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Light distribution within an illuminated 50 mm diameter integrating sphere model UPK-50-F with OP.DI.MA. coating manufactured by Gigahertz-Optik

Gigahertz-Optik

Alphabetical Listing of Product Part Numbers

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Optometers & Instruments: Radiometers, Photometers, Color Meters, Laser Power/Noise Meters

Optometer is the term Gigahertz-Optik uses to describe a optical radiation measurement instrument that is universally adaptable to any light measurement application. The light detector(s) connected to the instrument determines the meter designation and the units of measurement. To meet the demands of a wide range of industrial, medical, research and environmental applications single and multi-channel optometers with advanced features for mobile or bench-top use are offered. **Instruments** (Radiometers, photometers & color meters) are combinations of meters and specific light detectors selected for a given application. These dedicated systems are simple to use and save costs since only required features are provided.

Contact us for assistance in helping you select the right equipment for your application or for full custom product service.

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P-9710-1 / P-9710-2 Compact Optometer

- **Compact Single-Channel Meter for Service and Laboratory Use**
- **Universal Use in any Light Measurement Application**
- **Calibration Data Connector for Simple & Unlimited Detector Exchange**
- **Measurement of DC, AC and Flash Signals**
- **Short Slew-Rate for Fast Measurements**
- **100 µs Fast Sampling Rate**
- **Adjustable Integration Time from 100 µs to 6 s**
- **Wide Detector Signal Dynamic Range from 0.1 pA to 2 mA**
- **RS232 Interface for Remote Control Operation**
- **Optional Windows Software**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

The P-9710 Optometer is a highly efficient single-channel instrument designed for multipurpose use in any photometric and radiometric application.
In spite of its compact size it offers many high-level features complimenting sixteen different measurement modes. These functions plus portability enable the P-9710 to be characterized as both a laboratory grade instrument and a field service meter.

Calibration Data Connector:
A unique feature of the P-9710 is its detector head calibration data connector. All data pertaining to a detector including the model and serial number are stored in the connector. When plugged into the meter, this data is automatically transmitted and the system is ready to go. This guarantees faultless handling of the instrument when used with any number of different detector heads.

Wide Dynamic Range:
The P-9710's wide signal range of 0.1 pA to 2 mA covers the dynamic range of most current semiconductor photodiodes for nearly unrestricted use in any light measurement application.

Fast Measurements:
The P-9710 offers a fast signal input with 2 to 10 ms slew-rate (gain dependent). Its fast 100µs sample rate allows use of the P-9710 as a fast data logger. Another key feature for individual application set-ups is an adjustable integration time (calculated average) of up to 6 seconds.

Precision Measurement:
The P-9710 offers a linear 12-bit ADC input with 8 manually or automatically selected gain ranges with a maximum error over this large dynamic range 0.2 %.

Remote Control:
A bi-directional RS232 serial interface allows external remote control. Optional Windows based software is available for a quick turn-key solution or user generated programming is possible using the complete command set supplied. End-user recalibration by adjustment of the factory programmed calibration factors is possible using the OS CAL software via the RS232 interface or manually by menu function.

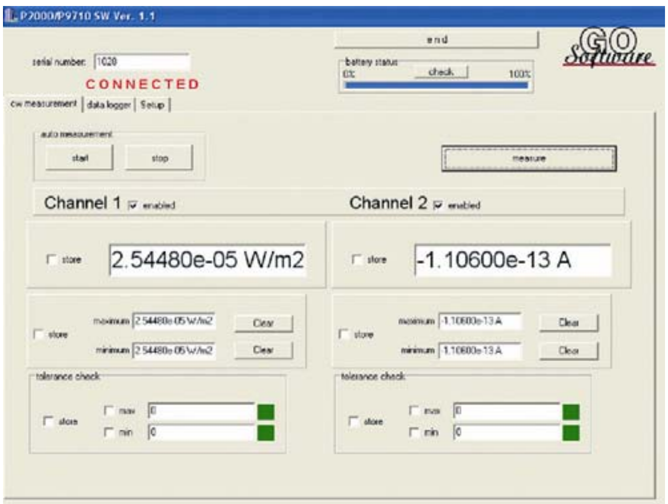
Process Integration:
An optional relay switch board is available for activation by the P-9710 in process control applications. A 'low-ok-high' indication through menu controlled set-up of the limit values is simple.

Multiple Applications:
The P-9710 mates with most of GO's detector heads to cover any photometric and radiometric measurement quantity.

Mobility:
The hand-held P-9710 is battery (rechargeable) or AC operated. A tough hard-shell case holds one, two or more detector heads for secure portability in service use.

Numerous Functions:
The unit's many functional modes of operation includes CW, dose, pulse energy, datalogger measurements and many more. If the sixteen different operation modes do not include the one you need we do offer custom design modifications.

Two Different Models:
The P-9710-1 is the right choice for most kinds of light measurement applications. Its short range dependent slew-rate allows the measurement of fast changing high power level signals. In the pulse energy mode the energy of single pulses > 20 ms in pulse length can be measured.
The P-9710-2 is required if the energy of a single pulse or pulse-chain of pulse lengths > 1 µs must be measured. The 20 ms slew-rate is independent of the gain range.
Other than the difference in pulse width measurement capability both versions offer the same functionality and technical qualities.



P-9710-1 / P-9710-2 Applications

Features like multiple functional modes, bench-top laboratory level specs and calibration data connector for error-free detector interchange make the P-9710 the right instrument for many field-service, laboratory and process applications. To complete the system, one or more of GO's wide range of photometric and radiometric detectors must be selected for use with the P-9710.

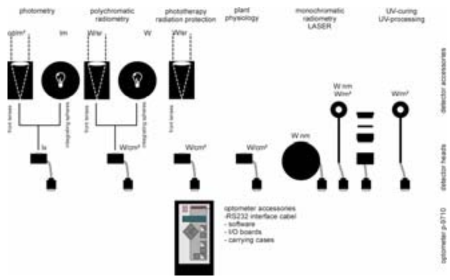
Our **Light Measurement Guide** ,available in our catalog and on our website, offers additional tutorials and application notes relating to the Measurement of Light and Measurement with Light.

Illuminance and Luminance Photometer

Because of it's wide dynamic range the P-9710 is suitable for high-level photometric applications. In combination with the VL-3701-2 detector, illuminance levels from 100 mlx (1 mlx resolution) to 1,000 klx can be measured. The LDM-9810-2 luminance detector head extends the application range of the P-9710. It's three selectable viewing angles of 20', 1° and 6° plus it's brilliant ocular view allow the precise location of the measurement area of interest. Both detector heads offer a low CIE standard V(Lambda) photometric matching uncertainty f_1' equal to or less than 3% (DIN Class A).

Universal Light Meter

The P-9710's calibration data connector ensures that you never have to remember to up-date the meter set-up when changing detector heads. This feature becomes very important if the P-9710 is to be used in multiple applications involving different detector heads. With so many modes of operation available, this is often the case. The P-9710 is the right choice when maximum versatility is a requirement.



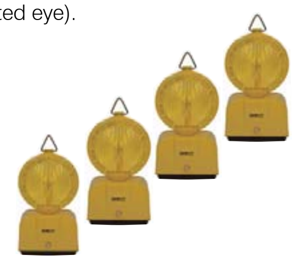
UV-Hazard Meter

The adverse effects of overexposure to incoherent optical radiation on skin and eye is being afforded increasing attention. The reasons can be attributed to rising ultraviolet levels in sunlight and the widespread use of high powered lamps in light therapy, cosmetics, UV curing, UV surface inspection, UV sterilization and others. A growing number of regulations exist describing how to measure, assess and classify light sources according to potential UV hazard. Typical spectral weighting functions for the acutely harmful effects of optical radiation are ACGIH, Erythema and Blue-Light Hazard.

The flexible P-9710 with the UV-3704-2 (erythema), UV-3708-2 (ACGIH) irradiance detectors and the LDM-9811 (Blue-Light Hazard, Retinal thermal hazard) radiance detector offer all required functional modes and features for accurate UV hazard measurement.

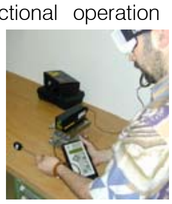
Effective Luminous Intensity Meter

To increase the intensity of light sources with limited average power they are used in flash mode which allows much higher peak powers than in CW mode. If the light flash is used for increased visual acuity, the flash peak power and the CW peak power do not show a linear correlation. Because of this evaluation of the effective intensity of pulsed light signals is done according to the Schmidt-Clausen method using with two different time constants C for daylight observation (0.1 s for light adapted eye) and night time observation (0.2 s for dark adapted eye).



Laser Stray-Light Meter

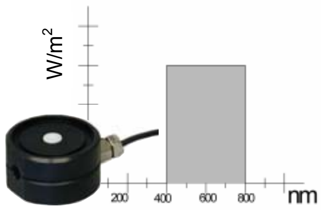
Laser are very useful tools in many measurement and production applications due to the attributes of high power, monochromatic and directional beam radiation. But laser radiation is also a health risk to the human eye. Laser stray-light (indirect or scattered) may even be a risk due to these high power levels. Standard EN 60825-1/11.01 describes these risks and measurements for hazard classification. The common tool used to measure laser stray-light employs detectors such us the LP-9901 with a 7 mm dia. free aperture which mimics the open pupil. The functional operation modes of P-9710 such as peak hold, data-logger & pulse energy support these measurement



VIS-NIR Radiometer / Pyrometer

Radiometric measurements, such as irradiance (W/m²), in the visible and near infrared part of the optical radiation spectrum are getting more attention since more VIS & NIR sources are being used in sensor, photomedicine, photocuring and other applications.

Gigahertz-Optik offers different types of detector heads for use with the P-9710 for irradiance measurements in the visible (400 to 800 nm), VIS/NIR (400-1100 nm), NIR/IR (800-1800 nm) including specific spectral ranges within the 400 to 1800 nm region.



Radiant Power and Laser Power Meter

Light sources with diverging (non collimated) beams such as LED's, laser diodes & dispersed laser beams measured with flat surface photodiodes may cause high measurement uncertainties due to differing incident angles and polarization. The re-reflected light from the detector surface can cause additional problems by interference effects in the cavities of laser diodes. To avoid these problems power detectors mounted to integrating spheres are recommended. Gigahertz-Optik offers sphere based detectors from 8 to 500 mm diameter for use with the P-9710.

Flash Energy Meter

Short pulse length flash lamps, normally associated with photographic strobes, are also used in ophthalmology and UV-curing processes. Measurement of the energy in a single light flash or in a pulse train of light flashes is typically done using light meters that store the detected signal in a capacitive circuit. In applications with very different pulse energy levels, common to light measurement, these meters are not very linear and difficult to calibrate. The P-9710 performs flash measurements using the extended pulse sampling method (EPSM) offering higher linearity for flashes ≥ 1μs. Calibration with DC calibration source standards ensure much lower calibration uncertainties.

Plant Physiology Meter >> Section Tutorials

UV Curing Meter >> Section Tutorials

LED Luminous Flux Meter >> Section Tutorials

Power Meter for Telecom Application >> Section Tutorials

LED Luminous Intensity Meter >> Section Tutorials

Detector Heads for use with P-9710 >> Section Light Detectors

P-9710-1 & -2, Operation Function Modes & Specifications

Operation Modes:

Because of it's unique electronic design and it's powerful microprocessor the P-9710 optometer is more than just a simple instrument for light intensity readings. Sixteen different modes of operation (functions) in combination with variable measurement parameter set-up capabilities makes the P-9710 one of the most flexible and powerful meters available. It can be found in both manual and remote control use in process control, long-term stability monitoring, service, teaching and R&D applications. This page shows the currently available functions and specifications. Custom design for user specified functions is available .

CW Measurement

CW mode is used to measure continuous DC or AC signals at the selected integration time from 100 μs to 6 s. The reading, units of measurement and the selected wavelength as applicable for the connected detector are displayed on the LCD. Manual or auto-range operation as selected.

CW Offset

A constant offset value, such as an ambient light level, can be entered for subtraction from the CW measured value.

CW Minimum or CW Maximum

Min. or max. value attained during the measurement period is displayed along with the current reading. during a measurement period (deleted by pressing 'reset' button).

Peak Minimum or Maximum, Peak to Peak

These modes allow analysis of signal stability within the selected integration interval (e.g. flicker of light sources). The min., max. or p-p values are displayed together with the CW average value. Only signals longer that the gain dependent slew-rate (see table below) can be measured.

I-Effective

Evaluation of the effective luminous intensity of a single light flash according to the Schmidt-Clausen method. The measurement is manually started by pressing the 'run' button. The integration time is selected in the 'set-up/pulse measurement time' menu function. The time constant C for daylight (0.1 s) and night time observation (0.2 s) can be selected in the 'set-up/IF time constant' menu function.

Pulse Energy

Energy measurement of a single pulse or a series of pulses within a selected measurement time. The measurement time is selected in the 'set-up/pulse measurement time' menu function. Pressing the 'run' button starts the measurement . In auto-range mode 'UL/ OL' (under/over-load) is displayed if a gain change is necessary.

Pulse Offset

A pre-set offset value, such as an ambient light level, can be subtracted from the I-Effective and Pulse Energy reading. 'Static Offset' subtracts a constant value. 'Continuous Offset' subtracts the actual measured value before the pulse measurement is started. Subtraction selection is made in 'pulse offset' menu.

Ratio relative (%), log. (dB), factor

Measurement of the ratio between a reference value and the actual measured value. Displayed as relative ratio (%) or logarithm ratio/attenuation (dB or dBm) or ratio factor.

Reference

The reference value is used for ratio measurements (see Ratio function). The ref. value can be set to 1 with the selected unit such as 1 W, 1 A.
A CW measurement value can be stored as reference value.
A manually entered value can be used as reference.
The reference value '1.000 mW' can be used to measure attenuation in dBm.

Hold

Beside the actual measurement value a current reading can be 'frozen' by pressing 'reset' button.

CW Level Check

Compares the measured CW value with stored pre-set lower and upper limit values. The actual measurement value and it's status is displayed. The limit values can be entered manually or via the RS232. The relay board P-9710Z-02 can be remote controlled to indicate the status by external lamps or integrate the meter in process control application.

Dose (Integrated Energy)

Measurement values are accumulated at a logging rate of 1 s and displayed as dose. The measurement can be manually started and stopped or be automatically stopped at a preset max. dose measurement time (1 s to 1,000 h) or a max. dose value. The actual measurement status can be displayed.

Automatic Data Logger

Up to 12,288 measurement values can be stored with a sampling rate of 0.1 to 6000 s.

Manually Data Logger

Up to 150 individual data records (meas. values & parameters) can be stored by pressing the run button

Manual Calibration Data

Individual calibration correction data can be manually entered

Remote Control

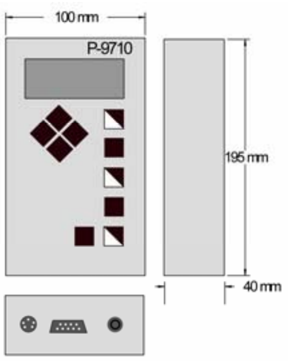
Instrument set-up for remote control operation via RS232

Default Initiation

Resets all parameters to the default condition

Specifications:

Dimensions:



Range and Uncertainty Specifications					
Range (A/V)	**Range max. signal**	**Slew-Rate (10-90%) P-9710-1 / -2**		**Error (with offset compensation) 1 year 23°C +/-5°C +/-(% of reading + % of range)**	**Gain (A/V) Analog Output**
P-9710-1 & P-9710-2		P-9710-1	P-9710-2	P-9710-1 & P-9710-2	
1 x 10^{-3}	2.000 mA	2 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-3}
1 x 10^{-4}	200.0 µA	2 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-3}
1 x 10^{-5}	20.00 µA	3 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-5}
1 x 10^{-6}	2.000 µA	3 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-5}
1 x 10^{-7}	200.0 nA	4 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-7}
1 x 10^{-8}	20.00 nA	4 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-7}
1 x 10^{-9}	2.000 nA	10 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-9}
1 x 10^{-10}	200.0 pA	10 ms	20 ms	0.2 % + 0.05 %	1 x 10^{-9}

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P-9710-1 & P-9710-2, Specification & Ordering Information

Specification:

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 8 decade stepped gain ranges with max. gain signal values from 2.000 mA to 200.0 pA . Manual or automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 100 μs time interval. Longer integration (100 μs to 6s) through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz (6s integration time setting) to >300 MHz. .
Zero Setting	Gain independent offset subtraction of unwanted ambient light signal.
Detector Connector	9 pin DSUB-socket . Detector heads with calibration data connector (type –2).

Function	
Parameter Settings	Menu controlled parameter set-up. Retention of the last settings in continuous memory. 10 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display absolute photometric or radiometric quantities. Calibration data stored in calibration data connector of the detector heads manually entered into the meter storage.
Dose Measurement	Integration of the measurement signal with 1 s sampling rate. Adjustable max. measurement time from 1 s to 1000 h. Adjustable maximum dose limit value. Current status display function.
Data Logger	Storage of up to 12,288 readings. Adjustable sampling rate from 0.1 to 6000 seconds. Manual recording mode. Display of readings stored in the flash Eproms on the display or on computer using the RS232 interface and software.
Analog Output	Gain dependent: 0 - 200 mV or 0 - 2 V (10 kΩ internal resistance). Integrated into RS232 connector.

General	
Display	2 x 16 character LCD with switch-able LED backlight.
Operating Temperature	5 to 40°C (41 to 104°F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122°F).
Dimensions/Weight	195 x 100 x 40 mm / 500 g (7.7 x 3.9 x 1.6 in /1.1 lb).
Serial Port Settings	RS232 (9600 baud, 8 data bits, 1 stop bit, no parity) 5 pin cylindrical TRIAD01 connector..
Power supply	Battery or AC operation. Built-in rechargeable lead battery, 6V,0.5 Ah. Approx 6 h with display illumination. Battery charge under 8 % is displayed. Operation from AC plug-in power supply 230V/50 Hz (other values on request) with specific U/I recharge characteristic.

Interface	
RS232	9600 Baud, 8 data bit, 1 stop bit, no parity. TRIAD01 / 5 pin connector with integrated analogue output.

Detector Head / Measurement Output	
Detector Heads	All available detector heads with –2 type calibration data connector. See chapter 'detector heads' to select the detector head for your application.
Data Connector	Storage of sensor data such as detector model number, serial number, calibration data . Calibration data of integral sensitivity or spectral sensitivity with or without accessory. Selection of the calibration data or the wavelength in the menu function of the P-9710. Automatic data transfer if detector head is connected to the meter.

Ordering Information	
P-9710-1	Optometer with gain dependent slew-rate, rechargeable battery with plug-in power supply and manual
P-9710-2	Optometer with gain independent slew-rate, rechargeable battery with plug-in power supply and manual
Detector Heads	All Gigahertz-Optik detector heads with –2 type calibration data connctor (example VL-3701-2)
P-9710Z-01	RS232 Interface Cable to connect P-9710 to a PC (9 pin serial connector) or P-9710Z-02 Relay Motherboard
P-9710Z-02	Relay Motherboard (power supply and housing not supplied)
P-9710Z-03	PCI I/O Interface Card
P-9710Z-04	Plug for the RS232/analog-output signal socket of the P-9710 optometer
P-9710Z-1/2	Adapter cable to connect detector with BNC-type connectors to P-9710
P-9710Z-2/1	Adapter cable to connect detector with calibration data connector (-2) to meters with BNC-type socket input
OS-P9710	Software for remote control of the P-9710-1, including OS-CAL.
OS-CAL	Software to enter calibration data via the P-9710 meter into –2 type data connector
BHO-01	Hard-shell Case for P-9701 with detector heads and accessories
BHO-02	Hard -shell Case for P-9710 with LDM-98xx detector head and accessories
BHO-08	Hard -shell Case 450x320x150 mm/17,7x12,5x5,9 in; (length x width x height) for individual use with P-9710 and accessories
BHO-09	Hard -shell Case 350x260x120 mm/13,7x10,2x4,7 in; (length x width x height) for individual use with P-9710 and accessories

X1$_1$ 4-Channel Hand-held Optometer

- © **Hand-held Four-Channel Meter for Field Service and Laboratory Use**
- © **Universal Use in any Light, Light Color and Radiation Measurement Application**
- © **Measurement of DC and AC Signals**
- © **Signal Range from 0.1 pA to 20 µA or 1 pA to 200 µA with 6 Gain Ranges**
- © **1 ms bis 1 s Sampling Rate**
- © **Adjustable Integration Time from 1 ms to 1s**
- © **CW, Dose and Color Operation Modes**
- © **USB Interface for Remote Control Operation**
- © **Battery & AC Operation (via USB)**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

The **X1$_1$** (Xone-one) optometer is one of the most versatile hand-held light measurement instruments available.
It combines a powerful electronic design packaged in a light-weight ergonomic housing. It's compact size makes it ideal for field service applications. However, it's other unique features like a USB interface and multi-application capability with an excellent price-quality-ratio qualify it as a laboratory grade instrument as well.

Four Input Channels:
A unique feature of the X1$_1$ is it's capability to operate detector

X1$_1$ with XD-9506 dual channel ACGIH Skin detector head

heads with up to 4 sensors. All 4 signals or combinations of them are shown on it's four line display with on/off backlighting.

Multi-application Capability:
The flexibility to combine the X1$_1$ with all Gigahertz-Optik detector heads enable it to be used in a

CT-4501 color & illuminance detector with luminance accessory

wide application range of radiometric, photometric and colorimetric measurements.

Multiple Detector Meter:
When more than one detector head is used with the X1$_1$ meter simple and faultless selection of the calibration data is accomplished from the menu mode.

Precise Measurements:
The X1$_1$ offers a high linearity 12-bit ADC input with 6 manually or automatically selected gain ranges. The max. error within this wide dynamic range is 0.2 %.
The amplifier is connected to the four signal inputs by an electronic switch.

Two Versions:

X1$_1$ with XD-9502 & XD-9506 detector for UV-A/white light ratio and ACGIH Skin protection measurements of UV sources for NDT testing of surface cracks.

The X1$_1$ is available in two versions for low or high signal applications.

- **X1$_1$–LS** up to 20 µA with 0.1 pA max. resolution
- **X1$_1$-HS** up to 200 µA with 1.0 pA max. resolution

Both versions feature a short slew-rate of typically 3 ms, a max. sampling rate of 1 ms and an adjustable integration time from 1 ms to 1 s.

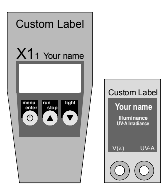
Simple Operation:
Operating the X1$_1$ is simple. Once it is set-up, all settings are stored and recalled on next power-up unless reprogrammed. Measurement values are displayed in absolute quantities for the particular detector connected. The meter set-up is supported by an easy to use menu. The menu allows selection of the operating mode, the detector and measurement parameter.

Functions:
The X1$_1$ offers a **CW mode** for DC or AC signals plus dose, color and remote control operation. In **dose mode** a measurement time of up to 256 hours can be selected.
In **color mode** with the CT-4501 detector, x,y chromaticity coordinates, color temperature and illuminance are measured. Additional accessories can be attached for the measurement of luminance, luminous flux and luminous intensity.
A USB interface allows **remote**

control operation of the meter (DLL file supplied).

Battery and AC Operation:
For on-site applications the X1$_1$ is operated by two standard 1.5 V AA batteries for a life-time of up to 500 hours.
In remote control operation the meter is powered through the USB bus for time and battery independent use.

Custom Label & Instrument:
The X1$_1$ can also be custom labeled and/or detectors designed to individual customer specifications. Contact the factory for more information.



Gigahertz-Optik

X11 Applications

Because of it's multiple function capabilities, high level specs and compact size the X11 is the right instrument for many field-service, laboratory and quality control applications.
In combination with Gigahertz-Optik's wide range of detector heads the X11 can be used for photometric, radiometric and colorimetric measurements.
The following pages offer typical X11 application's.
Our **Light Measurement Guide** , shown in our catalog and website offers additional tutorials and application notes dealing with the Measurement of Light and Measurement with Light.

Precise Illuminance & Luminance Meter with USB Interface

Facilities that integrate daylight into their lighting strategy need to check and monitor the lighting design over time. An efficient tool for long term data logging is a laptop computer with a USB interface remote controlled instrument.
The X11 with VL-3704 & LDM-

9801 detector heads form a DIN Quality Class B qualified illuminance and luminance meter with a USB interface. Along with the photometric detectors other detectors for light color, UV, VIS, and NIR can be combined with the X1 1.

UV Hazard (DGZfP-Merkblatt EM6) & Contrast (DIN EN 1956, ASTM and MIL Standard) Qualification of UV Radiation Sources used in Nondestructive Testing for Surface Defects

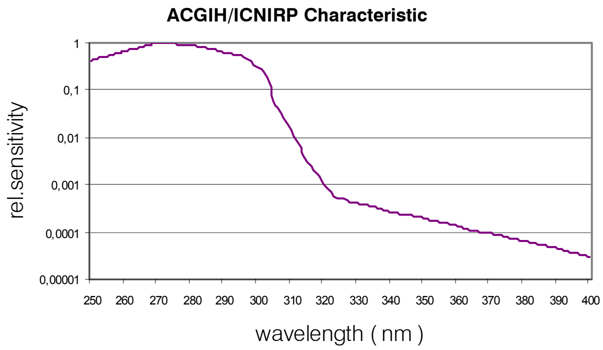
UV radiation sources are used to stimulate fluorescence in the **Liquid Penetration Method,** used in NDT to detect surface cracks in nonporous materials.
The ideal emission spectrum of these sources is high intensity UV-A radiation with no white light and very low levels of shorter wave UV-B and UV-C.
White light reduces the contrast of the fluorescence emitted from the defect while UV-C and UV-B radiation increase the risk for skin and eye damage. Any spectral leakage of the deeper UV and white light blocking filters used with these lamps due to age and use create two risks:

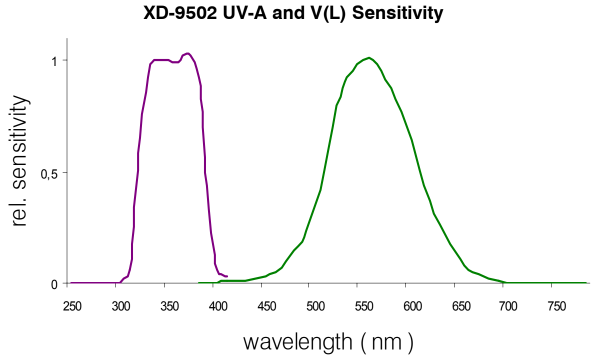
1. reduced contrast between fluorescence and background
2. increased UV hazard risk for operators skin and eye

Consequently periodical measurement of the UV sources with respect to UV hazard and contrast is needed.

