CALIBRATION PROCESS

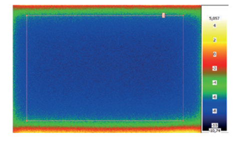
For accurate data evaluation, all non-ideal properties of a system must be corrected. Therefore, the IxMD needs a model and parameters.

Most of the measurements are made individually for each system.

All tests and characterizations are performed according to DIN5032-10-2019/ CIE 244:2021 unless specified otherwise.

Dark signal properties ($f_{3,0}$)

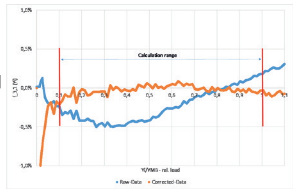
Measurement and characterization of the dark signal properties of a system including dark signal, dark signal non-uniformity and faulty pixels.
Apply all the dark signal properties for correction and calculate the detection limit (relative or using a common calibration factor).



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

Basic camera and sensor data ($f_{3,1}$)

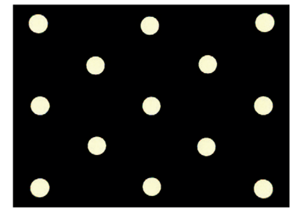
Measurement of basic camera and sensor data (not related to lenses) using the Photon Transfer Method (PTM) (EMVA1288, 2016) to estimate the system transfer factor k_{Sys}, the basic noise σ_0 and the full well capacity Q_F.
Furthermore, the non-linearity over different integration times with selected luminance values is measured and used for correction later on.



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

Lens shading (f_{21}, f_{22})

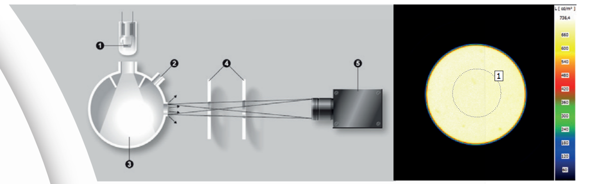
Flat field measurements with large homogenous objects using specialized integrating spheres and raster measurements using small homogenous objects and a moving stage.



Example: Raster measurement for the characterization of the lens shading after using all measured corrections.

Adjustment (f_{Adj})

Measure the calibration factor for each color filter.



Color calibration (ΔC)

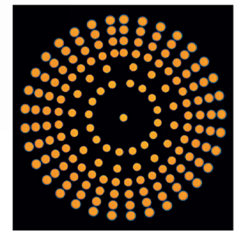
Measure different known light sources (e.g., LED-based L³ standards) and calculate a transformation matrix for the camera color space (4 to 8 filters) to the standard color space of the CIE 1931 standard colorimetric 2° observer.

Multi-Color calibration with different L³ standards.

Lens and filter distortion correction

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

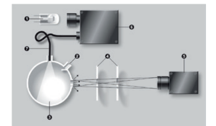
Example of a measurement grid for a sky lens (fisheye lens) to calculate the angular positions for every pixel e.g. necessary for UGR evaluation.

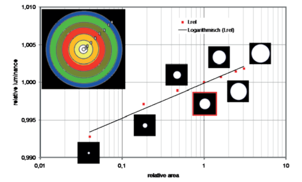


LMK color

Further characterization (f_1', $f_{6,T}$, f_{12}, f_{21}, f_{24}, f_{25}, f_{29})

After finishing all the measurements used for correction multiple characterizations are necessary to check the calibrated system (individual check with every system red, check the typical data black): Measurement setup according to DIN5032-10 for the spectral responsivity measurement of an ILMD e.g. to state f_1'.

