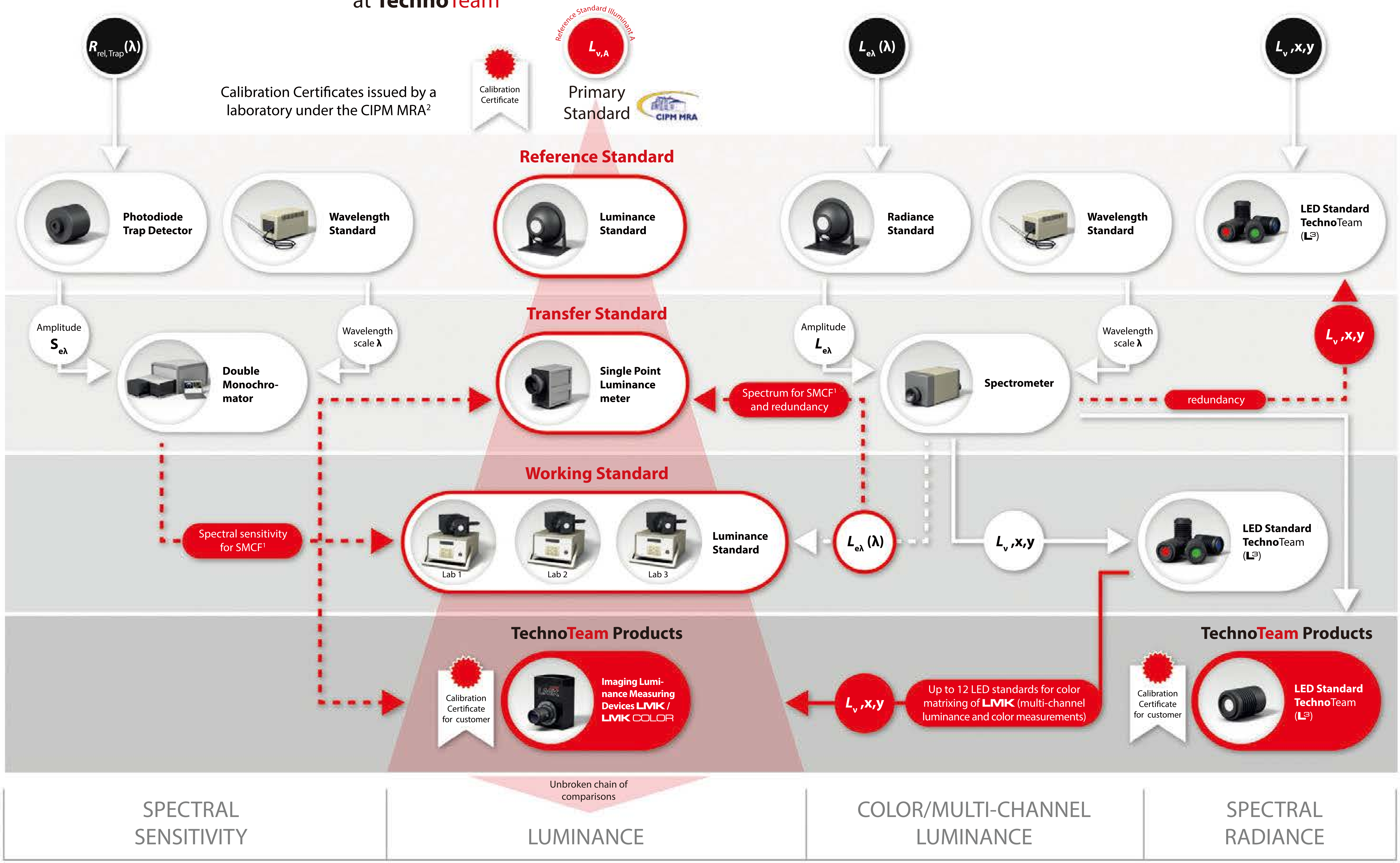


Measurement setup according to DIN5032-10 for the spectral responsity measurement of an ILMD e.g. to state f_1'.



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

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.

Presented by :

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