Contrast Measurement:
DIN EN 1956, ASTM and MIL Standards exist that describe the general conditions and standard practices for the test examinations, including the procedures to be followed. The minimum requirements for the illumination or irradiation conditions, test procedures to be used for checking the specified levels and suitable measurement equipment specifications are also covered.
The XD-9502 detector head is a great choice for the contrast measurement. A precise illuminance detector with a f1' photopic error of less than 6 % and a solar blind UV-A detector are combined in one housing for quick and simple measurements. Both sensors are traceably calibrated to the ISO EN 17025 accredited part of Gigahertz-Optik's calibration laboratory for optical radiation measurement quantities.

UV Hazard Measurement:
The assessment of UV radiation under the aspect of UV hazard is the subject of the new **DGZfP-Merkblatt EM6** regulation. EM6 specifies that all UV sources used in fluorescence penetrant test applications must be classified and regularly tested. The protective measures taken for the operators depend on the safety classification.
The classification criteria are the UV hazard effective irradiation E_{eff} based on the ACGIH/ICNIRP (*American Conference of Governmental Industrial Hygienists / International Commission on Non-Ionizing Radiation Protection)* regulation. In stationary testers EM6 states a potential risk to the skin only, because of built-in eye protection devices. The risk to the eye due to stray light is low because of its diffuse character.





The XD-9506 detector head is designed with two sensors (ACGIH-UV-B/C 250 to 325 nm and ACGIH-UV-A_{skin} 325 to 400 nm) to avoid any cross-talk between UV-A & UV-B/UV-C radiation. This cross-talk is a typical problem for single channel detectors when measuring UV-A rich sources.
The X11 is the right meter for both applications. In combination with the XD-9506 it displays the UV-A and UV-B effective irradiance as well as the total ACGIH effective irradiance.

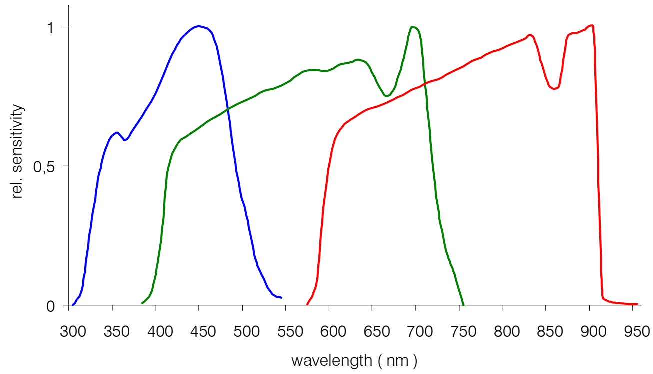
Light Color Meter

All Gigahertz-Optik optometers are characterized by their universal nature in photometric and radiometric measurement applications. The X11 offers the additional capability of performing colorimetric measurements of light sources as well.
Combined with the CT- 4501 detector head the X11 not only measures the x,y chromaticity values but also color temperature and illuminance in lx or fc (luminance, luminous intensity and luminous flux with attachments).
The CT-4501 is a precision 4-cell color detector which offers a full X_{short}, X_{long}, Y and Z spectral characteristic allowing the measurement of blue-enhanced light sources and tube lamps with low measurement uncertainty.
The low profile detector height of only 20 mm qualifies it for ANSI Lumen measurements.

X1$_1$ Applications & Operation Modes

Triple PAR Meter

Photosynthesis is one of the most important biochemical processes on the planet. In the process of photosynthesis green plants absorb carbon dioxide from the atmosphere and water from the soil, combining them with the aid of radiation energy to build sugar, releasing oxygen and water into the atmosphere.
To understand and control the interrelation of optical radiation and plants precise and predictable measurement is needed.
Most commercially available instruments measure the photosynthetic active radiation PAR, which covers the visible part of the optical spectrum from 400 to 700 nm. But optical radiation outside the visible spectrum also effects plant growth. To cover this entire spectral range of interest Gigahertz-Optik offers the TP-4501 "Triple PAR" detector head which includes one PAR sensor plus one sensor each for the shorter, 320 to 500 nm, and longer wavelength range from 590 to 900 nm. A fourth illuminance cell allows comparison of light intensity to the human eye response. The X1$_1$ optometer displays all four values at once. Dose measurement over a setable time period of up to 100 hours is possible.



Universal Meter for Photometry, Radiometry and Colorimetry

Light is everywhere and many companies are involved in making light or using it. Typical examples are light source manufacturers including traffic lights, endoscopes and light guides.
The best known measurement quantity used to qualify light is illuminance measured in lx or fc. But in today's situation where the color and color temperature of light are qualifying characteristics, where the luminance contrast on monitors in medical diagnostic applications needs to be regularly qualified, where intense light sources create potential risk for UV and blue-light hazard, simple lightmeters no longer do the job.
The X1$_1$ with all its available detector heads and accessories is the right answer for all who need to measure more than simply light intensity.

X1$_1$ Light Meter:
Combined with a VL-3704 & LDM-9901 detector head, spectrum independent light source measurements of illuminance & luminance can be precisely accomplished.

X1$_1$ Light & Light Color Meter:
Together with the CT-4501 detector head the X1$_1$ measures x,y chromaticity values, color temperature and illuminance. The 4-cell detector head technology ensures low measurement uncertainty in most situations.
Combined and calibrated with an integrating sphere the X1$_1$ allows the measurement of luminous flux & light color parameters.

X1$_1$ UV Hazard Meter:
Gigahertz Optik offers detector heads for UV-A, UV-B, UV-C, blue-light hazard, ACGIH and Erythema measurements.

X1$_1$ Universal Meter:
All applications described and several more based on GO's wide variety of detector heads and accessories require only one X1$_1$ optometer.

Functions:

The X1$_1$ optometer offers several modes of operation fulfilling it's multipurpose use capability.
Because of it's ability to operate detector heads with up to four cells, the X1$_1$ is the right meter for all Gigahertz-Optik multi-cell detectors. Not only does the meter work for single value display functions, special operational modes when in use with the CT-4501 tristimulus color detector head and the 2-cell ACGIH$_{skin}$ detector head XD-9506 are included. The USB mode enables the X1$_1$ to be used in data logger and full remote control operations.
All available functions at the time of printing this catalog are described. If you do not see a feature or function you require or if custom labeling of the X1$_1$ based on a specific application is of interest, please contact the factory to discuss our custom design services.

CW Measurement

CW mode is used to measure continuous DC or AC signals at the selected integration time from 1 ms to 1s. Both the measurement value and the measurement quantity is displayed.
For multi-cell detector heads the readings and units of each cell are displayed on a single line.
Selectable manual and auto-ranging operation.

Dose Measurement (Integrated Energy)

Measurement values are accumulated with a logger rate of 1 s and displayed as dose. The measurement can be manually started and stopped or be automatically stopped at a pre-set max. dose measurement time (1 s to 256 h).

Light Color Measurement (with CT-4501)

Combined with the CT- 4501 detector head, the X1$_1$ measures x,y or u'/v' chromaticity values, color temperature and illuminance in lux or foot-candles.
With accessory attachments and additional calibrations, measurement of luminance (front lens), luminous flux (integrating sphere) and luminous intensity (calibration at a given distance) is possible.
The chromaticity color values, color temperature and the light intensity of the accessory dependent measurement quantity are all simultaneously displayed.

ACGIH$_{skin}$ Irradiance Measurement (XD-9506)

Assessment of UV radiation sources characterized as 'UV-A rich' requires 2-cell detector head technology as offered by the XD-9506. The ACGIH effective UV-A and UV-B+UV-C irradiance values are displayed together with the SUM signal which represents the effective ACGIH 'weighted' irradiance.

Detector Selection

The calibration data of all detector heads ordered with the X1$_1$ are stored in the meter's calibration data eeprom. The detector connected to the meter is simply selected in the menu mode and all associated calibration data is applied.

Accessory Selection

The calibration data of any accessory components ordered and calibrated with the detector heads are stored in the X1$_1$ meter's calibration data eeprom. The calibration data for the connected detector head /component combination are applied when selected in the menu mode.

Remote Control Operation

On X1$_1$ USB connection to a computer the meter will automatically activate itself for remote control operation via the USB interface. All meter buttons are de-activated.

Gigahertz-Optik

X1$_1$ Specifications & Ordering Information

Specifications X1$_1$ Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 6 decade stepped gain ranges with max. gain signal values from 20 μA to 200.0 pA (X1$_1$ LS) or 200 μA to 2.000 nA (X1$_1$ HS) model . Manual or automatic range switching. 12 bit ADC with up to 14 bit at longer integration times.
Signal Processing	A/D converter with 1 ms time interval. Longer integration (1 ms to 1 s) through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz (1s integration time setting) to >300 MHz
Zero Setting	Gain independent offset subtraction of unwanted ambient light signal
Detector Connector	9 pin MDSM9-socket (type –4)
Function	
Parameter Settings	Menu controlled parameter set-up. Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display measurement values in photometric, radiometric or colorimetric quantities. Calibration data stored in meter.
Dose Measurement	Adjustable max. measurement time from 1 s to 256 h.
General	
Display	LCD graphic display 97x32 pixel. Display size 14.3 mm x 35.8 mm. Switch able LED backlight. 4 display lines with each 14 characters.
Operating Temperature	10 to 40 °C (50 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F)
Dimensions/Weight	145 x 63 x 30 mm / 150 g (5.7 x 2.5 x 1.2 in / 0.33 lb)
USB Port Settings	USB HID
Power supply	2 x battery size AA (2.2 to 3.2 V); USB operation bus powered
Interface	
USB	HID
Detector Head / Measurement Output	
Detector Heads	All available detector heads with –4 type connector. See chapter 'detector heads' to select the detector head for your application.

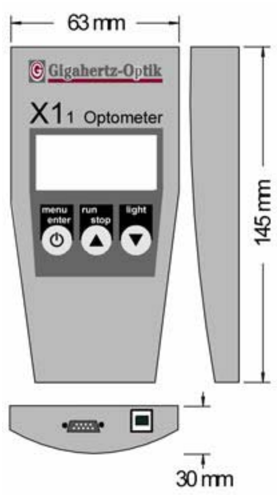
Range Specifications X1$_1$-LS

Range (A/V)	Range max.	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permissible Detector Capacitance
1x10-5	20.00 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-6	2.000 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-7	200.0 nA	3 ms	0.2 % + 0.05 %	10 nF
1x10-8	20.00 nA	3 ms	0.2 % + 0.05 %	10 nF
1x10-9	2.000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200.0 pA	30 ms	0.2 % + 0.05 %	10 nF

Range Specifications X1$_1$-HS

Range (A/V)	Range max.	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permissible Detector Capacitance
1x10-4	200.0 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-5	20.00 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-6	2.000 μA	3 ms	0.2 % + 0.05 %	10 nF
1x10-7	200.0 nA	3 ms	0.2 % + 0.05 %	10 nF
1x10-8	20.00 nA	3 ms	0.2 % + 0.05 %	10 nF
1x10-9	2.000 nA	3 ms	0.2 % + 0.05 %	10 nF

Dimension

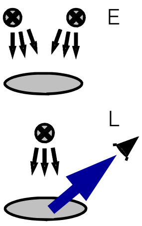


Ordering Information	
X1$_1$-LS	Optometer for low signal applications. –4 type connector. Including 2 x AA type batteries, USB DLL, USB cable and manual
X1$_1$-HS	Optometer for high signal applications. –4 type connector. Including 2 x AA type batteries, USB DLL, USB cable and manual
OS-X1	Software for remote control operation of the **X1$_1$**
BHO-01	Carrying case for X1$_1$ with 37-type detectors and one LDM-9901 detector
BHO-04	Carrying case for X1$_1$ with 37-type detectors and accessory
BHO-05	Carrying case for X1$_1$ with RCH-0xx and RCH-1xx type detectors
BHO-06	Carrying case for X1$_1$ with one CT-4501 or TP-4501 detector
Detector Heads	See chapter 'detector heads' to select the detector and detector accessories for your application

X9$_1$ Hand-held Light Meter

- © **Illuminance Range: 0.5 to 199.999 lx with 0.01 lx resolution**
- © **Luminance Range: 2.5 to 199.999 cd/m² with 0.05 cd/m² resolution**
- © **Precise Photometric Matching Detectors**
- © **DIN Class B Parameters**
- © **Compact Size & Ergonomic Design for Mobile Use**
- © **Large Size Display**
- © **High Reliability**
- © **Economical Price**
- © **Battery Operation**
- © **RS232 Interface**
- © **OEM Labeling**

Light Measurement
The most common methods for qualifying light intensity are measuring illuminance in lux or foot-candles and luminance in cd/m² or foot-lamberts. **Illuminance E**, in lx or fc describes the luminous flux per unit area falling on a surface. **Luminance L,** measured in cd/m² or fL describes the brightness of an illuminant or illuminated area.

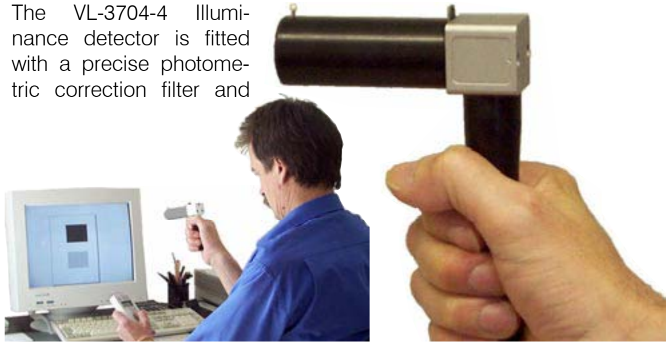


Light meters with illuminance and luminance detectors are the traditional instruments used in most lighting applications.
The wide variety of light sources available today creates problems for light meters calibrated specifically for use with tungsten lamps. Illumination generated by tube lamps with mercury line spectra must also be measured as well as the luminance contrast of monitors used in medical diagnostics for example. For this reason current DIN and EN regulations specify that light meters must have a maximum permissible error f_{tot} of ±10%. According to DIN-5032 Part 7 these are regarded as DIN class B instruments. This quality designation is necessary because class C instruments – incidentally many photometers on the market are not certified at all – that are used to measure different types of light sources such as standard illuminant A incandescent lamps, would yield large uncertainties of measurement.

X9 1 Comparison to DIN 5032 Class Limits (%)		Illuminance		Luminance	
Characteristics	Symbol	X9$_1$	DIN	X9$_1$	DIN
Calibration Uncertainty	U_{kal}	1.1	3	1.5	4
V(λ) Match	f_1	5	6	5	6
UV Response	u	0.01	2	0.01	2
IR Response	r	0.01	2	0.01	2
Directional Response	f_2	3	3	-	-
Linearity	f_3	0.2	2	0.2	2
Display Unit	f_4	0.1	4.5	0.1	3
Fatigue (at 1 klx)	f_5	0.1	1	0.1	1
Temperature Dependence	f_6	1	10	1	10
Modulated Light	f_7	0.1	0.5	0.1	0.5
Range Change	f_{11}	0.2	1	0.2	1

X9$_1$ Light Meter
Besides it's precision measurement capability the X9$_1$'s ('Xnineone') most outstanding feature is its easy handling. The LCD characters are 9 mm high for easy viewing. The compact X9$_1$ is handheld and battery operated. As part of the X9 family it offers a moderate price-performance ratio. This makes it the ideal light measurement tool for safety engineers, service technicians, lighting designers, ISO-certificated companies or anyone who's measured results are subject to audit.

X9$_1$ Illuminance Meter:
The VL-3704-4 Illuminance detector is fitted with a precise photometric correction filter and cosine diffuser. Its short height of only 20 mm allows measurement close to the reference level.



X9$_1$ Luminance Meter:
The LDM-9901-4 Luminance detector offers a field of view of 1° and a measurement range from 40 cm to infinity. To target the object to be measured, the LDM-9901 has notch and bead sight, which has marks for close-range and distance work.

Custom Labeling:
All meters in the X9 family are ready for customization including front panel, modes & detectors. Contact the factory for details.

Operation
The X9$_1$ is simple to operate. To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Peak Hold Measurement
Peak Hold mode is used to search for "hot-spot" light intensity. The peak reading is frozen on the display.

Gigahertz-Optik

X91 Specifications& Ordering Information

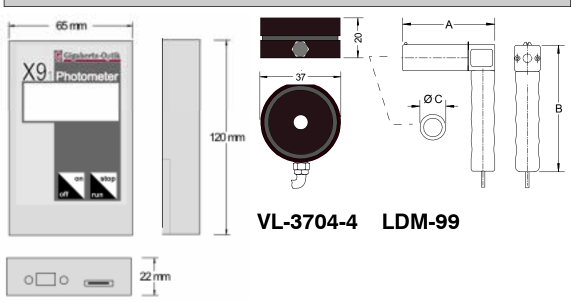
Specifications: X91 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket . Connected detector identification if meter switched ON (VL-3704-4 and LDM-9901-4 only).

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 %* + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 %* + 0.05 %	10 nF

Dimension:



Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display illuminance in lx and luminance in cd/m². Measurement quantity shown in display. Calibration data stored in calibration storage of the meter.
Peak Hold Measurement	Peak measurement value frozen in display. Erased with reset button. Peak mode indicate in display.

General	
Display	6 character LCD. Character height 9 mm. Indication of measurement quantities lx and cd/m², battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

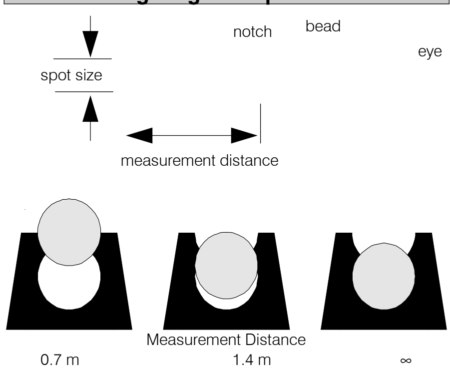
Specification: X91 with VL-3704-4 Illuminance Detector Head	
Typ. Measurement Range	0.5 to 999.999 lx (S/N ratio = 50)
Max. Resolution	0.01 lx
Detector Dimensions	Dia. 37 mm dia.. Height 20 mm; Cos. diffuser dia. 7 mm; Cable length 2 m
Calibration	lx or fc, Factory cal certificate

Specifications: X91 with LD-9901-4 Luminance Detector Head	
Typ. Measurement Range	2.5 to 999.999 cd/m² (S/N ratio = 50)
Max. Resolution	0.05 cd/m²
Field of view	1.1°,
Measurement Distance	0.4 m to infinity
Detector Dimensions	lens diameter 22 mm; Cable length 1 m
Calibration	Cd/m². Factory cal. certificate

LDM-9901

Distance (m)	Spot dia. (mm)
0.5	≈ 31
0.7	≈ 35
1	≈ 41
3	≈ 81
5	≈ 120
10	≈ 220
50	≈ 1000
100	≈ 2000

LDM-9901 Sighting Principle



Ordering Information	
X9 1	Light Meter lx & cd/m² without detector heads. Incl. handbook and battery. Detector calibration data stored in memory
X9 1 US	Light Meter fc & cd/m² without detector heads. Incl. handbook and battery. Detector calibration data stored in memory
VL-3704-4	Illuminance detector. Calibration certificate. ITT-type connector
LDM-9901-4	Luminance detector. Calibration certificate. ITT-type connector
VL-37Z-01	Stand/holder for VL37xx detectors. With bubble and three height adjustable feet. Required to mount detectors to tripods.
VL-37Z-02	Tripod with max. 125 cm height. Without detector mount VL-37Z-01.
LDM-99Z-01	Adapter plate with bubble level to mount and align the LDM-9901luminance detector onto standard tripods.
LDM-99Z-02	Ambient light shade made by elastic rubber to place the LDM-99 direct on the monitor face.
X9Z-01	RS232 interface cable to connect the X9 meters with 9 PIN SUB-D PC standard socket.
X9Z-02	External power unit for the X9 meters including meter modification (cancels battery operation)
BHO-04	Hard case to carry and store the X9 1 with one VL-3704 and LDM-9901

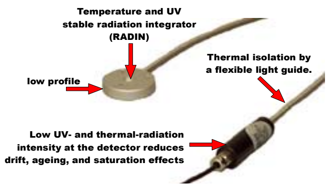
X9₂ Hand-held UV Curing Irradiance Meter

- © **Hand Held Single Channel Irradiance Meter**
- © **Signal Range 0.1 mW/cm^2 to 40.000 mW/cm^2**
- © **UV-A, BLUE and Broadband UV Spectral Responses**
- © **Low Profile - 8 mm High - Flexible and Rigid Detector Heads**
- © **High Operating Temperature to 100 °C**
- © **Cosine Corrected Field of View**
- © **Power Density Measurement Mode with Snapshot Hold Function**
- © **Dose Measurement Mode**
- © **Easy to Use**
- © **ISO/IEC/EN 17025 Traceable Calibration**
- © **RS232 Interface**

UV Radiation Intensity
UV curing is a process in which photocureable chemicals applied to substrates are irradiated with high energy UV or Visible radiation for curing. This energy accelerates polymerization (cross-linking) and consequently the hardening or drying process.
The irradiated energy needs to be controlled, since too low a dose will not cure the product, whereas too high a dose may damage or dry-out the surface layer of glues.
UV curing technology is used in the manufacturing process of many products we use everyday. Some examples are CD's, wood and tile flooring, magazine covers and inks on cans & other packaging.
Within the context of "Total Quality Management" it is appropriate to regularly check the proportion of radiation from UV sources that effects the polymerization process. The intense UV radiation generated by these sources combined in some cases with high heat levels, can lead to rapid degradation and large drift factors in conventionally constructed UV measurement devices. Unreliable process control measurements can result.

X9₂ Meter
Besides it's precision measurement capability the X9₂ ('Xninetwo') meter's most outstanding feature is its easy handling. To measure, the user simply switches on the meter and selects either the CW (W/cm^2) or Dose (J/cm^2) mode. The LCD characters are 9 mm high for easy viewing. The X9₂ is a compact handheld battery operated instrument.

Large Dynamic Range:
A novel detector design in combination with 7 decade linear electronics allows the X9₂ to offer a wide measurement range from 5 to 40.000 mW/cm^2 with 0.1 mW/cm^2 resolution!



Direct intense ultraviolet and heat radiation are absorbed and attenuated by a passive and therefore long term stable RADIN sensor element. The filter and photodiode, which are kept outside of the hot zone, only receive attenuated radiation passing through the RADIN at the end of the UV light guide.

The RCH-0 detectors with flexible light-guide are designed to measure in remote inaccessible locations

Two different style detectors (see chapter detector heads) are available:

RCH-0 Flexible Light-guide
The RCH-0 series heads are designed with a flexible 50 cm (20 in.) long light-guide protected by flexible stainless steel sheathing.

RCH-1 Rigid Light-guide
The RCH-1 series heads are designed with a rigid 22 cm (8.7 in.) light-guide protected by a rigid stainless steel tube.

Flood and Spot Sources:
A large dynamic range plus optional adapters allow the X92 to measure flood and spot sources. The low 8 mm (0.32 in.) height of the sensor element enables irradiance measurements very close to the target surface. A 9 mm dia. (0.35 in.) measurement aperture accepts adapters for LUMATEC*) 3, 5 and 8 mm dia. light-guides.

UVA, BLUE and UV Broadband Spectral Responses
Both detector models are available for different wavelength ranges corresponding to various photo-initiator and curing technologies.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.

Custom Labeling:
All meters in the X9 family are ready for custom design and labeling. Customization may include the meter front label, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for more details.

*) Lumatec-Deisenhofen Germany

Operation
The X9₂ is simple to operate. To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals.

Dose Measurement
Measurement values are accumulated at a logger rate of 1 s and displayed as a dose. The measurement is manually started and stopped.

Stop/Run Function
Current reading can be 'frozen' by pressing 'stop' button.

Gigahertz-Optik

X92 Specification & Ordering Information

Specification: X92 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket.

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 %* + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 %* + 0.05 %	10 nF

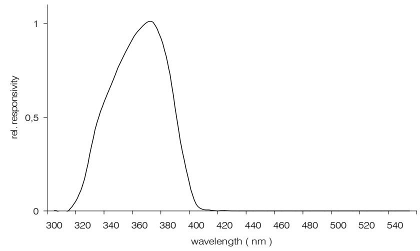
Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display irradiance in mW/cm^2. Calibration factors for full aperture and 3, 5 and 8 mm light guide adapters selected in menu mode. Calibration data stored in calibration storage of the meter.