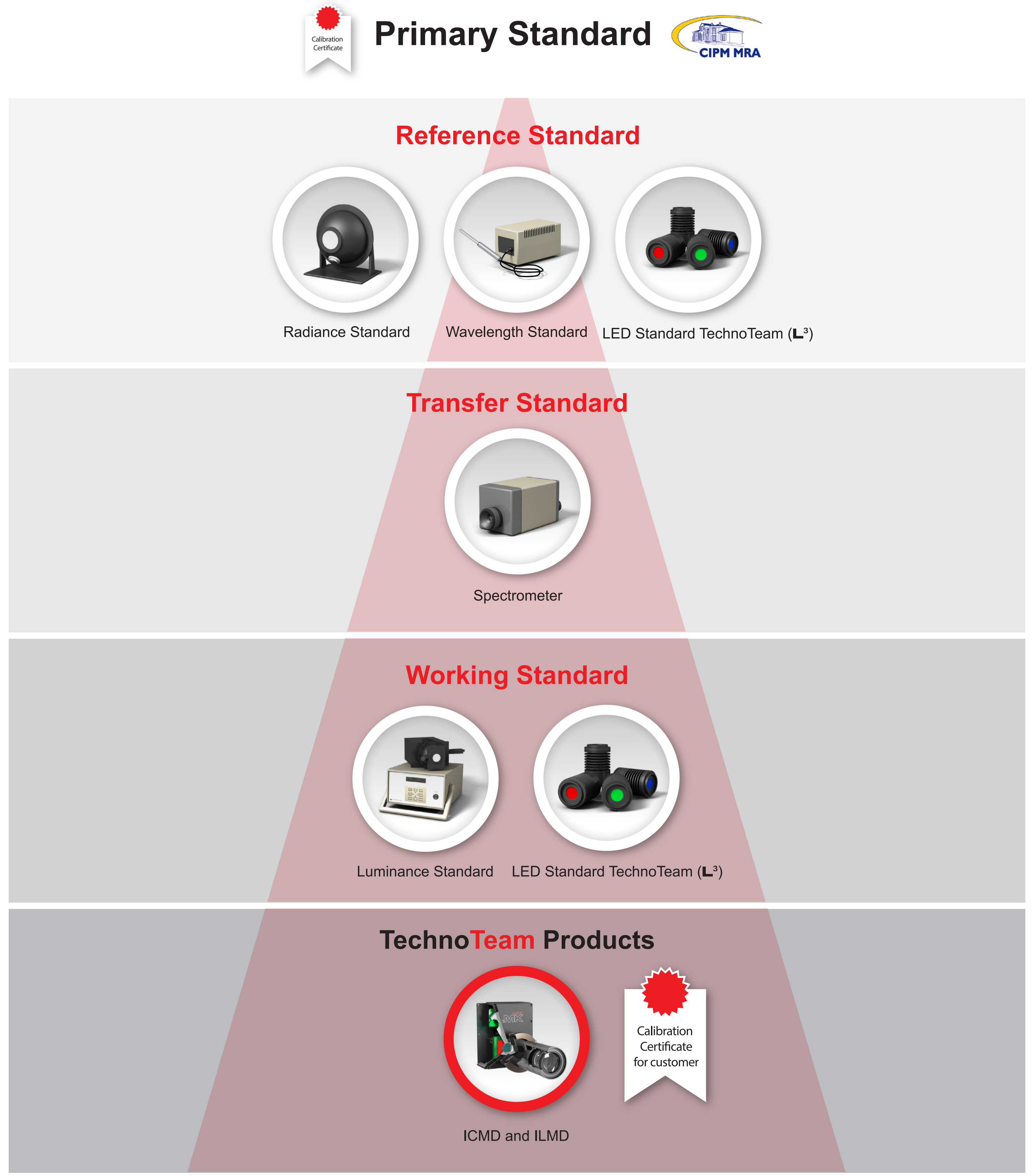




Example measurements results for the Size-Of-Source effect stated with the characteristic value f_{29}

TRACEABILITY

at TechnoTeam



Imaging Color Measuring Devices (ICMD) and Imaging Luminance Measuring Devices (ILMD)

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VIDEO PHOTOMETER

IMAGING LIGHT AND COLOR MEASURING DEVICES

LMK6

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®)

Spectral matching[1]

$V(\lambda)$ [$f'_1 = 3\,\%$][2]
$X(\lambda)$ [$f'_{1,E} = 4\,\%$][3]; $Y(\lambda)$ [$f'_1 = 2.5\,\%$][3]; $Z(\lambda)$ [$f'_{1,E} = 5.5\,\%$][3]

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[4]
Further measuring quantities can optionally be defined via scaling factors.