General	
Display	6 character LCD. Character height 9 mm. Indication of measurement quantities lx and cd/m^2, battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

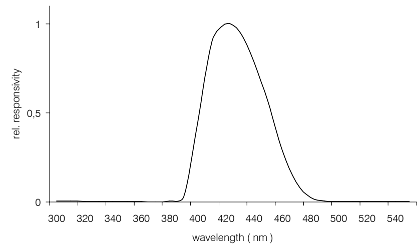
Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

Spectral Sensitivity:

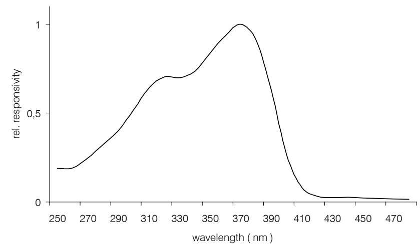
UVA (08)



BLUE (09)



Brodband UV (06)



Light Guide adapter

Light Guide Adapter Dimension (mm)				
Model:	Eff. size	d1	d2	h
RCH-Z-01	8 mm	10h7	9	10
RCH-Z-02	5 mm	7h7	6	10
RCH-Z-03	3 mm	5h7	4	10

X92 with RCH-0 or RCH-1 Detector Head:

UVA Detector	Max. irradiance	35,000 mW/cm^2	Max. resolution	0.1 mW/cm^2
BLUE Detector	Max. irradiance	35,000 mW/cm^2	Max. resolution	0.1 mW/cm^2
Broadband UV Detector	Max. irradiance	35,000 mW/cm^2	Max. resolution	0.1 mW/cm^2
RCH-0	Flexible light-guide.		Light-guide length	50 cm (20 in)
RCH-1	Rigid light-guide		Light-guide length	22 cm (8.6 in)
Temperature Range	RADIN Sensor	100 °C (212°F)	Detector	5-40°C (41 - 104°F)
Size	RADIN Sensor	8 mm x 37 mm ∅	Complete length	100 cm (39 in)

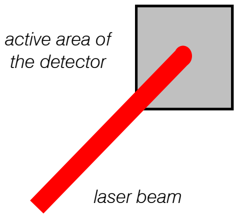
Ordering Information	
X9 2	Optometer with handbook and battery. Detector calibration data stored in memory
RCH-008-4	Low-profile UVA detector with flexible light-guide. Calibration certificate. ITT-type connector
RCH-009-4	Low-profile BLUE detector with flexible light-guide. Calibration certificate. ITT-type connector
RCH-006-4	Low-profile UV-broadband detector with flexible light-guide. Calibration certificate. ITT-type connector
RCH-108-4	Low-profile UVA detector with rigid light-guide. Calibration certificate. ITT-type connector
RCH-109-4	Low-profile BLUE detector with rigid light-guide. Calibration certificate. ITT-type connector
RCH-106-4	Low-profile UV-broadband detector with rigid light-guide. Calibration certificate. ITT-type connector
RCH-Z-01	8 mm type Lumatec Light-guide Adapter. Calibration data stored in meter memory
RCH-Z-02	5 mm type Lumatec Light-guide Adapter. Calibration data stored in meter memory
RCH-Z-03	3 mm type Lumatec Light-guide Adapter. Calibration data stored in meter memory
X9Z-01	RS232 interface cable to connect the X9 meter with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-05	Hard case to carry and store the X9 2 and one RCH-0 or one RCH-1 detector

X9$_3$ Hand-held Laser Power and Laser Stray-light Meter

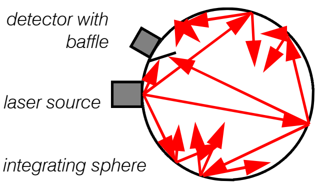
- © **Hand-held Single Channel Laser Power Meter**
- © **Low Profile Detector - 100 mW max.**
- © **Compact Integrating Sphere Detector - 500 mW max.**
- © **7 mm dia. Aperture Laser Stray-light Detector**
- © **Wavelength Range from 400 to 1100 nm**
- © **Simple Wavelength Selection**
- © **CW Snapshot Hold Function**
- © **Peak Hold Function**
- © **Economical Price**
- © **Battery Operation**
- © **RS232 Interface**

Laser Power Measurement
Lasers with low to medium power levels in the wavelength range from 400 to 1100 nm are well established in metrology applications. To quantify laser power three different measurement geometries exist.

Collimated Lasers
Lasers with quasi-parallel light bundles are typically measured using a flat-field detector with an active area larger than the laser beam diameter. There is some measurement error risk with flat field detectors due to polarization effects, re-reflection from the detector surface or windows and misalignment of the beam on the detector.



Non-collimated Lasers
Lasers with divergent light bundles (beams), such as laser diode array bars, are difficult to measure with a flat-field detector because of the different angles of incidence. The power output of these lasers is typically measured with detectors combined with an integrating sphere to collect all incoming radiation independent of the angle of



incidence.
Due to its unique design and the multiple reflections produced, integrating spheres offer:

- High attenuation permitting higher power measurements
- Reduction of polarization effects inaccuracies as found with flat-field detectors
- Flexibility with less aiming problems since sphere port diameter can be enlarged by increasing the sphere diameter to allow measurement of larger diameter beams

Laser Stray-light
Although very useful, laser radiation can pose a health risk to the human eye. Even stray-light from lasers may be hazardous due to the typically high power levels found. The EN 60825 standard describes the risk and measurement methods for risk classification. Laser stray-light can be assessed with the use of a detector head with a 7 mm dia. free aperture to mimic the open pupil.

X9$_3$ Meter
Besides it's precise measurement capability the X9$_3$ meter's most outstanding feature is its easy handling. To measure, the user simply switches on the meter and selects the wavelength corresponding to the laser wavelength. The LCD characters are 9 mm high for easy viewing. The X9$_3$ is a compact handheld battery operated instrument.

LP-9901 Flat Field Detector
A 7 mm diameter aperture makes this low profile design detector useful for laser power and laser stray-light measurement over a useful wavelength range from 400 to 1100 nm.
The wavelength dependent laser power measurement range is 1 μW to 100 mW with 0.02 resolution at 633 nm.
The wavelength dependent laser stray-light measurement range is 2.5 μW/cm^2 to 250 mW/cm^2 with 0.05 μW/cm^2 resolution at 633 nm.

LP-9910 Sphere Detector
With a free measurement aperture of 12.7 (0.5 in.) and an acceptance angle of +/- 45° this detector is well suited to measure collimated and non-collimated radiation beams from lasers, laser diodes, laser diodes with lens attachments and narrow beam diverging light emitting diodes. It's high precision Si-photodiode with a compact 50 mm diameter integrating sphere offers a useful wavelength range from 400 to 1100 nm with a power range from 0.5 W to 100 mW with 0.01 μW resolution at 633 nm.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.

Custom Label:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and applications assistance.

Operation
The X9$_3$ is simple to operate. To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals.

Power/Stray-light Meas.
Laser power in mW must be selected if the laser beam under fills the detectors area.
Laser stray-light in mW/cm^2 must be selected if the laser beam over fills the detectors area.

Auto/Manual Gain Ranging
Select manual ranging when the power range in production control applications stays at the same level to avoid time delays in auto-ranging mode.

Peak Hold Measurement
Peak Hold mode is used to search for “hot-spots” light intensities. The peak intensity measured is frozen on the display.

Stop/Run Function
Current reading can be ’frozen’ by pressing ’stop’ button.

Gigahertz-Optik

X93 Specifications & Ordering Information

Specifications: X93 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket .

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

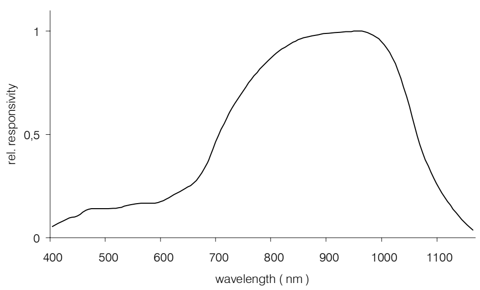
Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display the radiant power in mW or the irradiance in mW/cm^2. Calibration factors stored in meter.

General	
Display	6 character LCD. Character height 9 mm. Indication of appropriate measurement quantities, battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

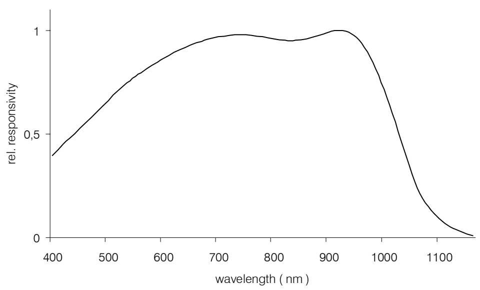
Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

X93 with Detector Head LP-9901 and LP-9910	
X93 with LP-9901-4	
typ. max. value*	30 mW at 900 nm, 100 mW at 633 nm
typ. max. resolution*	0.00002 mW*
wavelength range	400 – 1100 nm, calibrated in 10 nm increments
measurement aperture	7 mm diameter
dimensions	8 mm height, 37 mm diameter, handle length 100 mm
X93 with LP-9910-4	
typ. max. value*	100 mW*
typ. max. resolution*	0.00001 mW*
wavelength range	400 – 1100 nm, calibrated in 10 nm increments and additional laser wavelength**
measurement aperture	12.7 mm diameter
dimensions	50 mm sphere diameter
*) values may vary from unit to unit **) 441, 458, 473, 476, 488, 496, 514, 532, 543, 568, 594, 612, 633, 647, 1064 nm	

Spectral Sensitivity



LP-9901



LP-9910

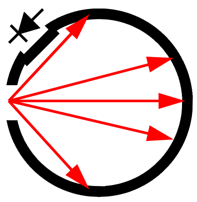
Ordering Information	
X9 3	Optometer with handbook and battery. Detector calibration data stored in memory
LP-9901-4	Low-profile detector head. Calibration in mW from 400-1100 nm in 10 nm increments and calculated irradiance in mW/cm^2. Calibration certificate. ITT-type connector
LP-9910-4	Integrating sphere detector head. Calibration in mW from 400-1100 nm in 10 nm increments. Calibration certificate. ITT-type connector
X9Z-01	RS232 interface cable to connect the X9 meter with 9 PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-05	Hard case to carry and store the X9 3 with one LP-9901-4

X9₄ Hand-held Radiant Power and Luminous Flux Meter

- © **Luminous Flux Meter for Spot Sources**
- © **Measurement Range: 0.0025 to 10.000 lm**
- © **Radiant Power Meter for Spot Sources**
- © **Measurement Range: 0.0005 to 1.000 mW**
- © **Beam Shape Independent Measurement**
- © **Compact Integrating Sphere with 12.5 mm dia. Measurement Aperture**
- © **CW Snapshot Hold Function**
- © **Easy to Use**
- © **Economical Price**
- © **Battery Operation**
- © **RS232 Interface**

Total Radiant Power
The total output of optical radiation emitted by a source is an important quantity for the determination of its efficiency. In many applications the intensity of that source is concentrated down to a spot. Typical examples are light emitting diodes (LED's), optical fiber bundles, endoscopes, spot lamps, etc. Since the beam is not really collimated, an integrating element is needed to collect the radiation emitted from many different directions.

Direction Independency
Integrating spheres measure the total intensity of optical radiation entering the sphere entrance port independent of the beam geometry.



Diffuse multiple reflections within the sphere's interior suppresses unwanted effects created by the angle of incidence like the formation of shadows, polarization, reflections or modes .

Photometry and Radiometry
The total emitted radiation of a light source can be measured in the radiometric quantity watts (W) or photometric quantity lumens (lm). The photometric quantity is used if the measurement values are to be compared to human visual impressions .

X9₄ Meter
Beside it's precise measurement capability the X9₄ meter's ("Xninefour") most outstanding feature is its easy handling. To measure, the user simply connects the detector and switches on the meter. The LCD characters are 9 mm high for easy viewing. The X9₄ is a compact hand-held battery operated instrument.

Integrating Sphere Detectors
Two different detector heads are available for use with the X9₄ for luminous flux and radiant power measurements. Both are based on the UP-50-L integrating sphere manufactured by Gigahertz-Optik. The hollow 50 mm diameter spheres are coated with barium sulfate. The mounted detectors are baffled to avoid direct irradiation from the light source under test. The measurement port aperture is 12.5 mm in diameter with an acceptance angle of 90°. Threaded adapters around the port can be used to mount the test source. A M6 threaded post mount hole is provided.

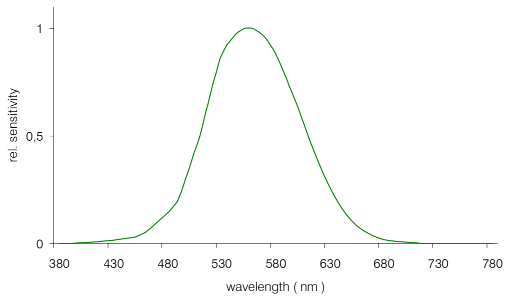
LSM-9901 Detector Head
To measure luminous flux a photometric detector is mounted to the sphere and both calibrated in lumens. To ensure low measurement uncertainty when measuring light sources with different light spectra, the detector head offers a precise photometric match to the CIE standard (DIN 5032 T3 Class B).

The measurement range is 0.0025 to 10,000 lm with a max. resolution of 0.00005 lm.

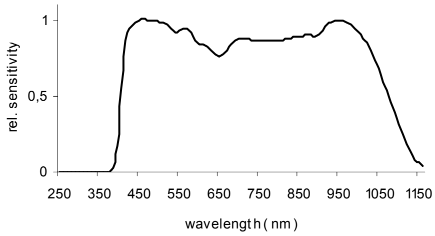
PRW-0505 Detector Head
To measure radiant power a radiometric detector is mounted to the sphere and both calibrated in W. With this system the radiant power from broadband sources or quasi monochromatic sources can be measured within the wavelength range from 400 to 1000 nm. The measurement range spans from 0.0005 to 1000 mW with a max. resolution from 0.00001 mW.

Traceable Calibration
The calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates.
Contact the factory for details and application assistance.



photometric function of LSM-9901-4



radiometric function of PRW-0505-04

Operation
The X9₄ is simple to operate. To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Stop/Run Function
Current reading can be 'frozen' by pressing 'stop' button.

X9₄ Specifications and Ordering Information

Specifications: X94 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 μA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket.

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1×10^{-4}	200.0 μA	30 ms	0.2 %* + 0.05 %	2 nF
1×10^{-5}	20,00 μA	30 ms	0.2 %* + 0.05 %	2 nF
1×10^{-6}	2,000 μA	30 ms	0.2 %* + 0.05 %	2 nF
1×10^{-7}	200,0 A	30 ms	0.2 %* + 0.05 %	10 nF
1×10^{-8}	20,00 nA	30 ms	0.2 %* + 0.05 %	10 nF
1×10^{-9}	2,000 nA	30 ms	0.2 %* + 0.05 %	10 nF
1×10^{-10}	200,0 pA	30 ms	0.2 %* + 0.05 %	10 nF

Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display luminous flux in lm or radiant power in W. Measurement quantity shown in display. Calibration data stored in calibration storage of the meter.

General	
Display	6 character LCD. Character height 9 mm. Indication of appropriate measurement quantities, battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

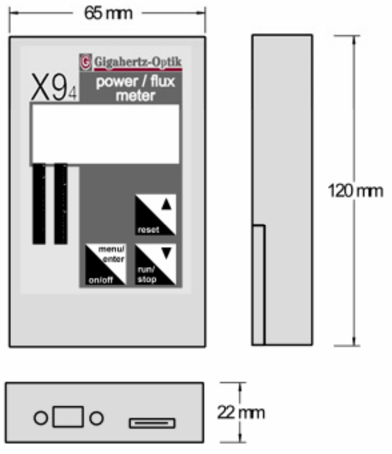
Specification: X94 with LSM-9901	
Typ. Measurement Range	0.0025 to 10,000 lm with 0.00005 lm resolution
Wavelength Range	380 nm to 780 nm, photometric characteristic
Measurement Port Aperture	12.5 mm diameter
Calibration	lm with factory cal. certificate

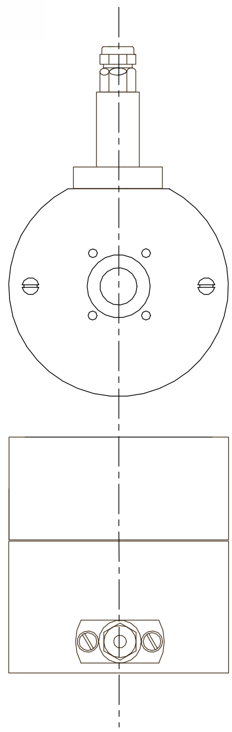
Specification: X91 with PRW-0505	
Typ. Measurement Range	0.0005 to 1,000 mW with 0.00001 mW resolution
Wavelength Range	400-1050 nm, radiometric characteristic
Measurement Port Aperture	12.5 mm diameter
Calibration	mW with factory cal. certificate

Spectral Sensitivity

See front page of X94 datasheet

Dimensions:



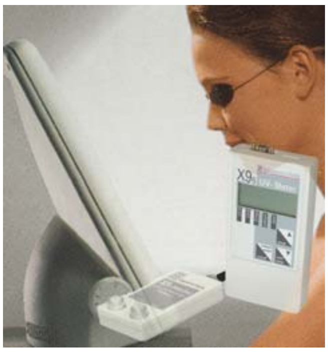


Ordering Information	
X9 4	Optometer with handbook and battery with detector(s) calibration data stored in memory
PRW-0505-4	Radiant power detector with integrating sphere. Calibration certificate. ITT-type connector
LSM-9901-4	Luminous flux detector with integrating sphere. Calibration certificate. ITT-type connector
X9Z-01	RS232 interface cable to connect the X9 meters with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-01	Hard case to carry and store the X9 4 with detector head

X96 Hand-held UV-A, UV-B & UV-B311 Irradiance Meter

- **Hand-held Dual-channel Meter for Field Service and Laboratory Use**
- **True Broadband UV-A and UV-B Sensitivity**
- **Calibration for Narrowband UV-B$_{311}$ UV Sources**
- **Cosine Corrected Field of View**
- **CW Measurement Mode for DC and AC Light**
- **Snapshot Hold Function**
- **Dose Measurement Mode**
- **Easy to Use**
- **Economical Price**
- **Battery Operation**
- **RS232 Interface**

UV-A & UV-B Phototherapy
UV is widely used by dermatologists in the treatment of certain skin diseases like Psoriasis and Vitiligo. Whole body exposure booths and hand and foot units employing light sources which emit broadband UV-A, UV-B, narrowband 311 nm UVB and combinations of UV-A and UV-B are used to irradiate the patient.
In PUVA phototherapy, also called photochemotherapy, UV-A is applied in combination with a photosensitizing agent which is taken in pill form or applied topically to the skin. This medication called psoralen, giving rise to the acronym PUVA, makes the skin more sensitive and responsive to the UV-A (315-400 nm) wavelengths.
Due to the risks of premature skin ageing and skin cancer from prolonged exposures, also with consideration to skin type, PUVA is only recommended for moderate to severe cases of Psoriasis. As a side note, psoralen is also being used as a photosensitizer in UV sterilization of blood.
UV-B broadband treatment is normally administered without a photosensitizing agent. It is considered safer than UV-A for wavelengths between approx. 290 to 315 nm, since it does not penetrate as deeply into the skin and is more energetic allowing shorter overall exposure times. However, it is generally accepted that wavelengths below 290 nm produce more erythema which can actually inhibit the therapeutic effects of the longer wavelengths.
As a result, narrowband UV-B sources emitting at predominantly 311-312 nm, have been developed. These TL-01 sources emit in the wavelength zone of most effectiveness while producing less erythemal hazard than broadband UV-B sources.
A TL-12 UV-B source with a slightly wider emission band between 280-350 nm, peaking at about 305 nm is also in use. For more information contact the National Psoriasis Foundation and the American and European Academies of Dermatology.
Dose, used here as irradiance accumulated over time, is normally measured in phototherapy applications.
Ultraviolet radiation is also used for photobiological studies like SPF testing. Again, the wavelength ranges of interest are typically UV-A, UV-B and UV-B311.
Radiometers with a precise spectral match to the spectral ranges of interest with low crosstalk between UV-A and UV-B are required for accurate dosimetry and quantification. A cosine corrected field of view, simple operation for inexperienced users and an attractive price level are also desirable.



X96 Meter
Beside it's precise measurement capability the X96 meter's ("Xninesix") most outstanding feature is its easy handling. To measure, the user simply switches on the meter and selects either the CW (W/cm²) or Dose (J/cm²) mode. The LCD characters are 9 mm high for easy viewing. The X96 is a compact handheld battery operated instrument.

XD-9501-4 Detector Head
The irradiance detector head houses separate UV-A and UV-B detectors whose spectral sensitivity and cosine corrected field of view meet accepted UV-A & UV-B spectral standards.

- The spectral sensitivity characteristic of the UV-A and UV-B detectors was developed by computer simulation using several sample filter and detector combinations. The optimum spectral functions were chosen after calculating the measurement uncertainty of each of these detector/filter/diffusers for a group of sample radiation sources. This method of characterizing the performance of integral measuring UV-meters was developed by the „Thematic Network for Ultraviolet Measurements" funded by the Standards, Measurements and Testing program of the Commission of the European Communities (see tutorials).
- Cosine correction of the detectors is of equal importance in achieving low measurement uncertainties.

Traceable Calibration
Instrument calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.
Calibration of UV-A and UV-B irradiance sensitivity as well as an additional narrowband UV-B calibration at 311 nm for TL-01 type sources is supplied. Individually measured plots of the UV-A and UV-B spectral sensitivities are provided as part of the calibration certificate.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates.
Contact the factory for details and applications assistance.

Operation
The X96 is simple to operate. To measure, connect the detector and switch on the meter.

Detector Selection
Selection of the UV-A, UV-B or UV-B$_{311}$ detector is easily done in the menu mode.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Dose Measurement
Measurement values are accumulated at a logger rate of 1 s and displayed as dose. The measurement is manually started and stopped.

Stop/Run Function
Current reading can be 'frozen' by pressing 'stop' button.

Gigahertz-Optik

X9$_6$ Specifications & Ordering Information

Specifications: X9$_6$ Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 μA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket . Connected detector identification if meter switched ON (VL-3704-4 and LDM-9901-4 only).

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C. ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-5	20,00 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-6	2,000 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 %* + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 %* + 0.05 %	10 nF

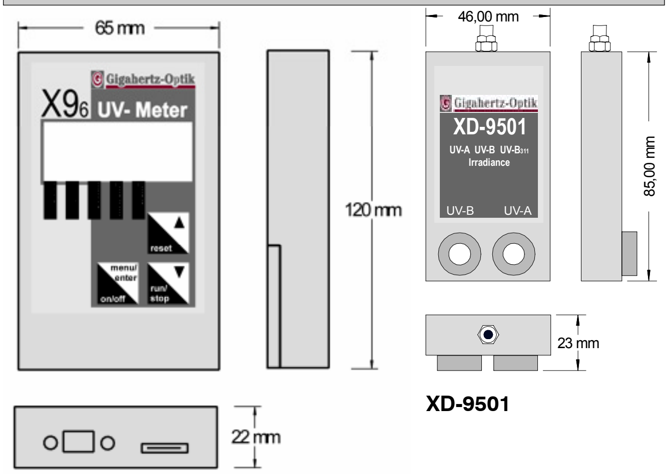
Functions	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal of UV-A and UV-B detector multiplied with calibration correction factor to display irradiance in mW/cm^2.

General	
Display	6 character LCD. Character height 9 mm. Indication of appropriate measurement quantities , battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

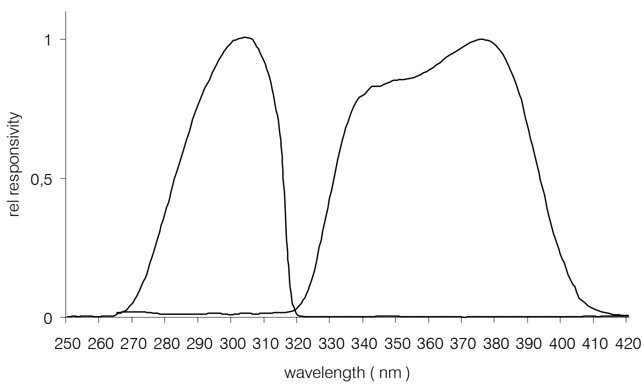
X9$_6$ with XD-9501-4	
typ. UV-A measurement range	0.0005 to 20.000 mW/cm^2 with max. 0.00001 mW/cm^2 resolution
typ. UV-B measurement range	0.00015 to 60.000 mW/cm^2 with 0.00003 mW/cm^2 resolution
Dose range for UV-A and UV-B	0.00001 J/cm^2 to 100.000 J/cm^2

Dimensions



XD-9501

spectral sensitivity characteristic



Ordering Information	
X9 6	UV-A, UV-B and UV-B311 irradiance and dose meter. Detector calibration data stored in memory . Includes detector head, XD-9501-4 battery , handbook and hard case.
X9Z-01	RS232 interface cable to connect the X9 meter with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)

X97 Hand-held Irradiance Meter

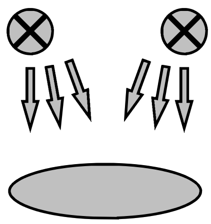
- **Hand-held Single Channel Irradiance Meter**
- **Wide Range of UV-VIS-NIR Polychromatic Irradiance Detector Heads**
- **Measurement of DC and AC Signals**
- **Peak Value Hold Function**
- **Signal Range from 0.1 pA to 200 μA with 7 Gain Ranges**
- **Automatic or Manual Gain Range Selection**
- **Easy to Use**
- **Offset Compensation**
- **Compact Size**
- **Battery Operation**
- **RS232 Interface**

Optical Radiation
Optical radiation describes that segment of electromagnetic radiation from λ=100 nm to λ=1 mm. Optical radiation can be measured using quantities related to radiation physics (radiometry), light engineering (photometry), photobiology, plant physiology and others. The application determines which quantities are appropriate.

Radiometry
Radiometry involves the metrological evaluation of optical radiation in physical radiation measurement quantities.

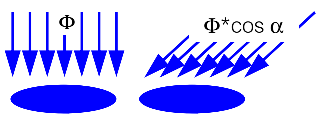
Polychromatic Radiometry
The most important aspect of radiometry is that radiation intensity is observed independently of wavelength. This distinguishes absolute radiometry from the actively weighted quantities such as those used in photometry, photobiology, plant physiology, etc., which is effective radiometry.
For this reason, radiation detectors for radiometric measurements covering a broadband wavelength range, like UV-A, VISIBLE for instance, must have a flat spectral sensitivity shape within the specified wavelength range.
Unfortunately only "thermal detectors" have this property. But their wide spectral bandwidth and low sensitivity prohibit their use in many applications so filter-corrected semiconductor detectors are more commonly used.

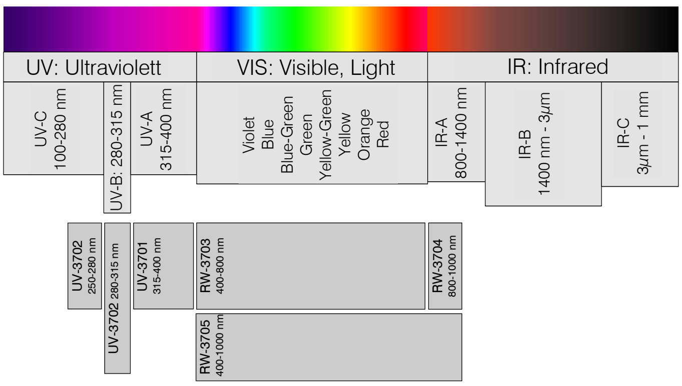
Irradiance E
Irradiance refers to the radiant power impinging on a particular surface from one or more sources of optical radiation. Irradiance is measured horizon-



tally and vertically in the units of watts per square meter (W/m²).
Irradiance is the most commonly measured quantity in optical radiation measurement applications. Due to ageing of the radiation source, irradiance levels need to be constantly checked if a minimum irradiance value needs to be maintained.