Measuring range[5]

Integration/exposure time from 100 µs to 15 s
1 ms ≈ max. 10,000 cd/m²
3 s ≈ max. 3.3 cd/m²

The detection limit[6] ($f_{3,0}$) for all integration/exposure times is about 0.04 % relative to the given maximum luminance value.
Higher luminance can be measured using optional neutral density filters.

Calibration uncertainty[7]

fix focused lenses ΔL [< 2 %]
focusable lenses ΔL [< 2.5 %]

Repeatability[8]

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 [< 0.0030] for white phosphor converted LED
Δx,y [< 0.0100] set of test colors[9]

Uniformity[6]

f_{21} [< 2 %]

Fields of application

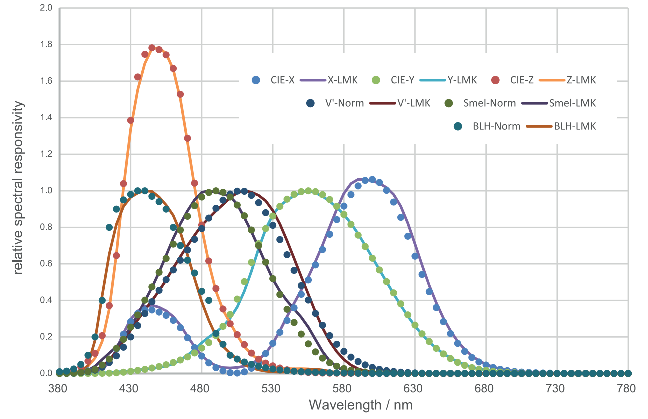
laboratory measurements, field measurements, industry automation

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 monochrome / 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 1931 standard colorimetric 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 $s_{mel}(\lambda)$ (ipRGC, acc. to CIE S 026:2018)
- Infrared filter (NIR range of 780 – 1,100 nm)
- Blue light hazard filter (acc. to IEC 62471)
- BK7 glass filter to work with the spectral responsivity of the sensor directly



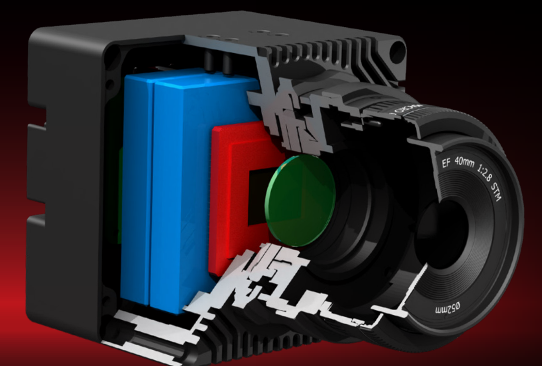
Spectral matching of the **LMK** 6 color

1 typical average result for entocentric lenses, specific results available with calibration certification or on request | 2 Spectral mismatch f'_1 according to ISO/CIE 19476:2014 | 3 Typical result for LMK color model type | 4 Dominant wavelength, saturation, correlated color temperature | 5 The luminance value stands for the measuring range end value at the specified exposure/integration time | 6 Definition and measurement according to CIE244:2021 | 7 Measurements according to CIE244:2021 using a luminance standard traceable to the PTB (Physikalisch-Technische-Bundesanstalt, the National Metrology Insitute of Germany) | 8 Measurement performed on a stabilized white LED light source L=100 cd/m² - mean value over 100 x 100 camera image pixel | 9 Maximum difference of the measured value to the reference measurement using 12 LED-based luminance/color standards

LMK6

VIDEO PHOTOMETER

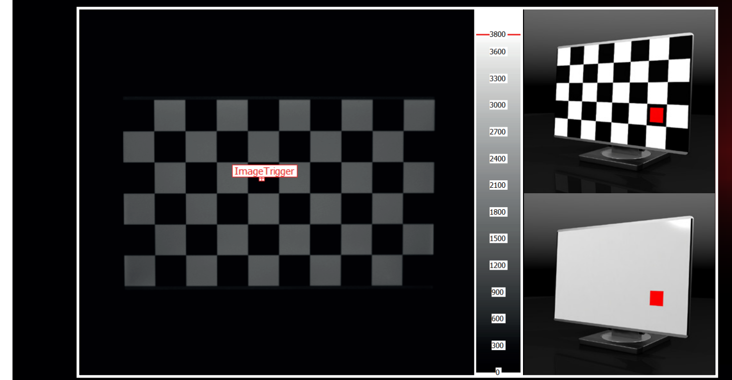
LMK color



LMK monochrome

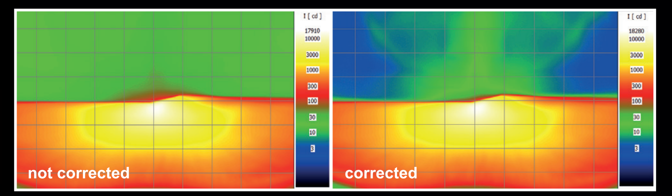
Triggered image capture

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.



High-contrast measurements

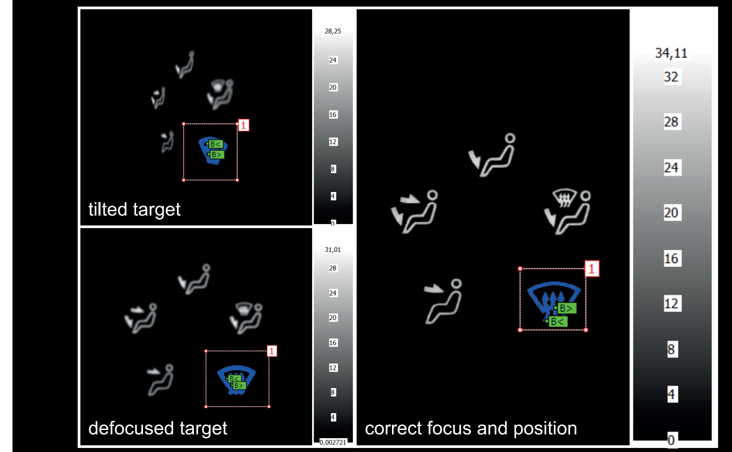
While dynamic means the light in different scenes, one speaks of contrast in the case of intensity differences within one image. Due to some constrictions, ILMDs can display much less contrast than the 1:10,000,000 dynamic range. Standard ILMDs achieve contrasts in the order of 1:1,500 at the bright-dark 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

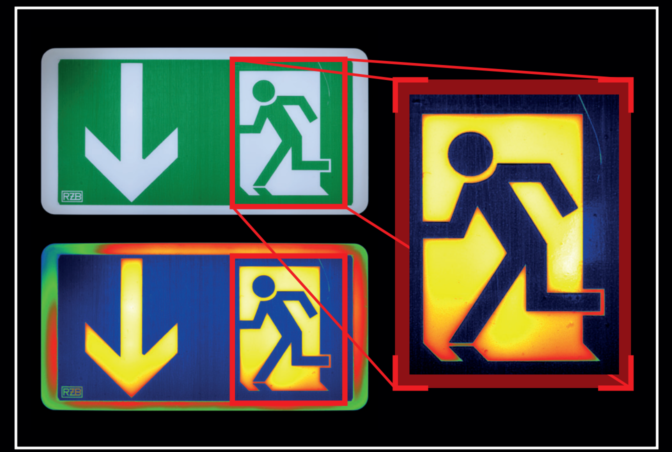
Smart live-view mode

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.