Cosine Field of View
When the incident optical radiation is not parallel, which in practice is normal, a cosine diffuser must be used to correct the





measurement geometry for irradiance detector heads.

Polychromatic Irradiance Detector Heads
Gigahertz-Optik manufactures a wide range of detector heads for polychromatic irradiance measurements with respect to a defined spectral response function. Detector heads are offered for the ultraviolet range (UV-A, UV-B, UV-C) as well as for the visible and near infrared range.
One or more of these detector heads can be combined with one of Gigahertz-Optik's broad range of optometers.

X97 Meter
For end-users whose application requires just one detector head and does not need multimeter level functional ability in their optometer, the X97 ("Xnin-eseven") Irradiance Meter is an economical alternative.
Besides it's precise measurement capability the X97 meter's most outstanding feature is its easy handling. To measure, the user simply connects the detector head and switches on the meter. The LCD characters are 9 mm high for easy viewing. The X97 is a compact handheld battery operated instrument.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities. Calibration includes detector irradiance sensitivity and an individually measured plot of spectral sensitivity with the calibration certificate.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and assistance.

Operation
The X97 offers simply operation. To measure, switch on the meter with the connected detector.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Peak Hold Measurement
Peak Hold mode is used to search for "hot-spots" light intensities. The peak intensity measured is frozen on the display.

Stop/Run Function
Current reading can be 'frozen' on display by pressing 'stop' button.

Auto/Manual Gain Ranging
Select manual ranging when the power range in production control applications stays at the same level to avoid time delays in auto-ranging mode.

X97 Specifications & Ordering Information

Specifications: X97 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz.
Detector Connector	9 pin MDSM9 socket.

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display irradiance in mW/cm².

General	
Display	6 character LCD. Character height 9 mm. Indication of appropriate measurement quantities , battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

X97 with Detector Head

Model No:	Spectral Response Function	Measurement Range in mW/cm²*	max. Resolution in mW/cm²*
UV-3701-4	UV-A (315-400 nm)	0.0005 to 1700	0.00001
UV-3702-4	UV-B (280-315 nm)	0.001 to 10000	0.00002
UV-3703-4	UV-C (250-280 nm)	0.0005 to 2500	0.00001
UV-3704-4	UV-Erythema	0.0005 to 1700	0.00001
UV-3706-4	Bilirubin	0.0005 to 100	0.00001
UV-3708-4	ACGIH (ICNIRP)	0.0005 to 5000	0.00001
UV-3709-4	Blue-Light Hazard	0.0005 to 500	0.00001
UV-3710-4	UV-A (320-400 nm)	0.0005 to 2000	0.00001
UV-3711-4	UV-B (280-320 nm)	0.0015 to 1000	0.00003
UV-3716-4	UV-A (305-400 nm)	0.0005 to 2000	0.00001
UV-3717-4	UV-A (315-400 nm)	0.0005 to 1700	0.00001
RW-3701-4	BLUE (400-500 nm)	0.0005 to 100	0.00001
RW-3702-4	RED (700-800 nm)	0.0005 to 100	0.00001
RW-3703-4	VISIBLE (400-800 nm)	0.0005 to 100	0.00001
RW-3704-4	NIR (800-1000 nm)	0.0005 to 100	0.00001
RW-3705-4	VISNIR (400-1000 nm)	0.0005 to 50	0.00001

*) typical values are calculated based on current measurement capability and may be limited by operating temp., power density and other factors

Ordering Information	
X9 7	Optometer with handbook and battery. Calibration data of the detector ordered with the meter are stored in memory.
Detector Head	One of any Gigahertz-Optik irradiance detector heads with ITT type (-4) connector.
X9Z-01	RS232 interface cable to connect the X9 meters with 9PIN SUB-D PC standard socket.
X9Z-02	External power unit for the X9 meters including the meter modification. Battery operation will be canceled.
BHO-04	Hard case to carry and store the X9 7 with one 37 type detector.

X98 Hand-held UV-A Irradiance & Illuminance Meter

- **Hand-held Dual-channel Meter for Field Service and Laboratory Use**
- **Dual Cell UV-A Irradiance and Illuminance Detector Head**
- **0.0002 to 900 mW/cm² & 0.01 to 199,999 lx measurement range**
- **Cosine Corrected Field of View**
- **CW Measurement Mode for DC and AC Light**
- **Snapshot Hold Function**
- **Dose Measurement Mode**
- **Quick & Easy Handling**
- **Economical Price**
- **RS232 Remote Control and Data Collection**

Combining a UV-A irradiance and photometric illuminance detector into one instrument is highly useful in two applications:

1) Liquid Penetrant Testing using the dye penetration examination process is a widely used method for the detection of surface cracks in nonporous metal and non-metal materials in NDT. For highest sensitivity, a fluorescent dye is used as the penetrating liquid and the test is carried out under UV-A ultraviolet 'blacklight' light sources. To reliably test with fluorescent agents, an adequate level of UV-irradiance containing a very low proportion of white (visible) light must be generated at the object under test to ensure proper contrast.

DIN EN 1956, ASTM and MIL Standards exist that describe the general conditions and standard practices for the penetrant test examinations, including the procedures to be followed. The minimum requirements for the illumination or irradiation conditions, test procedures to be used for checking these levels and suitable measurement equipment specifications are also covered.

2) Photostability

The current ICH (International Conference for Harmonization) guidelines specify that drug and drug products must be photo--tested to ensure that exposure to light does not cause photo-chemical degradation of the product or packaging. The product under test must receive a ***measured*** dose of both UV-A (200 watt-hours per square meter) and Visible (1.2 million lux-hours) optical radiation exposure. This requires both radiometric and photometric measurements in terms of illuminance in lux and UV-A (315 to 400 nm) irradiance in W/m² multiplied by exposure time in hours.

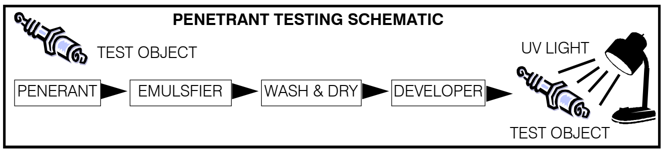
UV-A fluorescent and Xenon or Metal Halide simulated ID65 light sources are the only sources specified in the ICH guidelines.

Most often the phototesting is performed in a photostability chamber with long fluorescent light sources mounted above the products under test. Since this is an extended source type of measurement rather than a point source configuration, the detector angular sensitivity should be cosine corrected using a diffuser. This way the incoming light signals are properly weighted according to the cosine of the angle of incidence.

Profiling the photostability chamber for uniformity over the exposure plane is an important procedure since products placed in different areas inside the chamber should be uniformly exposed to the same light levels.

X98 Meter

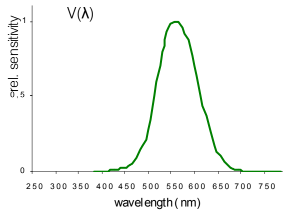
Besides it's precise measurement capability the X98 meter's ("Xnine eight") most outstanding feature is its easy handling. To measure, the user simply switches on the meter and selects either the CW (lx or W/cm²) or Dose (lxs or J/cm²) mode. The LCD characters are 9 mm high for easy viewing. The X98 is a compact handheld battery operated instrument.



XD-9502 Detector Head

The compact detector housing integrates two precision light detectors, one for illuminance and one for UV-A irradiance.

The photometric detector (lx) satisfies the requirements of DIN quality class B (DIN 5032 Part 7), and is suitable for use as a qualified industrial measuring instrument. This qualification governs the acceptable tolerances of the photometric response function (V (λ)) and the accuracy of the

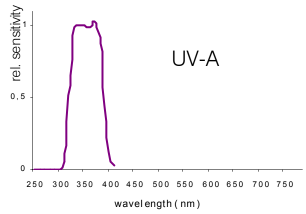


cosine function in particular.

The UV-A detector offers a spectral sensitivity characteristic according to DIN 5031 and the CIE, where the UV-A range is defined from 315 to 400 nm. The detector design effectively blocks the neighboring UV-B and visible light regions. The detector head is cosine corrected with a diffuser.

Traceable Calibration

Calibration is traceable to the ISO EN 17025 accredited part of



Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.

Custom Label:

All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and assistance.
the company for more details.

Operation

The X98 is simple to operate To measure, connect the detector and switch on the meter.

Detector Selection

Selection of the photometric or UV-A detector is easily done in the menu mode.

CW Measurement

CW mode is used to measure continuous DC or AC signals .

Dose Measurement

Measurement values are accumulated at a logger rate of 1 s and displayed as dose. The measurement is manually started and stopped.

Stop/Run Function

Current reading can be 'frozen' by pressing 'stop' button.

X9$_8$ Specifications& Ordering Information

Specifications: X9$_8$ Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 μA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket . Connected detector identification if meter switched ON (VL-3704-4 and LDM-9901-4 only).

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C. ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-5	20,00 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-6	2,000 μA	30 ms	0.2 %* + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 %* + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 %* + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 %* + 0.05 %	10 nF

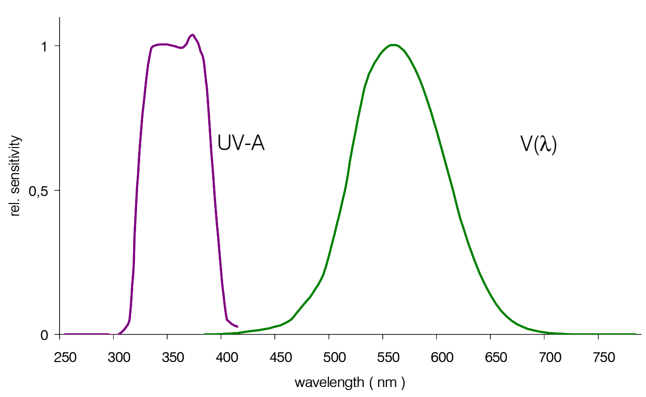
Functions	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal of UV-A and UV-B detector multiplied with calibration correction factor to display irradiance in mW/cm² and illuminance in lx.

General	
Display	6 character LCD. Character height 9 mm. Indication of measurement quantities lx and cd/m², battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

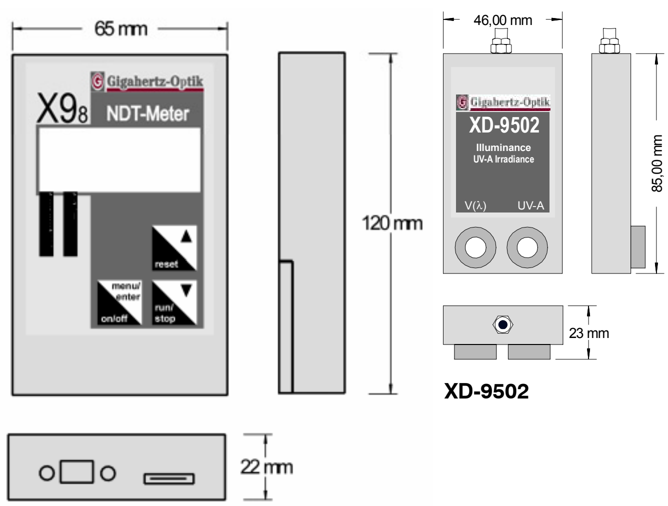
X9$_8$ with Detector Head	
typ. UV-A measurement range	0.025 to 900 mW/cm² with max. 0.00005 mW/cm² resolution
typ. Illuminance measurement range	0.2 to 999,000 lx with 0.004 lx resolution
Dose range	0.00001 to 900,000 lxs and 0.00001 J/cm² to 900,000 J/cm²

Spectral sensitivity characteristic



spectral sensitivity characteristic of both X9$_8$ detectors

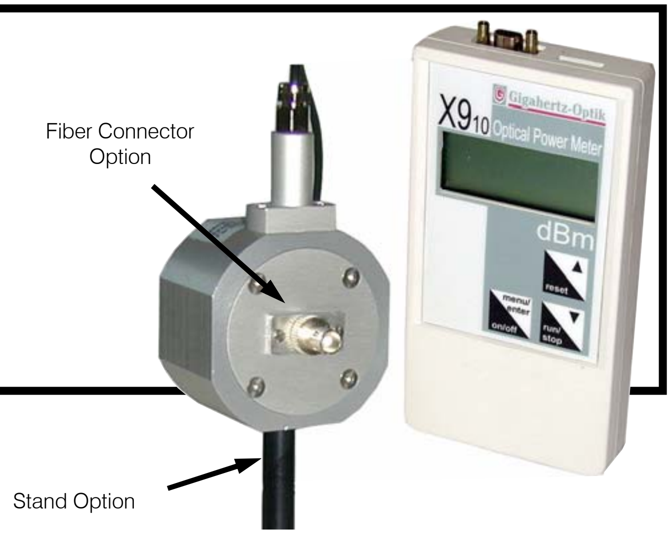
Dimensions



Ordering Information	
X9 8	Illuminance & UV-A Irradiance Meter including detector head . Detector calibration data stored in memory . Includes battery and handbook.
X9Z-01	RS232 interface cable to connect the X9 meter with 9 PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-04	Hard case to carry and store the X9 8 with detector.

X910 Integrating Sphere Power Meter for Telecommunication Testing

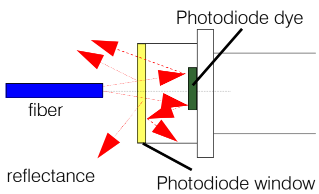
- © **Hand-held Meter for Field Service and Laboratory Use**
- © **Compact Integrating Sphere Detector for**
  - © **No Beam Misalignment Error**
  - © **No Polarization Effected Error**
  - © **No Beam ‚Bounce-Back‘ Error**
  - © **No Detector Saturation**
  - © **Economical Price**
- © **Dynamic Range from 10 dBm to -60 dBm**
- © **Spectral Range 400 to 1100 & 850 to 1700 nm**
- © **Battery Operation (Optional AC Power Operation)**
- © **RS232 Interface**



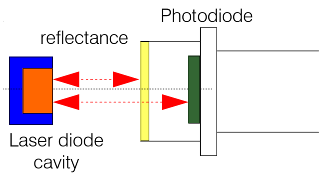
Radiant Power Measurement
Measurement of the power output of laser diodes or fibers is a daily routine in the field of telecommunication component testing.

Bare Detector Issues
Optical power meters with a bare detector directly receiving signal offer high sensitivity but at a cost. Potential measurement inaccuracies caused by the effects of polarization, local saturation, signal 'bounce-back' and beam misalignment can occur. Also, the use of large size photodiodes, required to reduce source to detector misalignment, increases cost.

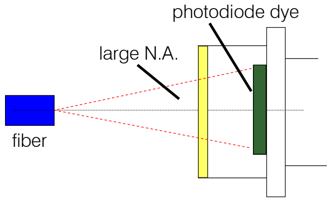
Reflectance & Polarisation



Bounce-Back

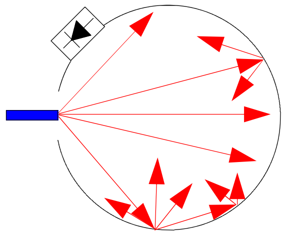


Large Detector Area



Integrating Sphere Detectors
A welcome alternative is the integrating sphere known in the world of photonics for its ability to reliably and accurately measure total flux from fibers, laser diodes, lasers, LEDs and any other light source.

The ***diffuse multiple reflections*** from the inner wall of the sphere suppresses the disturbance effects created by the angle of incidence which can form shadows, reflections, modes, etc.



The sphere is able to collect all of the source optical radiation output independent of beam geometry.

Since all of the incoming signal is captured and reflected inside the sphere multiple times before reaching the baffled detector mounted to it, the adverse effects of polarization, local saturation, signal 'bounce-back' and beam misalignment are reduced.

Small Size Detector
Due to the low attenuation property of compact integrating spheres, they can be used with photodiodes with a small active area. In combination with InGaAs photodiodes for the 850 to 1700 nm range, this brings the sphere detector price down in the range of large bare detectors!

Bare Laser Diodes
Because of the large divergent beam of laser diodes, bare detectors can not be used to measure the total power of bare laser diodes. Gigahertz-Optik's **X910** (Xnine ten) offers an economically priced instrument capable of all types of telecommunications testing in the areas of QC, fiber assembly/test, multimode LAN, patchcord, network installs and general laser diode, fiber and LED power measurements.

X910 Meter
Besides it's precise measurement capability the X910 meter's most outstanding feature is its easy handling. To measure, the user simply switches on the meter and selects the wavelength corresponding to the test laser wavelength. The LCD characters are 9 mm high for easy viewing. The X910 is a compact handheld battery operated instrument. AC option is available.

LP-01 Sphere Detectors
The LP-01 sphere detectors employ a 30 mm diameter integrating sphere machined out of OP.DI.MA. Gigahertz-Optik's unique white diffuse plastic. OP.DI.MA. offers optimum light throughput for high sensitivity, a nearly perfect diffuse reflection for best diffuse radiation distribution and long term stability. The sphere is housed in a rugged aluminum casing for protection and allows mounting to an optical post or bench. The sphere comes with an open 5 mm dia. measurement port.

Model LP-0101
Is supplied with a Indium Gallium Arsenide photodiode which covers the spectral range from 850 to 1700 nm. The use of a small area diode allows an economical price.

Model LP-0103
Is supplied with a Silicon photodiode which covers the spectral range from 400 to 1100 nm.

Fiber Connectors
Fiber optic connector adapters for FC, ST, SC connections are available as an option.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities. Each detector head is calibrated in 10 nm steps within its specified wavelength range.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and assistance.

Operation
The X98 is simple to operate to measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals in dBm or mW.

Wavelength Selection
A calibration table with spectral sensitivity data in 10 nm steps within the detectors specified spectral range allows simple wavelength selection.

Stop/Run Function
Current reading can be 'frozen' by pressing 'stop' button.

Gigahertz-Optik

X910 Specifications & Ordering Information

Specifications: X910 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz. .
Detector Connector	9 pin MDSM9 socket . Connected detector identification if meter switched ON (VL-3704-4 and LDM-9901-4 only).

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

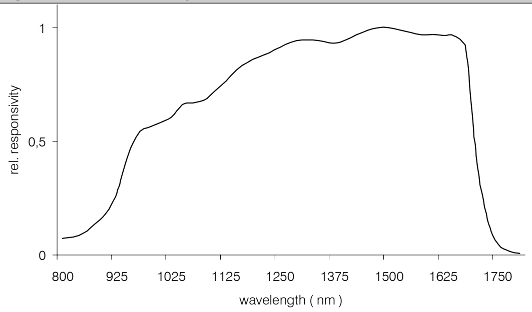
Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display the laser/optical power in dBm.

General	
Display	6 character LCD. Character height 9 mm. Indication of measurement quantities lx and cd/m², battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

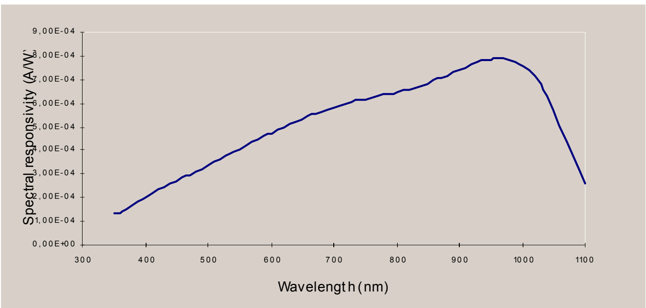
Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

X910 with Detector Head LP-0101 and LP-0103	
Measurement aperture	5 mm diameter
LP-0101	850 to 1700 nm, calibrated in 10 nm increments
Measurement range at 1350 nm	-60 to 10 dBm. with max. 0.01 dBm resolution
LP-0103	400 – 1100 nm, calibrated in 10 nm increments
Measurement range at 900 nm	-60 to 10 dBm. with max. 0.01 dBm resolution

Spectral Sensitivity LP-0101



Spectral Sensitivity LP-0103



Ordering Information	
X9 10	X9 10 meter with stored calibration data of ordered detector head, handbook, battery
LP-0101-4	Laser/optical power InGaAs detector head with factory calibration certificate. ITT type connector (-4).
LP-0103-4	Laser/optical power Si detector head with factory calibration certificate. ITT type connector (-4).
UFC-II/FC	FC adapter for integrating sphere
UFC-II/ST	ST adapter for integrating sphere
UFC-II/SC	SC adapter for integrating sphere
X9Z-01	RS232 interface cable to connect the X9 meters with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-08	Hard-shell Case
BHO-09	Hard-shell Case

X9₁₁ Hand-held UV-C Irradiance Meter

- © **Hand-held Single Channel UV-C Irradiance Meter**
- © **Measurement Range 0.05 to 1000 mW/cm² with 0.001 mW/cm² Resolution**
- © **Solar Blind UV-C Sensitivity**
- © **NIST Traceable Calibration at 254 nm**
- © **Solid-state Detector with Cosine Corrected Field of View**
- © **CW Mode with Snapshot Hold Function**
- © **Dose Measurement Mode**
- © **Easy to Use**
- © **Battery Operation**
- © **RS232 Remote Control Operation**

UV-C Radiation
Short wavelength high energy ultraviolet radiation in the UV-C spectral range from 100 to 280 nm is used in the ***germicidal/ bactericidal sterilization*** of air and water. UV-C at 253.7 nm is also employed in ***eprom erasure*** and the ***cleaning*** of sensitive surfaces in the semiconductor industry. ***UV curing*** is another area where UV-C is applied.

UV-C Light Sources
Due to its high and pre-dominantly monochromatic output at 253.7 nm, ***low pressure mercury*** is the light source of choice in these applications. Medium and high pressure Hg as well as metal halide and other broadband UV sources are also used, especially in UV curing.

Light Source Life-time
The life time of high power UV-C sources is limited. Therefore the UV-C intensity must be monitored periodically to control the process condition.

UV-C Detectors
Optical radiation detectors used in UV-C applications are subject to extreme stress due to the high energy UV-radiation involved. Special precautions are needed to ensure that the detector's life is longer than that of the light source.
Also, detector sensitivity must focus on the specified source spectra using UV resistant components.

Detector Stability
Radiometric detectors used for UV-C measurement and monitoring must be designed to remain stable with minimal degradation from long term exposure to the high irradiance and energy levels typically found in this application.

UV-C Isolation
The detector must be able to isolate the UV-C radiation and not allow any out-of-band signal to contaminate the reading.

Cosine Field of View
A precise cosine corrected field of view, simple operation for inexperienced users and an attractive price level are also desirable.

X9₁₁ Meter
Besides it's precise measurement capability the X9₁₁ (Xnine eleven) meter's most outstanding feature is its easy handling. To measure, the user simply connects the detector head and switches on the meter. The LCD characters are 9 mm high for easy viewing. The X9₁₁ is a compact handheld battery operated instrument. AC option is available.

UV-3718 Detector Head
A new technology solid-state solar blind photodiode detector was chosen for use in the UV-3718 detector head because of its UV stability and solar blind spectral sensitivity characteristic. The UV sensitivity of the detector is limited to 265 nm focusing response to the 254 nm spectral range.
Also, the detector employs a carefully designed diffuser to provided a precise cosine correction of the detector, which is of equal importance in maintaining low measurement uncertainties.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities and NIST standards.
Calibration of the detectors irradiance sensitivity at 254 nm as well as an individually measured plot of spectral sensitivity is part of the calibration certificate.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and assistance.

Operation
The X9₁₁ is simple to operate To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Dose Measurement
Measurement values are accumulated at a logger rate of 1 s and displayed as dose. The measurement is manually started and stopped.

Peak Hold Measurement
Peak Hold mode is used to search for "hot-spot" light intensities. The peak intensity measured is frozen on the display.

Stop/Run Function
Current reading can be 'frozen' by pressing 'stop' button.

Gigahertz-Optik

X9$_{11}$ Specifications & Ordering Information

Specifications: X9$_{8}$ Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz.
Detector Connector	9 pin MDSM9 socket.

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

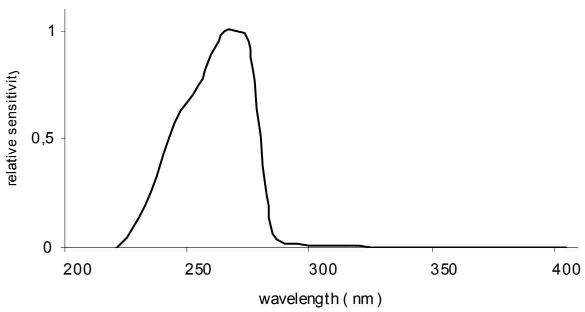
Function	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display irradiance in mW/cm².

General	
Display	6 character LCD. Character height 9 mm. Indication of measurement quantities lx and cd/m², battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, erases battery operation.