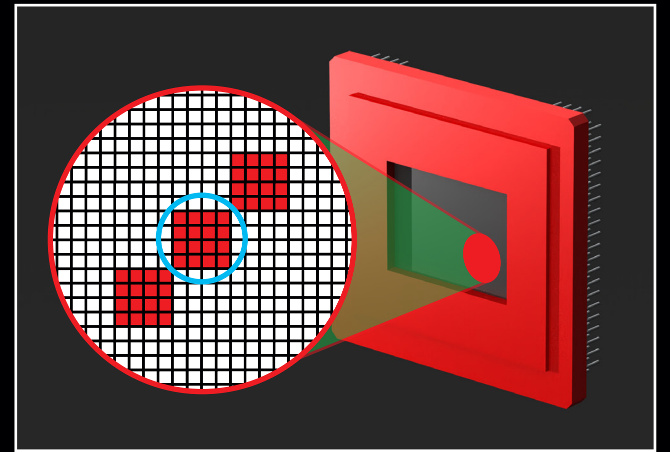
Sensor-level image region cropping

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**.



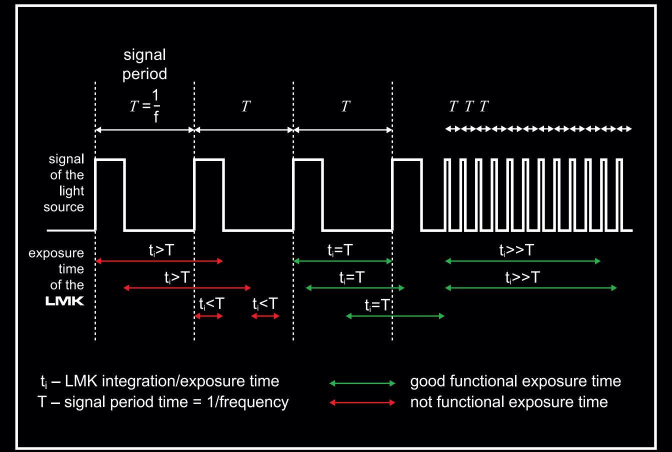
Binning

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.



Available lenses

	LMK 6-5	**LMK** 6-12	**LMK** 6-30
Autofocus			
14 mm	-	53° × 40°	73° × 58°
24 mm	-	32° × 24°	50° × 38°
50 mm	-	16° × 12°	24° × 18°
85 mm	-	9° × 6.5°	15° × 11°
135 mm	-	6° × 4.5°	9.1° × 7.1°
Manual focus			
8 mm	57.5° × 44.9°	83° × 67°	-
12 mm	40.1° × 30.8°	-	-
15 mm	-	-	72° × 57°
16 mm	30.7° × 23.3°	48° × 36°	-
25 mm	19.9° × 15.5°	31° × 23°	47° × 36°
50 mm	10° × 7.6°	16° × 12°	24° × 18°
80 mm	6.3° × 4.7°	10.1° × 7.4°	-
100 mm	-	-	13° × 10°
150 mm	3.3° × 2.5°	4.5° × 3.2°	-
Microscope			
× 5 magnification	-	2.760 x 2.070 mm	4.140 x 3.450 mm
× 10 magnification	-	1.380 x 1.035 mm	2.070 x 1.725 mm
× 20 magnification	-	0.690 x 0.518 mm	1.035 x 0.863 mm
× 50 magnification	-	0.276 x 0.207 mm	0.414 x 0.345 mm
Macroscope			
2.0/36/35	4.5 × 3.3 mm	7.3 × 5.1 mm	-
1.5/40/35	5.7 × 4.5 mm	9.0 × 6.5 mm	-
1.1/56/40	7.8 × 5.9 mm	12.8 × 9.3 mm	-
0.8/93/50	11.5 × 8.6 mm	17.6 × 13.2 mm	-
0.7/126/60	13.4 × 10.0 mm	20.8 × 15.0 mm	-
0.5/166/60	19.2 × 14.4 mm	30.0 × 22.0 mm	-
1.1/130/80	8.4 × 6.3 mm	13.0 × 9.5 mm	-
Conoscope			
Small	-	120° (circular)	120° (circular)
High-resolution	-	120° (circular)	120° (circular)
Foveal lens			
35 mm	14° × 11.13°	22.5° × 16.7°	35.1° x 26.6°
Fisheye lens			
		180° × 150°	180° (circular)

all field angle values are approximated