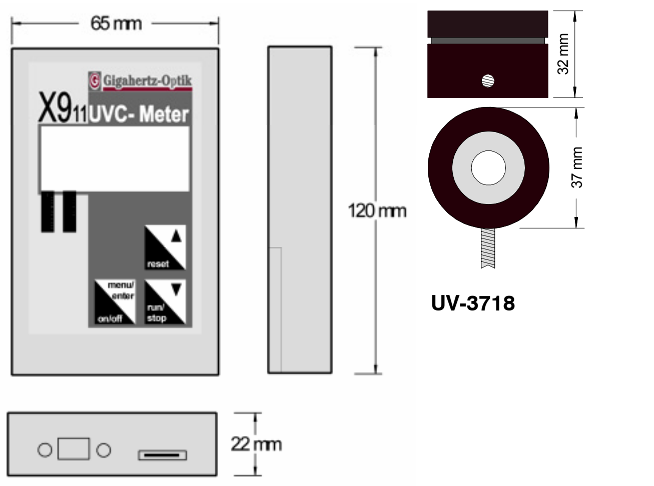
Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

Specifications: X9$_{11}$ with UV-3718 UV-C Detector Head	
Typ. Irradiance Measurement Range	0.05 to 1000 mW/cm² with 0.001 mW/cm² resolution
Dose Measurement Range	0.00001 J/cm² to 100.000 J/cm²
Detector Dimensions	Dia. 37 mm dia.. Height 32 mm; Cos. diffuser dia. 7 mm; Cable length 2 m

Spectral Sensitivity UV-3718



Dimensions



UV-3718

Ordering Information	
X9 11	UV-C irradiance and dose meter. Calibration data stored in memory. Includes battery and handbook.
UV-3718-4	UV-C irradiance detector head with factory calibration certificate. ITT type connector (-4).
X9Z-01	RS232 interface cable to connect the X9 meter with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-04	Hard Carrying Case

X912 Hand-held UV Hazard Meter

- © **Hand-held Single Channel UV Hazard Meter**
- © **ACGIH Effective Irradiance Measurement**
- © **Measurement Range 0,5 to 999 999 µW/cm² with 0,01 µW/cm² Resolution**
- © **Traceable Calibration of ACGIH Sensitivity**
- © **Solid-state Detector with Cosine Corrected Field of View**
- © **CW Mode with Snapshot Hold Function**
- © **Dose Measurement Mode**
- © **Easy to Use**
- © **Battery Operation, AC option available**
- © **RS232 Remote Control Operation**

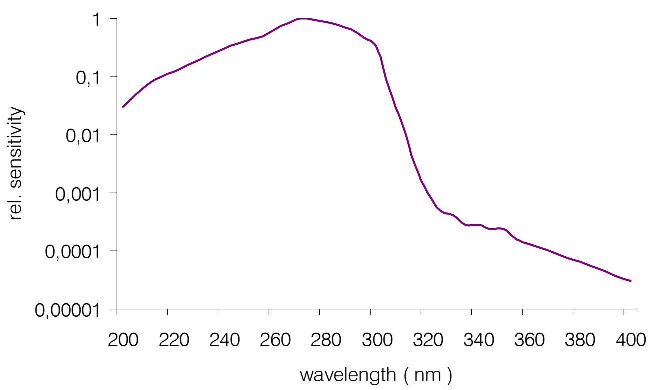
UV Hazard
Ultraviolet and blue-light optical radiation pose a potential health hazard for both human skin and eyes. Common sun burn, photo-keratitis (welder's eye) and burning of the retina or cornea are examples of injuries caused by overexposure to this radiation.

Higher Awareness of UV Risk
Because of the dramatic increase in global solar UV radiation and the cumulative nature of the harmful effects, the additional risk of UV exposure by artificial sources is a concern.
The efficiency of protective devices like sun creams, UV blocking fabrics and sunglasses are the subjects of study.

UV Hazard Risk Assessment
Photobiologists, industrial hygienists, health and safety officers measure UV irradiance (W/m²) and irradiance dose (J/m²) of all types of UV sources in the lab, field and in the work place in order to ensure safety and to study both the harmful and helpful effects.

It is important to note that UV levels and subject exposure times typically vary so datalogging over some time period is commonly employed.

ACGIH / ICNIRP Spectral Weighting Functions
The spectral weighting function for the acutely harmful effects of UV radiation, was developed by the *American Conference of Governmental Industrial Hygienists (ACGIH) and* the *International Commission on Non-Ionising Radiation Protection (ICNIRP)* .
If one examines the spectral curve describing this function, it can be seen that the spectral effectiveness in the UV-C and UV-B ranges is drastically higher than in the UV-A range. The reason for this is that the function was derived from those relating optical radiation to erythema (skin reddening) and photokeratoconjunctivitis (corneal inflammation). Threshold Limit Values given for the maximum permissible exposure of the skin define the range of wavelengths as 200 (180) to 400 nm in reference to the ACGIH-ICNIRP function. The limits of maximum permissible exposure for the eye in the range 200 (180) to 400 nm and 315 to 400 nm (UV-A) are defined separately. By definition ACGIH-ICNIRP UV-C/B is measured in effective irradiance according to the spectrally weighted function and the UV-A level is assessed by measurement of the total UV-A irradiance (no spectral weighting function) for UV-A rich sources.



ICNIRP Nominal Function

X912 Meter
Besides it's precise measurement capability the X912 (Xnine twelve) meter's most outstanding feature is its easy handling. To measure, the user simply connects the detector head and switches on the meter. The LCD characters are 9 mm high for easy viewing. The X912 is a compact handheld battery operated instrument.

UV-3708 Detector Head
The UV-3708 detector permits direct measurement of effective irradiance according to ACGIH/ICNIRP guidelines. It's designed with particular attention to the re-creation of the specified spectral sensitivity curve in the range from 300 to 350 nm with its very steep edge. In order to correctly evaluate irradiance, the detector head has a cosine diffuser. For applications concerning exposure of the eye to UV radiation, the UV-3708 detector head is used together with an additional detector head for UV-A.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities and NIST standards.
Calibration of the detectors irradiance sensitivity as well as an individually measured plot of spectral sensitivity is part of the calibration certificate.

Custom Labeling:
All meters in the X9 family are ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and application assistance.

Operation
The X911 is simple to operate To measure, connect the detector and switch on the meter.

CW Measurement
CW mode is used to measure continuous DC or AC signals .

Dose Measurement
Measurement values are accumulated at a logger rate of 1 s and displayed as dose. The measurement is manually started and stopped.

Peak Hold Measurement
Peak Hold mode is used to search for "hot-spot" light intensities. The peak intensity measured is frozen on the display.

Stop/Run Function
Current reading can be 'frozen' on display by pressing 'stop' button.

X9₁₂ Specification & Ordering Information

Specification: X912 Meter

Signal Input	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 μA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. 500 ms integration through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz.
Detector Connector	9 pin MDSM9 socket.

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-4	200.0 μA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 μA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 μA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

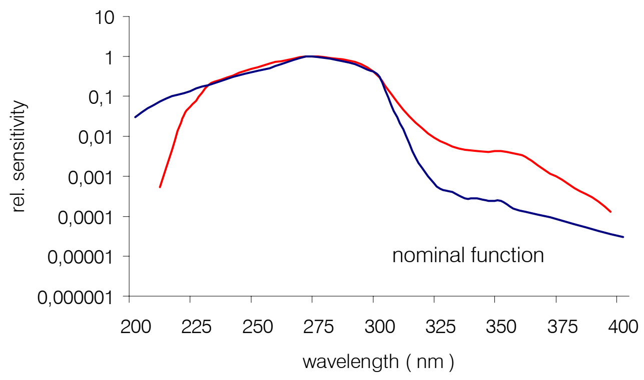
Functions	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display effective irradiance in μW/cm²

General	
Display	6 character LCD. Character height 9 mm. Indication of effective irradiance and dose, battery , battery low, peak, stop
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	120 x 65 x 22 mm / 150 g (4.7 x 2.6 x 0.9 in / 0.33 lb).
Power	9 V one-piece battery. Operation time about 100 h. Operation from a AC plug-in power supply 230V/50 Hz on option, cancels battery operation.

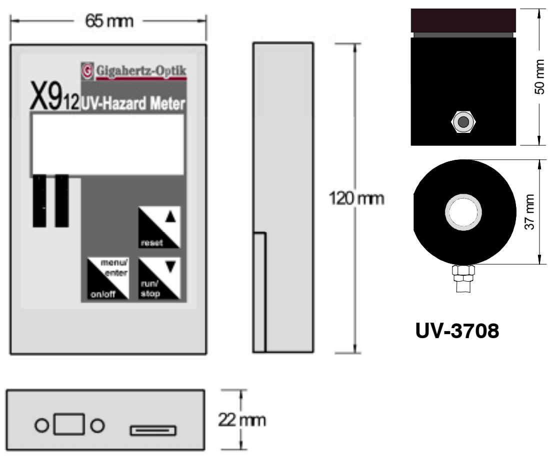
Interface	
RS232	9600 Baud, 8 8D, 1S,N. 8 pin plug Hirose, type 3260-8S1. Power supply operation recommended for remote control.

Specifications: X912 with UV-3708 ACGIH UV-Hazard Detector Head	
Typ. eff. Irradiance Measurement Range	0,5 μW/cm² to 999 999 μW/cm² eff. with 0.01 μW/cm² eff. resolution
Dose Measurement Range	0.00001 J/cm² eff. to 100,000 J/cm² eff.
Detector Dimensions	Dia. 37 mm dia.. Height 50 mm; Cos. diffuser dia. 7 mm; Cable length 2 m

Spectral Sensitivity UV-3708



Dimensions



Ordering Information	
X9 12	UV-Hazard irradiance and dose meter. Calibration data stored in memory. Includes battery and handbook.
UV-3708-4	UV-Hazard ACGIH/ICNIRP irradiance detector head with factory calibration certificate. ITT type connector (-4).
X9Z-01	RS232 interface cable to connect the X9 meter with 9PIN SUB-D PC standard socket
X9Z-02	External AC power unit for the X9 meter including meter modification (cancels battery operation)
BHO-04	Hard Carrying Case

PT-9610 Hand-held Laser Qualification Meter

© **Hand-held Single Channel Laser Qualification Meter for**
- **Laser Power Measurement**
  - **Wavelength Range 350 to 1100 nm**
  - **Measurement Range up to 90 mW**
- **Effective and Peak Noise Value Analysis**
  - **Effective Values with Wide Band, Low and High Frequency Selection**
  - **Peak Values with Positive, Negative and Peak to Peak Selection**

© **Service and Production Use**
© **Handheld Portable Meter**
© **Battery or AC Operation**

Laser Qualification
In most applications knowing the radiant power of a laser is the only qualifying parameter. That's why laser power meters are one of the most common instruments found in the lab and field service. But for specific applications, other parameters of the laser are also of interest.

Laser Noise
In laser use where measurement resolution is limited by the noise level of the laser radiation, the qualification of the noise level and noise function become important.
One example of this involves laser imaging scanners. The extremely high measurement bandwidth of these systems does not allow limiting the bandwidth of the detection system. Because of this not only laser power but to a greater extent the noise level and noise characteristic of the laser, used as a light source, influences the signal to noise ratio. So both laser power and noise must be qualified in incoming inspection, final testing and service.

PT-9610 Laser Qualification Meter
Gigahertz-Optik developed the PT-9610 in close cooperation with the laser industry.
The idea was to develop a simple mobile meter for applications where laser power plus it's time structure in the form of modulation needs to be determined in the same measurement procedure. This information was of interest because any short and long term changes in intensity would effect the resolution of the measurement procedure.

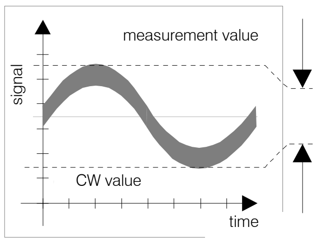
Functional Description
The PT-9610 operates in two basic modes. CW power is always measured, i.e. the average power together with the component of the power with which the power oscillates about the mean value (modulation component). Measurement mode of the modulation component can be selected for a more precise evaluation. The modulation component can be displayed as power ("absolute power, e.g. in W") or as a relative value related to the CW power.
A description of evaluation modes and display selections is summarized in the table shown on this page.
The device is also equipped with an analog output where the signal measured after the preamplifier is made available. The conversion factor between the detector signal and the output signal is between 10^3 V/A and 10^5 V/A, depending on the range of measurement. The output impedance is 10 kΩ.

PD-1 Detector Head
The PD-1 is supplied as part of the PT-9610 system. It can handle a dynamic range of laser power from 1 μW up to 90 mW (647 nm). This means that noise analysis using the maximum bandwidth of 1 MHz in the "RMS" or "Peak" modes has a resolution of 0.1% in the power range >1 mW. The detector head can be used for lasers in the wavelength range from 350 nm up to 1100 nm and offers a 5 mm diameter measurement aperture.

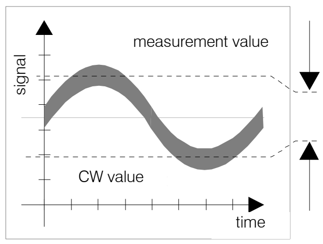
Traceable Calibration
Calibration of spectral sensitivity is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities. The calibration is done in 10 nm steps within the wavelength range from 350 to 1100 nm. A plot of the spectral sensitivity is part of the calibration certificate.

Evaluation Modes

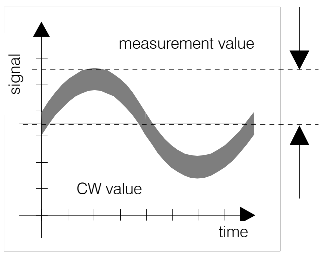
RMS WB
- r.m.s. value
- wide band



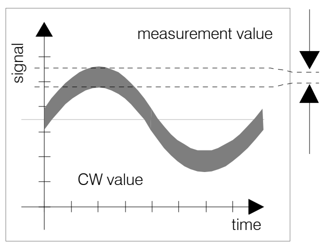
RMS LF
- r.m.s. value
- low frequency



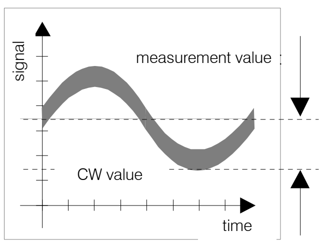
Peak +
- peak value
- positive



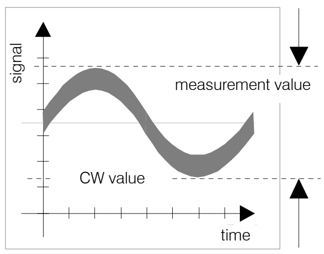
RMS HF
- r.m.s. value
- high frequency



Peak -
- peak value
- negative



Peak pp
- peak value
- peak to peak

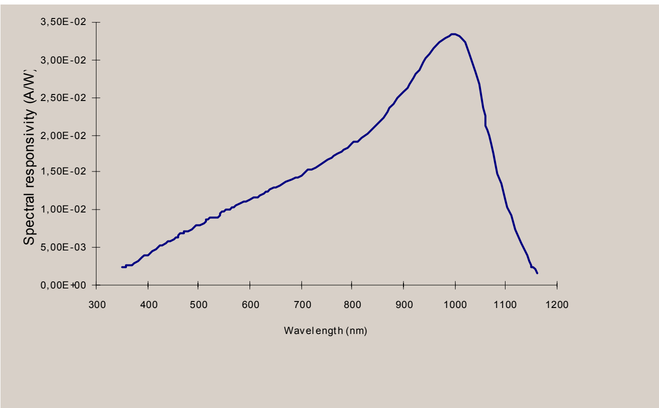


PT-9610 Specifications & Ordering Information

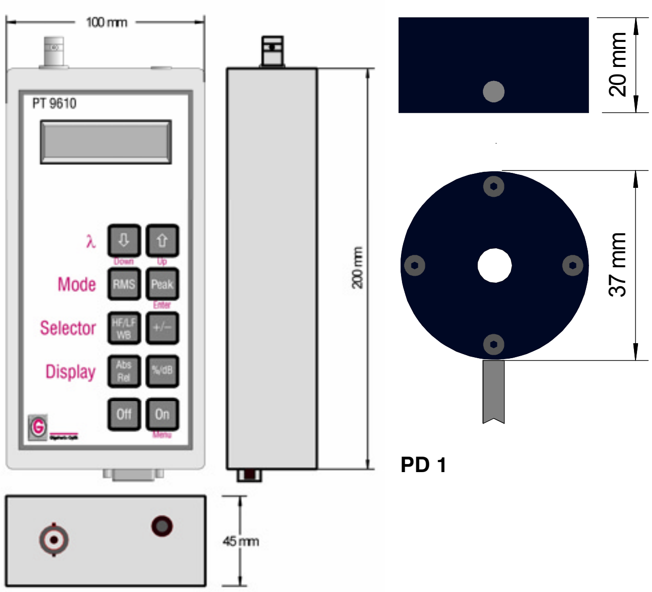
PT-9610 Specifications	
ADC resolution "CW + RMS":	0.025 % of the full scale range value
ADC resolution "Peak":	0.07 % of the full scale value (R1/WB)
	0.01 % of the full scale value (R1/LF)
	0.01 % of the full scale value (R2/WB)
	0.005 % of the full scale value (R2/WB)
Lower cut-off frequency for CW measurement:	10 Hz
Cut-off frequency in (-3 dB) mode:	500 kHz (R1), 1 MHz (R2 + R3)
Low pass filter in LF mode:	830 Hz (-3 dB) 480 Hz (-1.5 dB)
High pass filter in HF mode:	280 Hz (-3 dB) 480 Hz (-1.5 dB)
Calibration data storage:	External EEPROM in detector plug
Measuring ranges:	R1, R2 and R3 with manual or automatic range switching (menu function)
Operating panel:	Membrane keypad
Display:	LCD with switch able background illumination
Signal input:	9-pin SUB-D connector
Analog output:	BNC socket
Power supply:	Rechargeable battery or AC operation using external power supply unit (7.3 V/350 mA)
Dimensions:	Approx. 20 cm x 10 cm x 4.5 cm (8 in x 4 in x 1.8 in) (L x W x H)
Weight:	Approx. 500 g (1.1 lb) with batteries

PT-9610 with PD1 Specifications			
Limits of Measurement			
	R1	R2	R3
RMS WB	0.5 µW	1.5 µW	0.01 µW
HF	0.5 µW	1.5 µW	0.01 µW
LF	0.05 µW	0.3 µW	0.004 µW
Peak-Peak WB	2.5 µW	4 µW	0.02 µW
Max. Limits (637nm)			
CW	900 µW	9 mW	90 mW
Resolution	0.1 µW	1 µW	10 µW

PD-1 Spectral Sensitivity



Dimensions



Ordering Information	
PT-9610-PD1	Laser power and laser noise analyzer including PD1 detector , handbook, calibration certificate and plug-in power supply
PT-9610-RC-PD1	Laser power and laser noise analyzer with RS232 Interface. Including PD1, handbook, calibration certificate and power supply
PD1	Laser power detector for use with PT-9610. Calibration data stored in calibration data connector. Calibration certificate.
BHO-01	Carrying case for PT-9610 with PD1 detector and accessories.

HCT-99 Hand-held Luminous Color Meter

- © **Compact Luminous Color Meter for**
  - **Correlated Color Temperature**
  - **x,y and u‘,v‘ Chromaticity Coordinates**
  - **Illuminance**
  - **Optional Luminance, Luminous Flux and Luminous Intensity**
- © **Tristimulus Detector with Real X_{short}, X_{long}, Y and Z Spectral Functions**
- © **Field Service and Laboratory Use**
- © **USB Interface for Remote Control Operation**
- © **Economical Price**
- © **OEM Labeling**
- © **Battery Operation**

Luminous color

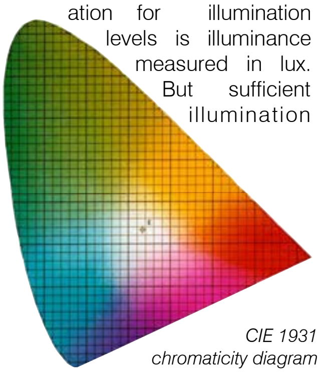
Color is defined as the attribute of visual perception consisting of any combination of chromatic and achromatic content. This attribute can be described by chromatic color names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic color names such as white, gray, black, etc., and qualified by bright, dim, light, dark or by combinations of such names.

Perceived color depends on the spectral distribution of the color stimulus, on the size, shape, structure and surroundings of the stimulus area, on the state of adaptation of the observer’s visual system, and on the person’s experience of prevailing and similar situations of observation.

Illuminance and Color

It has been known for many years and prescribed that high illumination levels will have positive effects on spiritual and physical performance. In comparison, low illumination levels can cause depression and even physical illness.

The classical photometric evaluation for illumination levels is illuminance measured in lux. But sufficient illumination is not the only factor for a healthy physical-biological home or work environment. Well balanced illumination and light-colors are necessary and conducive to a long term healthy life. A life surrounded by optical radiation.



CIE 1931 chromaticity diagram

So new generation light meters should also measure color since it is a significant part of the total visual sensation.

Luminous Flux and Color

Light source manufacturers and other users need to know the luminous flux and color temperature they are working with. Typically integrating spheres are used to measure these quantites.

Luminance and Color

Besides illuminance, luminance is one of the most important light measurement quantities used to specify the contrast situation on work stations and monitors.

Luminous Intensity and Color

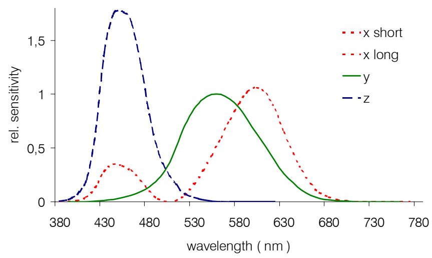
Spot lamps, like LED’s for example, are very often qualified by their directional light intensity.

HCT-99 Color Meter

The HCT-99 is a compact portable light-meter for general lighting applications which also measures chromaticity coordinates x,y and u‘,v‘ as well as correlated color temperature. The ergonomically designed meter is simple to use for the benefit of inexperienced users.

CT-4501 Detector Head

A compact design, 20 mm flat tristimulus detector is designed to measure broad-band light sources. Precisely corrected four cell design including the X_{short} function ensure precise luminous color measurement independent from the light source emission spectrum.



Optional Components To extend the unit’s light measurement application range beyond luminous color, add:

- Integrating Spheres: luminous flux (calibration in lm)
- Front lens: luminance (calibration in cd/m²)
- Steradian front tube: luminous intensity (calibration in cd)

Traceable Calibration

Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik‘s Calibration Laboratory for Optical Radiation Quantities and NIST standards. Calibration of detector sensitivity as well as an individually measured plot of spectral sensitivity is included as part of the calibration certificate.

Custom Labeling:

The HCT-99 is ready made for custom design and labeling. Customization may include the meter front panel, function/mode set-up, detector heads, manuals and calibration certificates. Contact the factory for details and application assistance.

Operation

The HCT-99 is simple to operate To measure, connect the detector and switch on the meter.

CW Measurement

CW mode is used to measure continuous DC or AC signals. Color temperature, x/y or u’/v’ and illuminance are displayed all at once.

Stop/Run Function

Current reading can be ’frozen’ on display by pressing ‘stop’ button.

Calibration Selection

To re-set the measurement application add the attachment to the CT-4501 and select the calibration in the menu mode.

Gigahertz-Optik

HCT-99 Specifications & Ordering Information

Specifications: HCT-99 Meter

Signal Input	
Detector Input	4 photocurrent signal inputs with multiplex electronic function to one photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 6 decade stepped gain ranges with max. gain signal values from 20.0 μA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 1 ms time interval. Variable integration time through averaging of multiple measurements. Selectable from 1 ms to 1 s per channel.
Measurement Time	4 times the selected integrating time..
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz.
Detector Connector	9 pin MDSM9 socket, 4 measurement inputs

Range Specifications

Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Permitted Detector Capacitance
1x10-5	20,00 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 μA	3 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	3 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	3 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

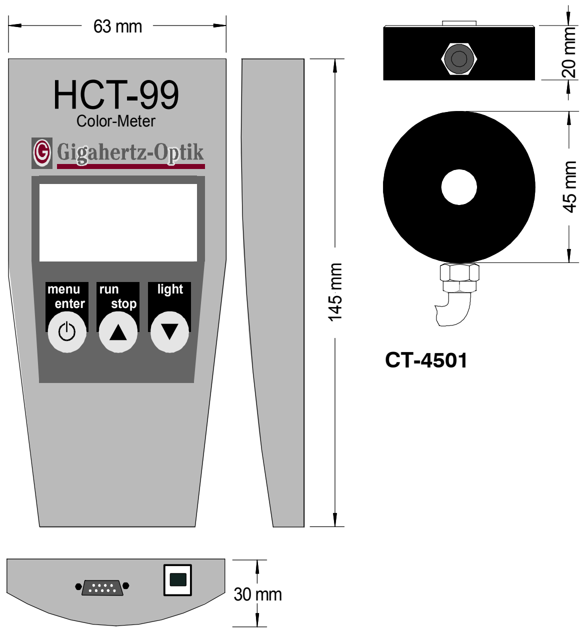
Functions	
Parameter Settings	Retention of the last settings in continuous memory. 3 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display in the different measurement quantities.

General	
Display	LCD graphic display (97 x 32 pixel). Text: 4 rows each 14 characters. LED background illumination (switchable)
Operating Temperature	10 to 40° C (50 to 104° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122° F).
Dimensions/Weight	145 x 63 x 30 mm / 150 g (5.7 x 2.5 x 1.2 in / 0.33 lb).
Power	2x battery size AA (2.2 - 3.2V). Current consumption: 6mA + 30mA (display illumination). USB: bus powered

Interface	
USB	USB Spec. 1.1 (HID device)

Specifications with CT-4501 Detector Head (typical Values)	
Illuminance	0.5 to 199999 lx with 0.01 lx resolution
Luminance	1° Lens / ≈ 2.5 to ≈ 5 x 10 ^{8} cd/m^2 5° Lens / ≈ 0.1 to ≈ 2 x 10 ^{7} cd/m^2 10° Lens / ≈ 0.02 to ≈ 3 x 10 ^{6} cd/m^2
Min. Illuminance for Color Meas.	0.5 lx (CIE standard illuminant A)
	0.5 lx (CIE standard illuminant D_{65})
Color uncertainty	0% with CIE standard illuminant A,
• filter illuminated with standard illuminant A	< 1 % with BG 34, nom. x0.3914/y0.3925
	< 1 % with BG 7, nom. x0.2646/y0.4057
	< 1 % with OG 530, nom. x0.5417/y 0.4538
• nominal x 0.4476, y 0.4074	< 1 % with VG 3, nom. x0.3656/y0.5272
	< 2 % with RG 6, nom. x0.6860/y0.3135
	< 20 % with SFK 100, nom. x0.1450/y0.0426
	< 1 % with SFK 101, nom. x0.4299/y0.5376
	< 2 % with SFK 102, nom. x0.5457/y0.4511
X_{short} f_1 Error	≤ 8.5 %
X_{long} f_1 Error	≤ 7 %
Y f_1 Error	≤ 4 % (also photopic vision detector)
Z f_1 Error	≤ 3 %
f_2 Cosine Error	≤ 3 % (for illuminance measurements)
Cal. Uncertainty	≤ 1.1 % ((V(λ))
Size & Weight	45 mm dia. x 20 mm; 2 m cable with -4

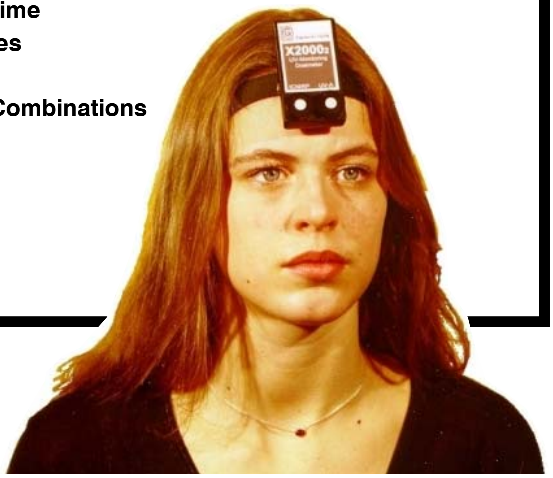
Dimensions



CT-4501

Ordering Information	
HCT-99	Luminous color meter with CT-4501-4, hard carrying case, batteries, USB cable, USB DLL and manual
Luminance Option	See section light detectors: SRT front lenses for 45-type model CT-4501
Luminous Flux Option	See section integrating spheres
OS-X1	Software for remote control operation of the X11

© **Personal Dosimeter for Phototherapy and UV/Light Hazard Applications**
© **Data-logger to Document Irradiation as Variable of Measurement Time**
© **Free Programming, High-speed and Long-term Measurement Modes**
© **Large Data Storage Capacity of 129,000 samples**
© **ACGIH/ICNIRP, Erythema, UV-A, UV-B, UV-C Detectors and other Combinations**
© **Cosine Corrected Field-of-View**
© **Compact and Lightweight (60 g / 0.13 lb)**
© **Low Power Consumption Electronics for Long Battery Life Time**
© **RS232 Interface for Initialization and Data Read Out**
© **Windows XP Compatible Software**



Incoherent Optical Radiation
In simple terms incoherent optical radiation refers to radiation, other than that emitted by lasers, in the wavelength range between 100 nm and 1 mm.

Health Risks from Incoherent Optical Radiation
Shallow penetration depth restricts the health risk primarily to the eye and skin.

- Acute effects to skin
  - ©Erythema
  - ©Burning
- Chronic effects to skin
  - ©Skin cancer
  - ©Skin ageing
- Acute effects to eye
  - ©Photochemical and thermal retinal damage
  - ©Photokeratitis
- Chronic effects to eye
  - ©Cataract development
  - ©Degeneration of the retina

Light Protection
The cumulative effects of incoherent optical radiation on the skin and eye are under ever increasing scrutiny. Longer exposures to higher levels of solar radiation plus artificial UV sources account for this.
Dose levels are on the rise due to:

- reduced atmospheric UV shielding
- longer leisure time
- longer lifetime
- growing occupational use of high powered UV sources

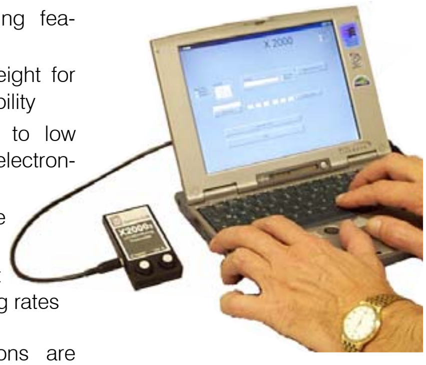
As a result professional associations, institutes of health, radiation protection bureaus, dermatological institutes, responsible lighting manufacturers, insurance companies and others are interested in understanding the risks posed by natural and any artificial light sources used in industry and limit additional exposure dose during the work period.

Light Dose
When evaluating potential occupational harm from incoherent optical radiation, it is the effective radiance (or the time integral of the radiance) that is a concern for the retina, whereas for the skin, cornea and lens of the eye the critical quantity is effective irradiance (or the exposure or dose).

Light Dose Measurement
Photobiological sensors are available which allow detection of the exposure dose. Response time issues and missing information about peak exposure and exposure interruptions are a concern with these sensors.
Personal data-logging radiometers that can be worn by the subject enable recording and documenting of measured irradiation as it varies of the measurement time to allow a more precise evaluation of the exposure profile.

X-2000 Personal Dosimeter
The X-2000 meter series was developed as a personal UV monitoring dosimeter, which enables a point-by-point measurement of individual exposure tracked chronologically over a specific time period. A complete continuous profile of the measured signals is logged.
To fulfill the need of a personal dosimeter the X-2000 series offers several outstanding features:

- small size and low weight for better subject acceptability
- long battery life due to low power consumption electronics with flash buffer
- large data sample memory
- free programming, fast and long-term sampling rates

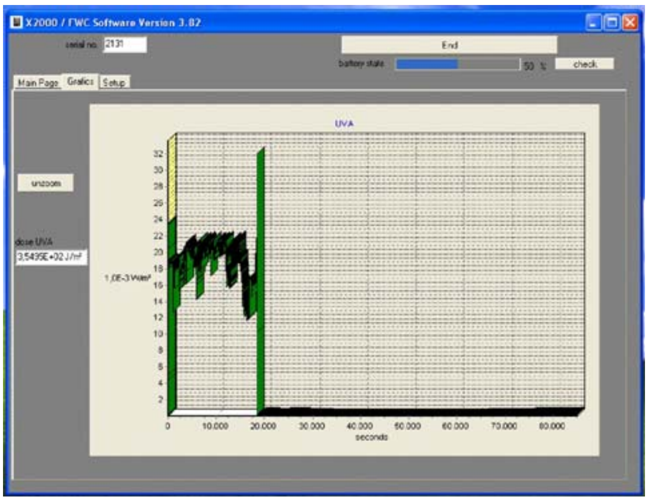


Spectral Sensitivity
Various spectral functions are offered to fulfill different health hazard assessment requirements (see following page).

Cosine Corrected F.O.V.
Each detector is supplied with a cosine corrected field-of-view for precise, effective irradiance measurements.

Software
Initialization and data read-out via the RS232 interface is made easy with optional windows compatible OSDL software. Data storage in CSV file type allows export to programs like Excel.

Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities and NIST standards.
Calibration of the detector(s) irradiance sensitivity plus an individually measured plot of its spectral sensitivity is part of the calibration certificate.

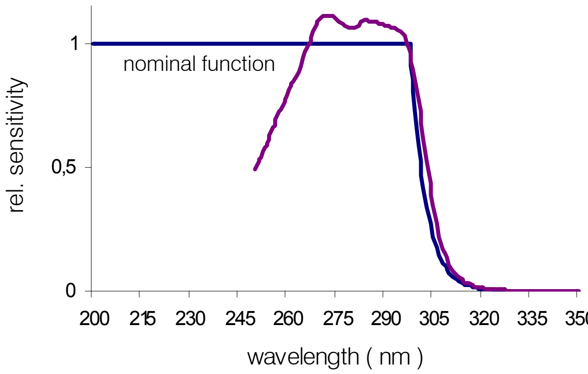


X-2000 Applications

The X-2000 series can be used in different health hazard applications because it can be configured with various detectors with different spectral sensitivity characteristics. This page describes those detectors.
Our **Light Measurements Guide** shown in our catalog and website offers additional tutorial and application notes concerning UV / light hazard measurements. Please contact the factory to discuss custom design X-2000 series instruments.

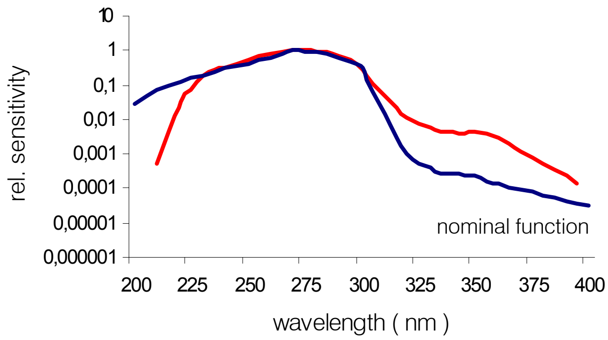
Erythema

The typical symptom of erythema (sunburn) is acute skin inflammation caused primarily by over exposure to the UV-B component of solar radiation. Present opinion is that UV-A also plays a part in causing erythema because there is so much of it present in sunlight. Photobiological investigations have shown that intensive exposure to UV during leisure time and at work increases the risk of skin cancer. Children in particular should be protected from strong UV radiation as the damage is cumulative. The dose received in the first years of life can be an important factor in the development of skin problems in later years.
By definition Erythema is measured in effective irradiance and dose.



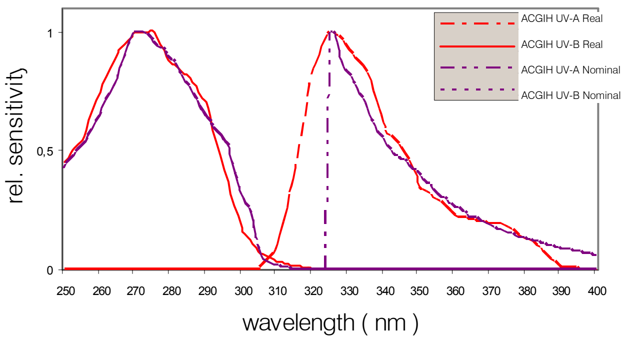
ACGIH/ICNIRP

The spectral weighting function for the acutely harmful effects of UV radiation, was developed by the *American Conference of Governmental Industrial Hygienists (ACGIH) and* the *International Commission on Non-Ionising Radiation Protection (ICNIRP).*
Upon examination of the spectral curve describing this function, it is important to note that the spectral effectiveness in the UV-C and UV-B ranges is very high as compared to the UV-A range.
ACGIH-ICNIRP Threshold Limit Values for the maximum permissible exposure of the skin are defined over the wavelengths from 200 to 400 nm. The limits of maximum permissible exposure for the eye in the range 200 (180) to 400 nm and 315 to 400 nm (UV-A) are defined separately. ACGIH-ICNIRP TLVs are specified in effective irradiance and dose.



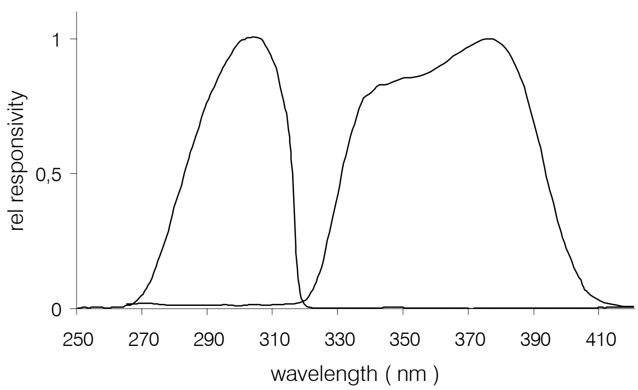
$\text{ACGIH/ICNIRP}_{\text{Skin}}$ for UV-A Rich Sources

Measurement of UV radiation for the purpose of UV hazard assessment is the subject of the new **DGZfP-Merkblatt EM6** regulation. EM6 specifies that all UV sources used in fluorescent penetration test applications must be classified and regularly tested. Protective measures must be taken for the operators depending on the safety class.
The classification criteria is the E_{eff} UV hazard effective irradiation based on the ACGIH/ICNIRP guideline. The built-in eye protection devices mounted on stationary testers enable EM6 to state a possible risk to the skin only. Stray light risk to the eye is low because of the radiation's diffuse character. **Because of the UV-A rich spectral source characteristic** a two cell (ACGIH-UV-B 250 to 325 nm and ACGIH-UV-A_{skin} 325 to 400 nm) design is needed to completely isolate UV-A from UV-B&UV-C radiation.

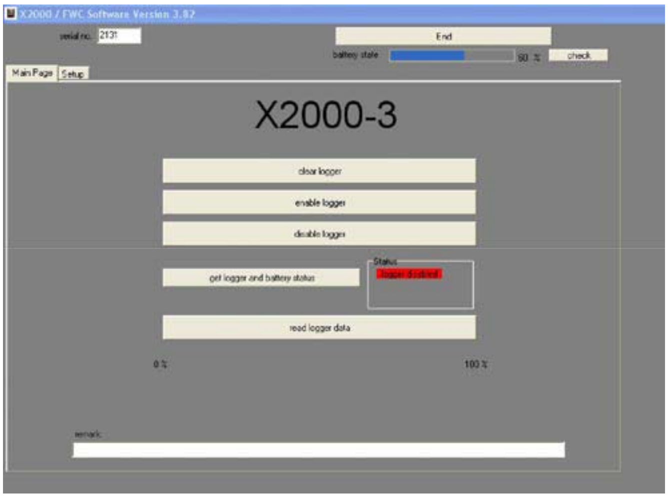


UV-A & UV-B

UV is widely used by dermatologists in the treatment of certain skin diseases like Psoriasis and Vitiligo. Whole body exposure booths and hand and foot units employing light sources which emit broadband UV-A, UV-B and combinations of UV-A and UV-B are used to irradiate the patient.
In PUVA photo therapy, also called photo chemotherapy, UV-A is applied in combination with a photosensitizing agent which is taken in pill form or applied topically to the skin. This medication called psoralen, giving rise to the acronym PUVA, makes the skin more sensitive and responsive to the UV-A (315-400 nm) wavelengths.
Due to the risks of premature skin ageing and skin cancer from prolonged exposures, also with consideration to skin type, PUVA is only recommended for moderate to severe cases of Psoriasis.
UV-B broadband treatment is normally administered without a photosensitizing agent. It is considered safer than UV-A for wavelengths between approx. 290 to 315 nm, since it does not penetrate as deeply into the skin and is more energetic allowing shorter overall exposure times. However, it is generally accepted that wavelengths below 290 nm produce more erythema which can actually inhibit the therapeutic effects of the longer wavelengths.



The wireless X-2000 personal dosimeter is a self contained device. A computer is needed to initialize the measurement mode and the start/stop time of the measurement and also the data read-out transfer via the RS232 interface. The following descriptions are based on the current version of the X-2000 and optionally supplied Gigahertz-Optik software. A complete description of the interface and command list is supplied with the meter which allows skilled operators to write their own software as well.



Measurement Mode Initialization

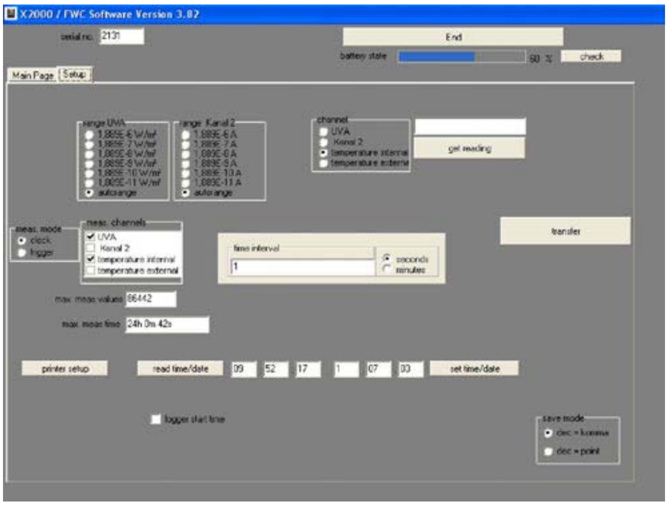
Before the measurement is started, the user has to initialize the measurement mode and the start and stop time. Initialization is done via the RS232 interface.

Irradiance and Temperature Measurement

In a two detector configuration sampling by one or two detectors can be selected. All X-2000 versions are supplied with an internal temperature sensor which allows sampling of the operating temperature condition in field service applications. The measurement range is –30 to +85°.

High-speed Data-logger Mode

This mode is selected if light flashes or light sources with fast intensity changes are to be measured. The sampling rate can be selected between 5 ms and 1,984 s. The integrating time must be set to a shorter time than the sampling rate. The gain dependent slew rate of the signal amplifier must be considered as well as the gain switching time.
If a maximum sampling rate is required, manual range setting and using one detector only is recommended.



Variable Integrating Time

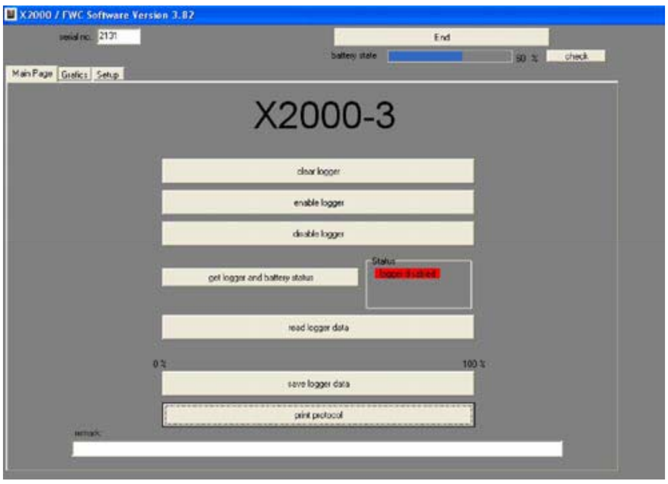
As with most Gigahertz-Optik meters, all X-2000 versions offer selectable integrating times. This is achieved by the averaging of multiple measurements with the shortest integrating time at 1 ms. This function allows an adjustable selection of long integrating times for low (noisy) signals or short integrating times for fast measurements. Besides the integrating time, the slew-rate of the signal amplifier must be considered. Slew-rate is gain dependent, specified from 3 ms to 30 ms.

Manual and Auto-ranging

The X-2000 offers six gain ranges that can be selected manually or automatically. In fast measurement applications the gain switching time must be considered. This depends on the integrating time selected and number of gain ranges switched. In automatic gain mode the sampling rate should not be shorter than the max. gain range switching time!

Long Term Data-logger Mode

This mode is selected if data over a long measurement period must be sampled. The sampling rate can be set between 1 s and 127 min. To optimize battery life the meter can be set to "sleep-mode" between the measurements which reduces power consumption to only 5 μA.



Calculating Maximum Measurement time

To calculate the max. measurement time, first the memory requirement for one sample must be calculated (see specs.). Then the max. data storage capacitance of 518,656 Bytes must be divided by the calculated memory requirements. The battery capacity should be checked against the current consumption expected for the different operation modes (see specs.).

Programmable logger Start time

The data-logger can be activated by unplugging the RS232 connector from the meter, by a signal higher than the trigger level or by a start date and time. On disconnection from the computer a LED flashes and confirms the set-up is active.

RS232 Interface

Because of the large amount of power consumed by the RS232 interface, remote control operation of the X-2000 is not recommended. RS232 connection should only be made for initialization or data read-out and disconnected when not in use.

Gigahertz-Optik

X-2000 Specifications & Ordering Information

Specifications:

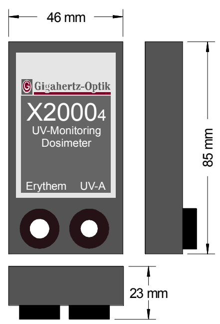
Measurement Ranges (typ. Values)		
UV-A Irradiance	50 nW/cm^2 to 180 mW/cm^2 with max. 1 nW/cm^2 resolution	
UV-B Irradiance	165 nW/cm^2 to 670 mW/cm^2 with max. 3.3 nW/cm^2 resolution	
ACGIH Irradiance	500 nW/cm^2 to 2000 mW/cm^2 with max. 10 nW/cm^2 resolution	
Erythema Irradiance	165 nW/cm^2 to 670 mW/cm^2 with max. 3.3 nW/cm^2 resolution	
ACGIHskin Irradiance	UV-A : 25 μW/cm^2 eff. to 0,1 mW/cm^2 eff. with max. 0,5 μW/cm^2 eff. resolution UV-B/C: 50 μW/cm^2 eff. to 0,2 W/cm^2 eff. with max. 1nW/cm^2 eff. resolution	
Internal Temperature	-30°C to +85°C, (-22 to 185°F), max. resolution 1/10°C	
Data-Logger		
Logger Storage Capacity	1.042.944Bytes (1 Mb)	
Memory Requirements for Logger Data:	Status	1 Byte
	One detector	3 Byte
	Two detectors	6 Byte
	Internal temperature	2 Byte
	Voltage input*	2 Byte
Logger Data Sample Rate	sleep mode off	5 ms to 1.984 s
	sleep mode on	1 s to 127 min
Power Consumption	In Operation	5 mA (at 1.3 V)
	Flash Writing	200 mA for 20 ms
	Sleep Mode	5 μA
	RS232 Connected	16 mA
General Technical Data:		
Max. Number of Detectors	2	
Measurement Ranges	6 (max. values 200 pA – 20 μA)	
Integration Time	1ms - 2s (current signal only, see slew-rate in gain range specification)	
Calibration Data	Max. 255 data sets for each current input	
Voltage Measurement	1 input (default gain setting: 100). Not activated in standard models.	
Interface	RS232, 8D, 1S, N; Baud rate: 57600 or 9600	
Operating Voltage	1.0 to 1.6 V (optional input 1.8 to 3.2 V, not activated in standard version)	
Operation Temperature	5 to 45°C (41 to 113°F) recommended, -20 to 70°C (-4 to 158°F) with reduced battery life time and accuracy	
Size / Weight	85 mm x 46 mm x 23 mm / 60 g (3.4 x 1.8 x 0.8 in / 0.13 lb)	
Battery	type N (model “Lady“)	
Software Functions	Windows 9x / NT4.0 / XP; programmable data-logger, programmable start time; logger data in "CSV" format for readable file (e.g. by Excel).	

Range Specifications

Range* (A/V)	Max. Input Value* max.	Slew-Rate* (10 - 90%)	Error* (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),
1x10-5	20.00 μA	3 ms	0.2 % + 0.05 %
1x10-6	2.000 μA	3 ms	0.2 % + 0.05 %
1x10-7	200.0 nA	3 ms	0.2 % + 0.05 %
1x10-8	20.00 nA	3 ms	0.2% + 0.05 %
1x10-9	2.000 nA	30 ms	0.2 % + 0.05 %
1x10-10	200.0 pA	30 ms	0.2 % + 0.05 %

*electronic specifications

Dimensions:



Ordering Information	
OS-X2000	Software for initialization and data read-out of the X-2000 via RS232.
X-2000-1	UV-Erythema instrument including BHO-06 hard case, battery, RS232 interface cable and handbook
X-2000-2	ACGIH and UV-A instrument including BHO-06 hard case, battery, RS232 interface cable and handbook
X-2000-3	UV-A instrument including BHO-06 hard case, battery, RS232 interface cable and handbook
X-2000-4	UV-Erythema and UV-A instrument including BHO-06 hard case, battery, RS232 interface cable and handbook
X-2000-5	UV-A and UV-B instrument including BHO-06 hard case, battery, RS232 interface cable and handbook
X-2000-6	UV-C (254 nm) instrument including BHO-06 hand case, battery, RS232 interface cable and handbook
X-2000-7	$ACGIH_{Skin}$ (250 to 325 nm & 325 to 400 nm cell) instrument with hard-case, battery, RS232 interface cable and handbook

P-2000 2-Channel Bench-top Optometer

- © **Two Channel Bench-top Optometer for Laboratory, Quality Control and Production**
- © **Universal Use in Any Light & Optical Radiation Measurement Application**
- © **Calibration Data Connector for faultless Detector Exchange**
- © **Measurement of DC, AC and Flash Signals**
- © **Signal Range from 0.1 pA to 2 mA**
- © **Adjustable Integration Time, 100 μs to 6 s**
- © **CW, Flash Energy, Dose, Data-Logger, RS232, IEEE488 Operation Mode**
- © **Analog Output**
- © **Optional Window Software**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

The P-2000 Optometer is an efficient dual-channel instrument designed for multipurpose use in any photometric, radiometric, transmittance, reflectance, absorbance application.
It offers many high-level technical features combined with a brilliant display and several different measurement modes.
These functions and the possibility of remote control operation by two different interfaces enable the P-2000 for the universal laboratory use as well as for process control integration.

Calibration data connector:

An unique feature of the P-2000 is its detector head calibration data connector. All data pertaining to a detector including the model and serial number are stored in the coupler. When connected to the meter, this data is automatically transmitted and the system is ready to go. This guarantees faultless handling of the instrument when used with any number of different detector heads as it is usual in laboratory use.

Large dynamic range:

The P-2000's wide signal range of 0.1 pA to 2 mA covers the dynamic range of most current semiconductor photodiodes for nearly unrestricted use in any light measurement application.

2 Signal Channel

The two signal channels do allow the connection and parallel operation of two detectors. This allows the use of the P-2000 in application with extended wavelength laser power measurements, dual wavelength-band measurements, attenuation measurements with variable reference e.g.

Variable measurement time:

Each channel of the P-2000 offers a fast signal input with 2 to 10 ms slew-rate (gain depending). The fast sample rate of 100μs allows the use of the P-2000 as a fast single channel data logger. The integration time is adjustable by average calculation of up to 6 sec. This is an other key feature for individual application set-up's .

Precise measurements:

The P-2000 offers a high linear 12bit ADC input with 8 manually or automatically selected gain ranges. The max. error within this large dynamic range 0.2 %.

Remote control:

A bi-directional RS232 serial interface and the IEEE488 interface allow external remote control operation. Optional Windows based software is available for a quick turn-key solution via the RS232 interface. The complete command set supplied in the meters manual allows the user to develop his own program.

Process integrating:

In combination with the optional available relay switch board the P-2000 is the right tool for process control with low-ok-high indication. The menu controlled set-up of the limiting values is simple.

Multiple applications:

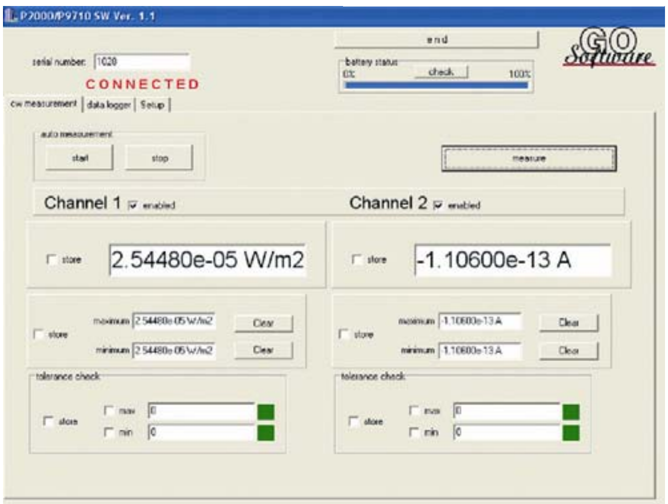
The P-2000 can be combined with most of GO's detector heads for photometric and radiometric measurement quantities.

Many functional modes:

The unit's many functional modes of operation includes CW, dose, pulse-energy, data-logger measurements and many more. If the sixteen different operation modes should not include the one of your need we do offer custom design modifications.

Re-Calibration

For re-calibration by calibration labs or within industrial processes the factory programmed calibration factors can be changed with the OS CAL software via the RS232 interface. The IEEE488 interface allows external remote control.

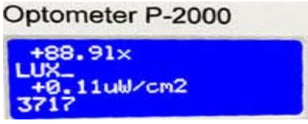


P-2000 Applications

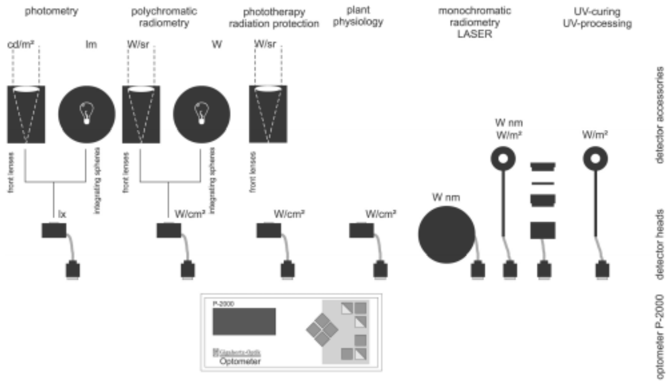
Because of it's multiple functional modes and high-level specifications, the bench-top meter P-2000 is the right instrument for laboratory and process applications. GO's wide range of detector heads enables the P-2000 to be used in many different photometric and radiometric applications. It's two signal channels extend the application range by attenuation, transmission and reflectance measurements. The following page offers typical P-2000 application's. Our **Guide to Light Measurement's** available in our catalogue and website offers additional tutorial and application notes.

Universal Light Meter

Even in the computer dominated world instruments with large size, brilliant display needs to exist. The reasons are all the applications where the operator needs the direct feedback to his operation and all the stand-alone set-ups.
But it's not only the brilliant blue back-lighted display. It's the combination of high-grade specifications with safe and universal handling which had made the P-2000's to the right choice for many laboratories and production facilities. The calibration data connector for



example ensures that you will never forget the up-date of the meter, if you change to an other detector head. You can also use the meter while one of the detector heads is out for re-calibration. New detector heads, purchased years later than the meter are just plugged in and work. Multiple operation function modes ensure highest flexibility in the use of the P-2000. And last not least



the RS232 or IEEE488 interfaces enables the use of the P-2000 optometer in remote control operation.

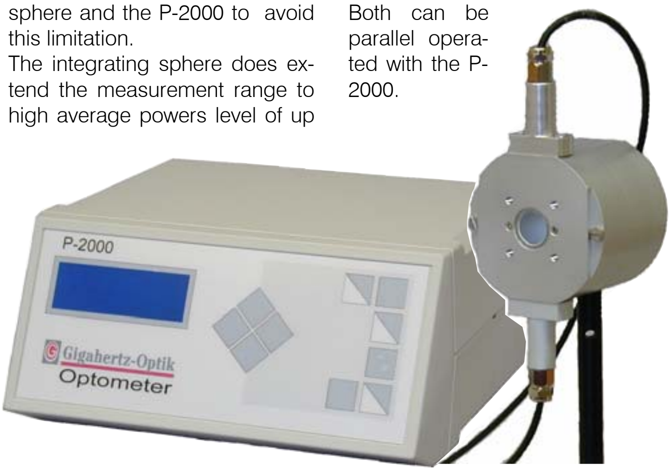
Photostability Testing

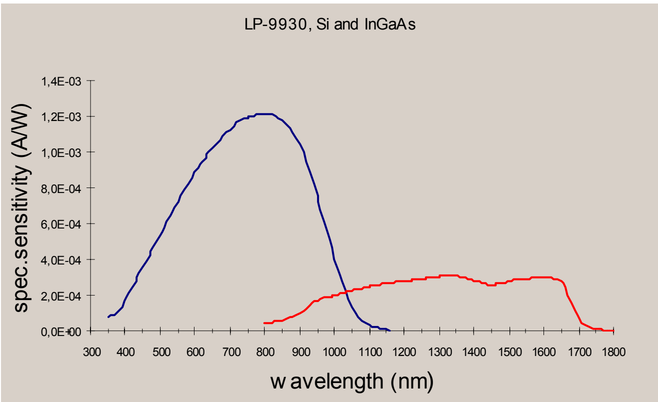
The current ICH (International Conference for Harmonization) guidelines specify that drug and drug products must be photo--tested to ensure that exposure to light does not cause photochemical degradation of the product or packaging. The product under test must receive a ***measured*** dose of both UV-A (200 watt-hours per square meter) and Visible (1.2 million lux-hours) optical radiation exposure. This requires both radiometric and photometric measurements in terms of illuminance in lux and UV-A (315 to 400 nm) irradiance in W/m² multiplied by exposure time in hours.

With UV-3717-2 and VL-3701-2 Gigahertz-Optik offers a UV-A irradiance and photometric illuminance detector head which fulfills the requirements for the evaluation of the UV-A and photometric exposure in photostability testing application. The P-2000 is the effective meter to operate both detectors in parallel

Extended Wavelength Range Laser Power Meter

Semiconductor photodiodes offer low noise and high sensitivity, but are limited in the spectral sensitivity range and in high power detection.
Two photodiode, such as a silicon and InGaAs one, can be combined with an integrating sphere and the P-2000 to avoid this limitation.
The integrating sphere does extend the measurement range to high average powers level of up to few-hundred Watt and peak powers up to the kWatt range. The sphere's integration function does allow the parallel use of two diodes in the same beam which will extend the wavelength range from 350 to 1750 nm without the need to replace the detector. Both can be parallel operated with the P-2000.





Luminous flux Meter for Light-guides, Endoscopes & LED's

Spot sources are light sources, which emit directional in one axis. Typically the light beam has a convergent or focused shape. The measurement of the luminous flux in lm of such light sources requires a detector head which collects all light independent of beam shape, beam diameter and spot intensity. Integrating sphere based photometric detectors are a practical choice for this application. Different sphere diameter offer flexible selection of the measurement port diameter and max. power level. The spheres integrating function makes the measurement independent from the beam shape. Combined with a photometric corrected detector head, such as model VL-3701 and the P-2000 optometer a precise instrument for luminous intensity measurement is given. Calibration standard lamps and software is offered for re-calibration by the end-user in the case of frequent use of the instrument.

Detector Heads for use with P-2000 >> Chapter Detector Heads

P-2000 Operation Function Modes & Specification

Operation Functional Modes

Because of it's unique electronic design and it's powerful micro-processor the P-2000 optometer is more than just a simple instru-ment for light intensity readings. Sixteen different operation func-tion modes in combination with a variable measurement parameter set-up function makes the P-2000 to on of the most flexible meter available. Because of that it's in manual and remote control use in process control, long-time stability search, service, teaching and R&D application. This page will show the available function at the dead-line of this catalog. If you do not find your function mode pls. ask for up-dates and custom modification.

CW Measurement (Ch1 or Ch2 or Ch1&2)

CW mode is used to measure continuous DC or AC signals with the selected integration time from 100 μs to 6s. Beside the measurement value and meas-urement quantity the connected detector/selected wavelength is shown in the lower line of the display. Manual and auto-rang-ing operation.

CW Offset (Ch1 or Ch2 or Ch1&2)

A constant offset value, such as given by ambient light, can be subtracted from the CW meas-urement value.

CW Minimum or CW Maximum (Ch1 or Ch2 or Ch1&2)

Together with the measurement value the min. or max. value reached during the measure-ment period is displayed. during a measurement period (erased by pressing 'reset' button).

Peak Minimum or Maximum, Peak to Peak (Ch1 or Ch2)

This modes allow to analyse the signal stability within the selected integration interval e.g. flicker of light sources. The min., max. or p-p values are displayed to-gether with the CW average value. Only signals longer that the gain dependent slew-rate (see tabular below) can be measured.

I-Effective (Ch1 or Ch2)

Evaluation of the effective lumi-nous intensity of a single light flash according to the Schmidt-Clausen method. The measure-ment is manually started with the 'run' botton. The integration time can be selected in the menu function 'set-up/pulse measure-ment time'. The time constant C for daylight (0.1 s) and night time observation (0.2 s) can be se-lected in the menu function 'set-up/IF time constant.

Pulse Energy (Ch1 or Ch2)

Measurement of the energy of single pulses or a pulse chain within the selected measurement time. The measurement time is selected in the menu function 'set-up/pulse measurement time'. The measurement is star-ted with the 'run' botton. In auto-range operation 'UL/ OL" (under/ over-load) is displayed if a gain change is necessary.

Pulse Offset (Ch1 or Ch2)

A offset value, such as given by ambient light, can be subtracted from the I-Effective and Pulse Energy measurement value. 'Static Offset' does subtract a constant value. 'Continuous Offset' does subtract the actual measured value before the pulse measurement is started. Selec-tion in menu 'pulse offset'.

Default Initiation

Resets all parameters to the default condition.

Ratio relative (%), log. (dB), factor (Ref. Ch1 or Ch2)

Measurement of the ratio bet-ween a reference value and the actual measurement value. Dis-played as relative ration (%) or logarithm ratio/attenuation (dB or dBm) or ratio factor.

Reference (Ch1 or Ch2)

The reference value is used for ratio measurements.
The ref. value can be set to 1 with the selected quantity such us 1 W, 1 A.
A CW measurement value can be stored as reference value.
A manual entered value can be used as reference.
The reference value '1.000 mW' can be used to measure the attenuation in dBm.

Hold (Ch1 & Ch2)

Beside the actual measurement value a current reading can be 'frozen' by pressing 'reset' but-ton.

CW Level Check (Ch1 or Ch2 or Ch1&2)

Compares the measured CW va-lue with stored pre-set lower and upper limit values. The actual measurement value and it's sta-tus is displayed. The limit values can be entered manually or via the RS232. The relay board P-9710Z-02 can be remote con-trolled to indicate the status by external lamps or integrate the meter in process control applica-tion.

Dose (Integrated Energy) (Ch1 or Ch2 or Ch1&2)

Measurement values are accu-mulated with a logger rate of 1 s and displayed a dose. The measurement can be manually started and stopped or be auto-matically stopped at a max. dose measurement time (1 s to 1,000 h) or a max. dose value. The ac-tual measurement status ca be displayed

Automatic Data Logger (Ch1 or Ch2 or Ch1&2)

Up to 12,288 measurement val-ues can be stored with a sam-pling rate of 0.1 to 6000 s.

Manually Data Logger (Ch1 or Ch2 or Ch1&2)

Up to 150 individual data records (meas. values & parameters) can be stored by pressing the run button.

Manual Calibration Data

Individual calibration correction data can be manually entered.

Remote Control

Instrument set-up for remote control operation either for the RS232 or for the IEEE488 inter-face.

IEEE488 address

Sets the address for the IEEE488 communication.

Specification:

Range and Uncertainty Specification

Range (A/V)	Range max. signal	Slew-Rate (10-90%)	Error (with offset compensation) 1 year 23° C +/-5° C +/-(% of reading + % of range)	Gain (A/V) Analog Output
1 x 10^{-3}	2.000 mA	2 ms	0.2 % + 0.05 %	1 x 10^{-3}
1 x 10^{-4}	200.0 µA	2 ms	0.2 % + 0.05 %	1 x 10^{-3}
1 x 10^{-5}	20.00 µA	3 ms	0.2 % + 0.05 %	1 x 10^{-5}
1 x 10^{-6}	2.000 µA	3 ms	0.2 % + 0.05 %	1 x 10^{-5}
1 x 10^{-7}	200.0 nA	4 ms	0.2 % + 0.05 %	1 x 10^{-7}
1 x 10^{-8}	20.00 nA	4 ms	0.2 % + 0.05 %	1 x 10^{-7}
1 x 10^{-9}	2.000 nA	10 ms	0.2 % + 0.05 %	1 x 10^{-9}
1 x 10^{-10}	200.0 pA	10 ms	0.2 % + 0.05 %	1 x 10^{-9}

P-2000 Specification & Ordering Information

Specification:

Signal Input	
Detector Input	Two photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 8 decade stepped gain ranges with max. gain signal values from 2.000 mA to 200.0 pA . Manual or automatic range switching. One 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 100 μs time interval. Longer integration (100 μs to 6s) through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz (6s integration time setting) to >300 MHz.
Zero Setting	Gain independent offset subtraction of unwanted ambient light signal.
Detector Connector	9 pin DSUB-socket . Detector heads with calibration data connector (type –2).

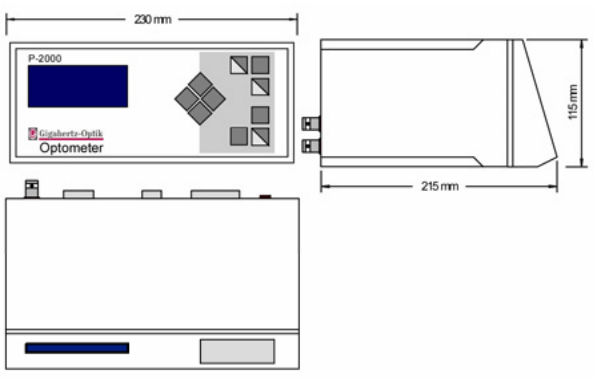
Function	
Parameter Settings	Menu controlled parameter set-up. Retention of the last settings in continuous memory. 10 function buttons.
Measurement Quantity	Ampere calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to display absolute photometric or radiometric quantities. Calibration data stored in calibration data connector of the detector heads manually entered into the meter storage.
Dose Measurement	Integration of the measurement signal with 1 s sampling rate. Adjustable max. measurement time from 1 s to 1000 h. Adjustable maximum dose limit value. Current status display function.
Data Logger	Storage of up to 12,288 readings. Adjustable sampling rate from 0.1 to 6000 seconds. Manual recording mode. Display of readings stored in the flash Eproms on the display or on computer using the RS232 interface and software.
Analog Output	Two, gain dependent: 0 - 200 mV or 0 - 2 V (10 kΩ internal resistance). BNC type sockets

General	
Display	LCD module, LED backlight illuminated, 4 rows x 20 character
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	230 mm x 215 mm 115 mm / 800 g (9.1 x 8.5 x 4.5 in /1.8 lb).
Serial Port Settings	RS232 (9600 baud, 8 data bits, 1 stop bit, no parity) 5 pin cylindrical TRIAD01 connector..
Power supply	Battery or AC operation. Built-in rechargeable lead battery, 6V,0.5 Ah. Approx 6 h with display illumination. Battery charge under 8 % is displayed. Operation from AC plug-in power supply 230V/50 Hz (other values on request) with specific U/I recharge characteristic.

Interface	
RS232	9600 Baud, 8 data bit, 1 stop bit, no parity. TRIAD01 / 5 pin connector with integrated analogue output.
IEEE488	AH1, SH1, L4, T4

Detector Head / Measurement Output	
Detector Heads	All available detector heads with –2 type calibration data connector. See chapter ‘detector heads’ to select the detector head for your application.
Data Connector	Storage of sensor data such as detector model number, serial number, calibration data . Calibration data of integral sensitivity or spectral sensitivity with or without accessory. Selection of the calibration data or the wavelength in the menu function of the P-9710. Automatic data transfer if detector head is connected to the meter.

Dimension



Ordering Information

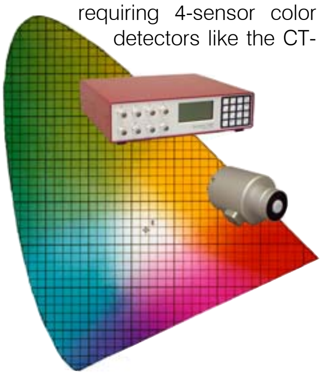
P-2000-1	Optometer with gain dependent slew-rate, rechargeable battery with plug-in power supply and manual
Detector Heads	All Gigahertz-Optik detector heads with –2 type calibration data connector (example VL-3701-2)
P-2000Z-01	RS232 Interface Cable to connect P-9710 to a PC or P-2000Z-02 Relay Motherboard.
P-2000Z-02	Relay Motherboard (power supply and housing not supplied)
P-2000Z-1/2	Adapter cable to connect detector with BNC-type connectors to P-2000
P-2000Z-2/1	Adapter cable to connect detector with calibration data connector (-2) to meters with BNC-type socket input
OS-P2000	Software for remote control of the P-2000-1, including OS-CAL.
OS-CAL	Software to enter calibration data via the P-2000 meter into –2 type data connector
BHO-08	Hard -shell Case to carry and store the P-2000 with accessories
BHO-09	Hard -shell Case to carry and store the P-2000 with accessories

P-9801 8-Channel Synchronous Optometer

- **8-channel Bench-top Meter for Laboratory Use and Application Integration**
- **Universal Use in any Light & Color Measurement Application**
- **Synchronized Operation of up to 8 Detectors or two CT-37 Color Detectors**
- **Measurement of DC and AC Signals**
- **Wide Detector Signal Dynamic Range from 0.1 pA to 2 mA**
- **100 μs Fast Sampling Rate**
- **Adjustable Integrating Time from 1 ms to 10 s**
- **CW, Dose, Data-Logger, Color, ext. Trigger RS232, IEEE488 Operation Mode**
- **Optional Windows Software**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

There are many applications for ***multiple detector head arrangements*** in light measurement. Examples include luminous color measurements of light sources requiring 4-sensor color detectors like the CT-3701, profiling or monitoring of irradiance dose for process control at various locations in UV curing or for multi-wavelength radiometry for UV-A, UV-B, VIS and NIR irradiance measurements.

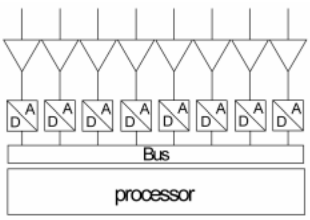


Desirable features of multi-channel light meters used for these jobs would include:

- simultaneous measurement of all detector channels
- wide detector signal dynamic range
- short and variable measurement time
- fast, multi-channel data-logging
- remote control operation

The P-9801 offers all of these features. It is a highly efficient eight-channel optometer designed for multipurpose use in any photometric, radiometric and colorimetric application.

Eight Identical A/D Channels
Eight identically built photocurrent-to-voltage amplifiers and eight 12 bit highly linear analog-to-digital converters (ADC) enable signal digitization of the 8 signal amplifiers at exactly the same time.



Wide Dynamic Range:
Each channel's wide 0.1 pA to 2 mA signal range covers the dynamic range of most current semiconductor photodiodes for nearly unrestricted use in any light measurement application.

Fast Measurements:
Each channel offers a slew rate of 2 to 10 ms (gain dependent) allowing fast signal detection of events like the switch-on characteristic of light sources or the pulse energy in UV polymerization processes. A quick 100 μs sample rate enables the P-9801 to work as a fast eight channel data logger with >5k sample storage capacity for each channel. In low light level applications the measurement process time can be increased up to 6 s through multi-sampling and calculated averaging of signal.

Precise Measurements:
The 8 manually or automatically selected amplifier gain ranges are calibrated using a traceable current source for a maximum linearity error of 0.2 %. The 12 bit ADC (resolution increases to 14 bit for longer measurement times) offers optimum linearity.

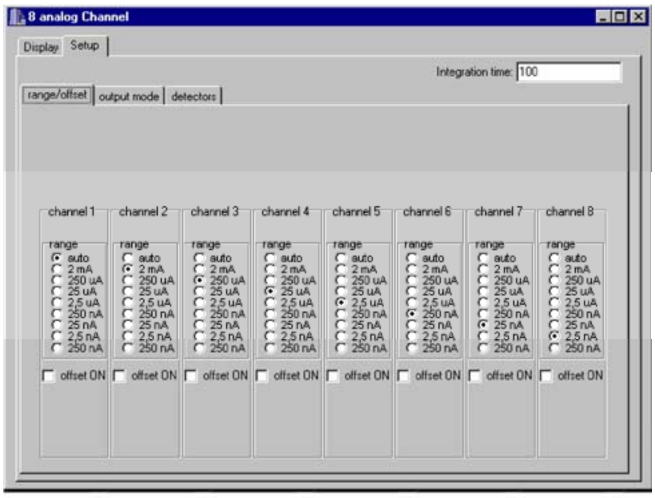
Remote Control:
A bi-directional RS232 serial and IEEE488 interface allows external remote control.
Optional Windows based software is available for a quick turn-key solution or user generated programming is possible using the complete command set supplied. Adjustment of the factory programmed calibration factors can be accomplished using OS-CAL software (optional).

System Integration:
The P-9801 is suitable for integration into other equipment with features like 19" rack mounts.

Metal-shielded Housing
A high quality metal housing offers best EMV shielding for applications in sensitive ambient environments.

Multiple Applications:
The P-9801 is compatible with most of GO's detectors covering any photometric, radiometric and colorimetric measurement quantity.

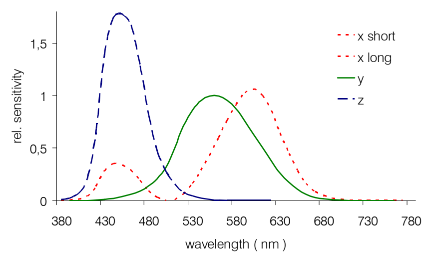
Numerous Functions:
The unit's many modes of operation include CW, dose, data-log and external trigger.



P-9801 Applications

Featuring simultaneous operation of up to eight detectors, the P-9801 is one of the most powerful optometers available today. Additional high end specifications such us large and linear signal dynamic ranging, fast measurement and sampling time makes the P-9801 the right tool for any photometric, radiometric and colorimetric application. All single and multi-cell Gigahertz-Optik detectors can be used with the P-9801. Plus RS232 and IEEE488 interfaces enable integration of the P-9801 in process control applications. This page describes a few typical P-9801 applications.
Our **Light Measurement Guide** available in our catalog and website offers additional tutorial and application notes for the Measurement of Light and Measurement with Light.

Luminous Color Measurements



Color sensations are human sensory impressions and color measurement technology must express them in descriptive and comprehensible quantities.
Colorimetry is the study of the dimensional relations between colors. It assumes that colors can be described by dimensional figures and that these dimensional figures can be measured. In this context, color measurement is a comparison of one color with another, since colors, as sensory impressions, cannot be traced back to other physical quantities such as current or temperature. The comparative instrument used is the human eye. In 1931 the Commission Internationale de l' Eclairage (CIE) recommended, for the unambiguous determination of colorimetric measures, the use of 3 spectral evaluation functions x (λ), y(λ) and z(λ), derived from the measurements made by Guild and Wright for a 2° field of view in humans with normal color vision. For many color measurement tasks it is important to determine the color temperature of luminous objects. According to DIN 5031-P.5, the color temperature t_c of a radiator requiring characterization is the temperature of a Planck's radiator at which it emits radiation of the same color type as that of the radiator being characterized. The P-9801 in use with one or two CT-3701 luminous color detector heads allows the measurement of color (x/y and u'/v' values) and color temperature of self emitting light sources. The CT-3701's four cell detector head design accurately measures high color temperatures or predominantly blue light sources. A small diameter cosine corrected measurement aperture avoids errors caused by non uniform illumination. Simultaneous operation of the four cells allows fast, remote controlled color measurements in production processes or fast sampling rate data-logging to measure the switch-on characteristic of lamps and other events.

Luminous Color Measurements Combined with Photometric & Radiometric Quantities

Along with measuring the luminous color and color temperature of light sources, photometric & radiometric information may be required such as:

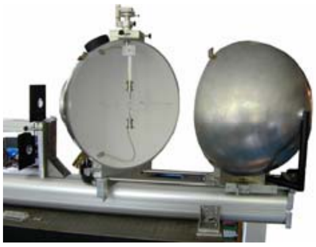
- illuminance & irradiance
- luminance & radiance

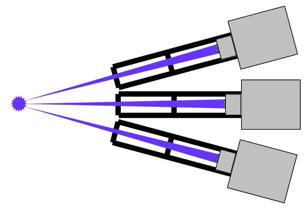
- luminous flux & radiant power
- luminous intensity & radiant intensity

The wavelength range of interest for typical radiometric quantities spans the UV to the NIR. A common radiometric application involves checking the blocking efficiency of UV and IR (heat) blocking filters.
Multi-wavelength range measurements are easily performed using multiple and/or different kinds of detector heads connected to the P-9801. Using the 4-cell design CT-3701 color detector head as the base unit, other input components can be attached to it to fulfill the measurement geometries for different applications :

- standard diffuser (illuminance)
- front lens (luminance)
- integrating sphere (luminous flux)
- steradian tube (luminous intensity)

Integrating sphere based measurement systems can be built for both directional (spot) and non-directional (flood) lamps. Several P-9801s, each with (2) CT-3701 plus steradian front tubes can be operated in parallel via the IEEE488 bus to control the luminous color and luminous intensity distribution of light sources.

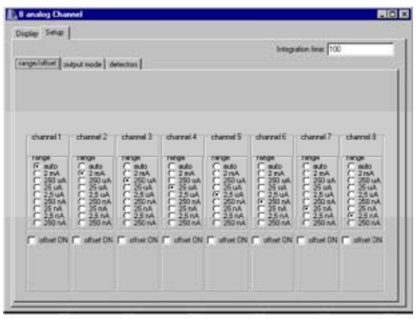




Commonly used radiometric detectors are the UV-3717 (UV-A) & RW-3704 (800-1100 nm).

High-speed Eight-channel Irradiance Data-logger

If the design of a radiation source ensures a uniform irradiation of a surface area, the irradiance only needs to be measured at one point to control intensity. If the source uniformity is not known, the irradiance must be measured at several points to ensure uniform irradiance over the surface area. Also, if the irradiation exposure is very short and if the distance from the surface area to the light source is not constant multi-point irradiation is needed. In three-dimensional UV curing applications the irradiance dose depends on the sample to UV source distance and the irradiation time. To measure the irradiance dose uniformity in these applications a multi-channel simultaneous sampling of signal with data-logging capability is needed to document the irradiation-time profile.
The P-9801 can operate up to eight RCH-type detectors to measure the irradiance of high-power UV-sources used in UV curing processes. This model detector offers a low profile for close to the sample surface measurements. The P-9801's built-in data-logger allows stand alone use or it can be used with the P-9801-RP software (optional) for remote control operation.



Accessories for P-9801 >> Chapters: Light Detector, Integrating Spheres

P-9801 Operation Modes & OS-P9801 Software

Operation Modes

Because of it's fast and precise eight-channel amplifier electronics and 16 bit microprocessor the P-9801 optometer is one of the most powerful optometers available. Several useful functions and user adjustable measurement parameter set-up makes the P-9801 one of the most flexible as well.
Multiple functions, features plus IEEE and RS232 interfaces make the P-9801 ideal for remote control operation in process control, high-speed multichannel data-logging, R&D and many more applications.
This page describes the various functions of the unit. Contact the factory to discuss customized units with other user specified operational modes or complete custom application solutions.

CW Measurement

CW mode is used to measure continuous DC or AC signals at a user selected integration time from 1 ms to 10 s. Readings and measurement units of all eight channels are displayed. User selectable manual or auto-ranging operation.

CW Offset

A constant offset value, such as an ambient light level, can be measured and subtracted from the CW measurement value.

Ratio Relative (%), Relative log. (dB), Relative factor

Measurement of the ratio between a reference value and the actual measurement value. Displayed as relative ratio (%) or logarithm ratio/attenuation (dB or dBm) or ratio factor.

Reference

The reference value is used for ratio measurements and can be set to 1 with the selected unit such us 1 W, 1 A for example.
A CW measurement value can be stored as reference value.
A manually entered value can be used as reference.
The measurement value of an other channel can be used as reference (dynamic reference).

Dose (Integrated Energy)

Measurement values are accumulated and displayed as dose. The measurement can be manually started and stopped or be automatically stopped at a max. dose measurement time or a max. dose value. The actual measurement status can be displayed

Data Logger

Up to 5,957 measurement values per channel can be stored at a sampling rate of 0.1 to 6000 s.

Fast Data Logger

Up to 5,957 measurement values per channel can be stored at a sampling rate of 2 to 100 ms in manual range mode.

Default Initialization

Allows re-set of meter to the standard parameter and mode set-up as supplied by the factory.

Color Measurement

Up to two color detector heads can be simultaneously operated with the P-9801 (channel 1 to 4 and 5 to 8). Color temperature, chromaticity values x/y or u'/v'' and photometric quantity (illuminance, luminance, luminous intensity or luminous flux) are displayed at one time.
Adjustment of factory calibration factors by the end-user is possible. The trigger input of the P-9801 can be used to check the operating temperature of one or two CT-3701 detector heads. The display flashes if temp. drops out of operating range.
If only one color detector is used, the other four channels are available for other detectors. These four readings are displayed together with the color values.

Manual & Auto ranging

Manual or auto ranging operation can be user selected. Manual ranging is recommended for fast measurements or to monitor readings at some constant level.

Self Calibration

Calibration data for a user detector can be adjusted against a known calibration or in-house standard. The measured values of the standard are used to calculate new calibration data.

Analog Output

The P-9801 offers one analog output. One of the 8 channels can be switched to the analog output.

Display Digits

With longer integrating times the ADC resolution will increase up to 14 bits. In this case the displayed measurement value resolution can be increased to maximum of 5 digits.

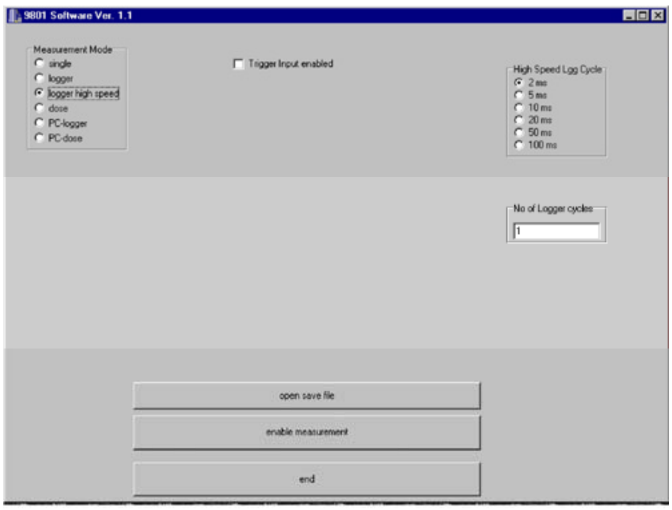
Remote Control

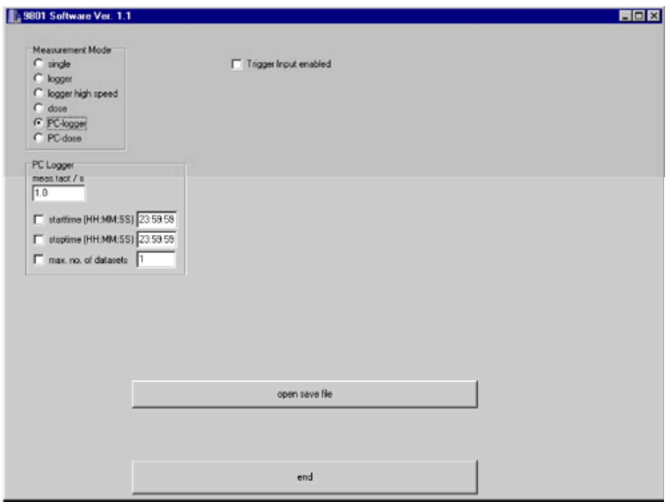
Instrument can be set-up for remote control operation using either RS232 or IEEE488 interface.

IEEE488 Address

Sets the address for the IEEE488 communication.

OS-P9801 Software





Gigahertz-Optik

P 9801 Specifications & Ordering Information

Specifications:

Range and Uncertainty Specifications

Range (A/V)	Range max.	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Gain (A/V) Analog Output
$1x10^{-3}$	2.000 mA	2 ms	0.2% + 0.05%	$1x10^{-3}$
$1x10^{-4}$	250.0 µA	2 ms	0.2% + 0.05%	$1x10^{-4}$
$1x10^{-5}$	25.00 µA	3 ms	0.2% + 0.05%	$1x10^{-5}$
$1x10^{-6}$	2.500 µA	3 ms	0.2% + 0.05%	$1x10^{-6}$
$1x10^{-7}$	250.0 nA	4 ms	0.2% + 0.05%	$1x10^{-7}$
$1x10^{-8}$	25.00 nA	4 ms	0.2% + 0.05%	$1x10^{-8}$
$1x10^{-9}$	2.500 nA	10 ms	0.2% + 0.05%	$1x10^{-9}$
$1x10^{-10}$	250.0 pA	10 ms	0.2% + 0.05%	$1x10^{-10}$

Signal Input

Detector Input	Eight photocurrent to voltage converter amplifiers with following voltage to voltage amplifiers (x10). 8 decade stepped gain ranges with max. gain signal values from 2.000 mA to 200.0 pA . Manual or automatic range switching. Eight 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 100 µs time interval. Longer integration (1 ms to 10 s) through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz (6s integration time setting) to >300 MHz. .
Zero Setting	Gain independent offset subtraction of unwanted ambient light signal.
Detector Connector	8 BNC sockets . Detector heads with BNC connector (type –1).

Functions

Parameter Settings	Menu controlled parameter set-up. Retention of the last settings in continuous memory. 10 function buttons.
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied by calibration correction factor to display absolute photometric or radiometric quantities. Calibration data stored in calibration data connector of the detector heads manually entered into the meter memory.
Dose Measurement	Setting of the max. integration time for all channels, or the max. dose that will end the dose measurement. Start/stop function. Information request of the current status of the dose measurement
Data Logger	Sampling rate 0.1 s to 6000.0 s or fast sampling in steps between 2 ms to 100 ms; max. 5957 stored values / channel.
Color Measurement	Signal inputs 1-4 and 5-8 for detectors A and B. Calculation of the color values x/y or u'/v', illuminance E or luminous flux phi and the color temperature T_c. "lamp selection" for adaptation to different types of lamps, up to 8 of which can be stored; calibration routine for automatic compensation of the stored and measured calibration data of a standard lamp; temperature monitoring via trigger input
Trigger Input	Measurements can be triggered (started) by external event using Trigger Input
Analog Output	BNC socket; output signal from the assigned input amplifier

General

Display	LCD display, LED background illumination (switchable), 160x80 pixels
Operating Temperature	+5 to +40 °C (+41 to +104°F)
Dimensions/Weight	280 mm x 250 mm x 70 mm; 1 kg (11 in x 9.8 in x 2.8 in; 2.2 lb)
Serial Port Settings	RS232 (9600 baud, 8 data bits, 1 stop bit, no parity) 5 pin cylindrical TRIAD01 connector..
Power supply	6.5 - 7.5 VDC / 1A; cavity plug 5.5/2.5 mm, Plug-in AC power supply unit 230 V/50 Hz; 7.5 VDC/1 A; cavity plug 5.5/2.5 mm, inner conductor positive.
Electromagnetic Compatibility	Electromagnetic compatibility is assessed in accordance with EN 61326-1 Class B (noise emission for "living areas", noise immunity for "continuous supervised operation"

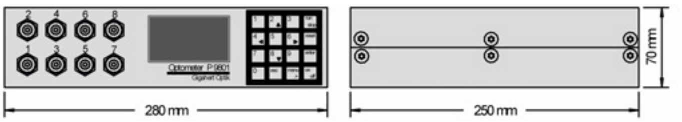
Interface

RS232	RS232, adjustable baudrate 600 - 57600.
IEEE488	IEEE488 with settable device address; optional checksum calculation; for debugging purposes, received commands (Hexadecimal/ASCII) or measurement results can be displayed in parallel to remote operation

Detector Head / Measurement Output

Detector Heads	All detector heads with –1 type BNC connectors. See chapter 'detector heads' to select the detector head for your application.

Dimensions



Ordering Information

P-9801	Optometer with handbook and plug-in power supply
Detectors	All Gigahertz-Optik detector heads with BNC-type (-1) connector
OS-P9801-RP	Software for photo- & radiometric application
OS-P9801-RPC	Software for colorimetric application
BHO-02	Carrying case for P-9801 with CT-3701 color detector head and accessories
P-98Z-01	Rack-Mount

P-9802 Multi-channel Meter

- © **Multi-channel Bench-top Optometer for Process Integration**
- © **Variable set-up of 2 to 36 Measurement Channels**
- © **Measurement of DC and AC Signals**
- © **Signal Range from 0.1pA to 200 ∝A**
- © **20 ms to 4 s Adjustable Integration Time**
- © **CW and Dose Operation Mode**
- © **RS232 Remote Control**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

Arrangements of multiple detector heads are used for many light measurement tasks associated with quality assurance or process control. Typical examples include:

- luminous intensity distribution measurement of directional spot lamps and flood lamps (see the graph on this page)
- determination of the ANSI lumen value of projection equipment using nine or more illuminance detector heads
- matrixes of detectors for 1 : 1 room lighting simulations
- monitoring systems for assessment of effective irradiance for plant physiology in green-houses and climatic chambers
- multi-channel test cabinets used for investigating the aging behavior of lamps, LEDs and other light sources.

Due to the large amounts of data generated, evaluation of these measurement signals is usually carried out under PC supervision or by PLCs.

The P-9802 is designed as a multi-channel instrument exclusively for use under remote control over an RS232 interface. Its electronics design is based on a master board with an external RS232 interface and an internal I²C bus. Up to 18 amplifier modules can be controlled by this internal bus through the master board.

The number of modules is application dependent and allows a very flexible set-up of the P-9802 to individual needs. The basic version of the P-9802 has one amplifier module with two signal inputs. Additional amplifier modules allow the optometer to be expanded up to a maximum of 18 amplifier modules, i.e. 36 signal inputs.

Each module implements a signal amplifier with two switchable signal inputs. A microprocessor controls the operating modes, the input channel switching and the calibration data. The calibration data of each module is stored in eeprom.

The detector heads are connected via BNC sockets located on the front and back panels of the instrument.

Precise Measurements:
The P-9802 offers a highly linear 12 bit ADC input with 7 manually or automatically selected gain ranges. The max. error within this wide dynamic range is 0.2 %.

Multi-application Capability:
The flexibility to combine the P-9802 with most Gigahertz-Optik detector heads enables it's use in a wide application range of radiometric and photometric measurements.

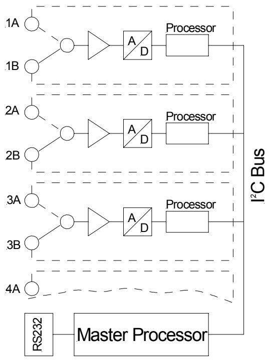
Traceable Calibration
Calibration is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities. Calibration of detector sensitivity as well as an individually measured plot of spectral sensitivity is part of the calibration certificate.

Operation
The P-9802 offers simple operation via RS232 interface.

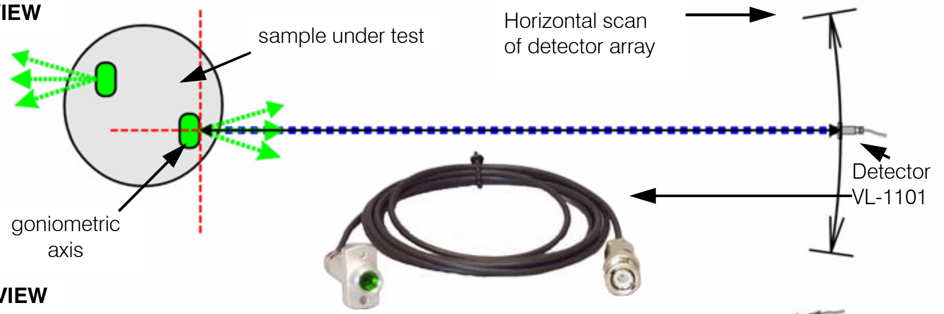
CW Measurement
CW mode is used to measure continuous DC or AC signals .

Dose Measurement
Measurement values are accumulated at a logger rate of 1 s and displayed as dose.

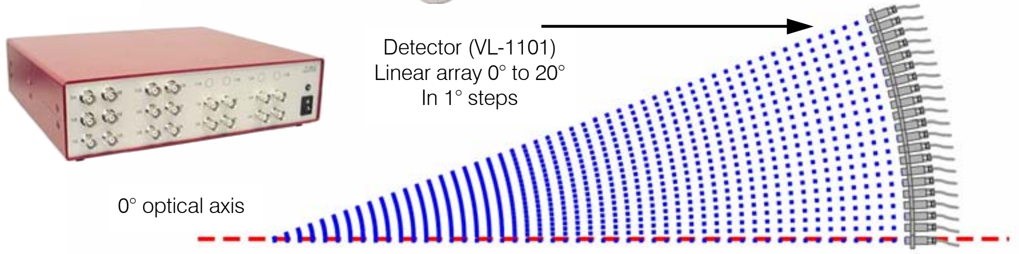
Auto/Manual Gain Ranging
When test signal levels remain in the same range, the gain range can be manually selected to avoid any auto-ranging time delays.



TOP VIEW



SIDE VIEW



P-9802 Specifications & Ordering Information

Specifications:

Signal Input of (one amplifier board)	
Detector Input	Photocurrent to voltage converter amplifier with following voltage to voltage amplifier (x10). 7 decade stepped gain ranges with max. gain signal values from 200.0 µA to 200.0 pA . Automatic range switching. 12 bit ADC with up to 14 bits at longer integration times.
Signal Processing	A/D converter with 20 ms time interval. Longer integration up to 4 s through averaging of multiple measurements.
Frequency Range	Signal conversion from 0.166 Hz to >300 MHz.
Detector Connector	BNC socket.
Signal Channels	2 up to max. 18 identical measuring amplifiers boards, each with 2 switchable signal inputs; simultaneous acquisition of measurements from all A or B channels

Range Specifications

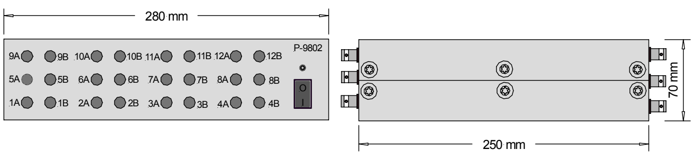
Range (A/V)	Max. Input Value	Slew-Rate (10 - 90%)	Error (with offset compensation) 1 year, 23°C ±5°C ±(% of reading + % of range),	Max. Detector Capacitance
1x10-4	200.0 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-5	20,00 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-6	2,000 µA	30 ms	0.2 % + 0.05 %	2 nF
1x10-7	200,0 A	30 ms	0.2 % + 0.05 %	10 nF
1x10-8	20,00 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-9	2,000 nA	30 ms	0.2 % + 0.05 %	10 nF
1x10-10	200,0 pA	30 ms	0.2 % + 0.05 %	10 nF

Function	
Parameter Settings	Remote controlled via the RS232 interface. Retention of the last settings in continuous memory.
Operating Modes	CW; Peak, Dose, Relative (%), Channel 1/Channel 2 (%)
Dose Measurement	Integration of the measured values at 1 sample / 100 ms intervals; Automatic stop when reaching the max. measuring time (1 to 65535 s).
Measurement Quantity	Amperes calibrated with DKD calibrated current source. Current signal multiplied with calibration correction factor to selected measurement quantity.
Calibration Data	max. 255 calibration entries per measuring amplifier calibration via the RS232 interface.

General	
Operating Temperature	5 to 40 °C (41 to 104 ° F) (75 % rel. H, non-condensing). Storage Temperature: 0 to 50°C (32 to 122 °F).
Dimensions/Weight	280 mm x 250 mm x 70 mm; approx. 1 kg (11 in x 9.8 in x 2.8 in; ~2 lb)
Power	Plug-in AC power supply unit 230 V/50 Hz. 6 VDC/200 mA. Cavity plug 5.5/2.5 mm, inner conductor positive

Interface	
RS232	9600 B, 8D, 1S, N, DSUB 9 pin plug

Dimensions



Ordering Information	
P-9802	Optometer with 2 measurement channels. Handbook and plug-in power supply
P-9802Z-1	Additional amplifier board (2-channels). Max. up to total 18 boards.
OS-P9802	Software for data readout and Excel transfer
Detectors	All Gigahertz-Optik detector heads with BNC-type (-1) connector
P98Z-01	Rack-Mount Option

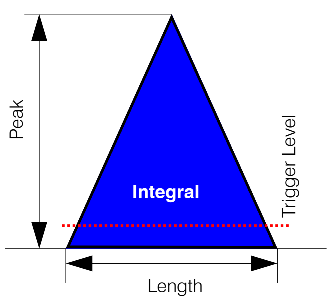
TR-9600 High-speed Data Logger & Pulse-form Analyzer

- © **Single Channel Bench-top Instrument**
- © **Single Light Flash & Pulse Train Measurement**
- © **Measurement in Absolute Radiometric & Photometric Quantities**
- © **100 ns Slew Rate Signal Amplifier**
- © **Data-logger with 10 Mega Sample / sec Rate**
- © **Transient Recorder with 512 000 Sample Capacity**
- © **Remote Control Gain Selection**
- © **Remote Control Trigger Mode Selection**
- © **IEEE488&RS232 Remote Control**
- © **Windows Based Software**

Fast Light Signals
Some light sources such as xenon lamps and LEDs are used to generate short light flashes only a few microseconds in pulse length. Because of the short pulse length with long pulse repetition rate, the peak power generated by these light sources can be much higher than in DC mode while not increasing the average power.
Typical applications for pulsed xenon lamps or LEDs in the visible spectral range include anti-collision lights, warning flashers, fairway strobes, stroboscopes and photo flashers. In the UV range xenon sources are used in polymerization of chemicals and photobiological studies. Pulsed infrared LED's are used for IR remote control, telemetry and in conveyor control switches.

Pulse-form Analysis
Most Gigahertz-Optik optometers are able to measure the average power of high frequency modulated AC light sources. But in some applications - see application notes on following page - more data is required like:

- **peak power**
- **pulse width**
- **pulse shape**



- **single pulse energy**
- **pulse repetition rate**

The key information is the pulse shape, measured in absolute quantities.

Pulse-shape Measurement
The measurement of the pulse shape is accomplished through data logging at a sample rate (measurement and storage) much faster than the pulse length. Since both, signal and measurement time are stored, a signal to time dependent database of the signal shape is recorded.

Fast Rise Time Amplifier
For very fast pulses, a signal amplifier with a rise and fall time shorter than the pulse rise and fall time is required. Flashes only a few microseconds long require amplifiers with a slew-rate of equal to or less than 1 μs.

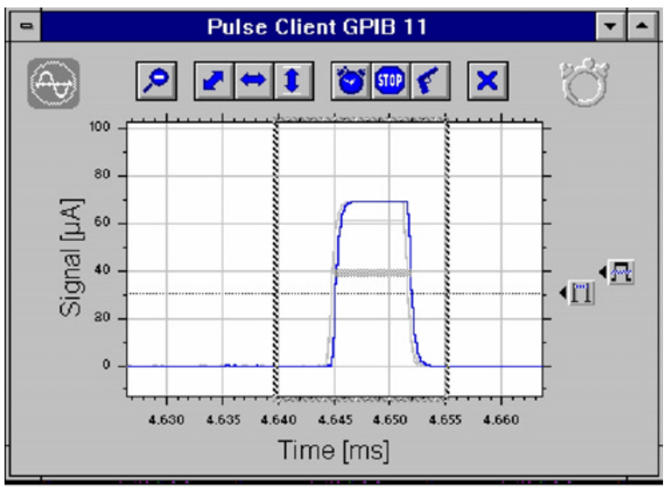
High-speed Data-logger
Besides the fast amplifier a high-speed storage medium is needed that allows retention of the measurement signal and measurement time with a high-speed sampling rate.
A transient recorder allows sampling rates of up to 10 Mega samples per second or one sample every 100 ns.
When the transient recorder is activated, the measurement data are continuously stored by run round overwriting of the recorded data. A trigger incident will stop the run around storage mode. All samples after triggering will be stored up to maximum storage capacity except for a specified number of samples, which represent the signal before the trigger incident.

TR-9600 Data-logger
The TR-9600 combines a fast slew-rate amplifier with a high-speed transient recorder for pulse–shape measurement applications.
Because of the large volume of data handled the TR-9600 is designed for remote control operation via its RS232 or IEEE488 interface.
Two versions of the TR-9600 are available:
- **TR-9600-1** offers a slew-rate of 1 μs with 10 remote controlled gain ranges from 30 nA/V to 1 mA/V.
- **TR-9600-2** offers a slew-rate of 100 ns with 4 remote controlled gain ranges from 10 μA/V to 300 μA/V.

Both meters feature a remote controlled sampling rate from 1 ksample/s to 10 Msample/s sampling rate with a data storage capacity of 512 ksamples that can be increased up to 2 Msamples (option).
The Windows based software supplied with the TR-9600 provides all necessary functions to do remote control pulse-shape measurements and analysis via the RS232 or IEEE488 interface.
A versatile triggering facility controls the recording.
The measured signal is stored as a database which allows the display of a time-intensity graph with an axis segment function and calculation of peak value, pulse integral and pulse length of one or more pulses.

Detector Heads
Several photometric and radiometric detector heads with short rise and fall times are available for use with the TR-9600 to allow measurements in absolute quantities such as illuminance, luminous intensity and radiant power.

Traceable Calibration
Calibration of the detector heads is traceable to the ISO EN 17025 accredited part of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.



TR-9600 Applications

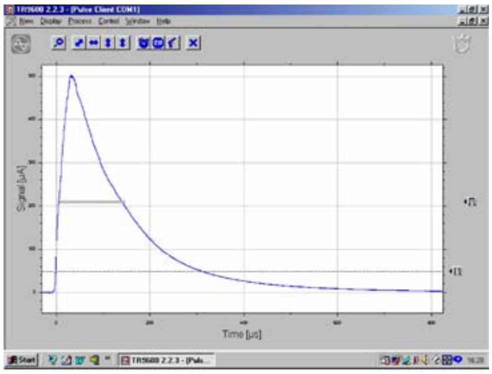
Because of it's unique features the TR-9600 is the right tool to measure the pulse-shape of high frequency modulated light or short light flashes. Due to the fast rise & fall times needed in this application the number of detector heads available is limited to those listed in this data sheet. However, custom design detector heads as well as new applications are open to discussion. This page offers some typical TR-9600 applications. Our **Light Measurement Guide** in our catalog and website offers additional tutorial and application notes in the field of Measurement of Light & Measurement with Light.

Illuminance, Luminous Intensity and Luminance Measurement of Light Flashes

The evaluation of a single light flash or a chain of light flashes in absolute photometric quantities is one domain of the TR-9600.
In combination with the VL-3704-1 with its rise time of less than 1 μs and a sample rate of up to 10 Msample/s complete details are available, such as:

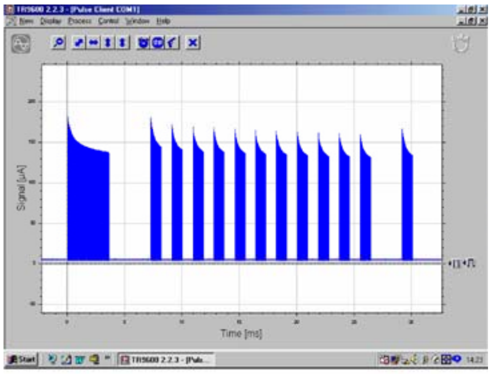
- peak illuminance in lx
- Quantity of light in lx·s
- pulse length in μs
- rise time in μs

The same detector can be used to measure luminous intensity when the detector is placed at a given distance from the source.
Luminance in cd/m² can be measured using the LDM-9901-1 detector head.
Both detectors offer a precise photometric corrected sensor to ensure low measurement uncertainty independent from the light source emission spectrum. The measurement data is available in ASCI file format for documentation.



Pulse-shape, Peak-power and IR Remote Control Unit Coding

Infrared Light Emitting Diodes (LEDs) are used in remote control units in the audio and automotive industries as well as in data link systems. The light beam of the remote control unit includes coded information for the receiver. The information is in bar code like form but transmitted as a chain of pulse signals.
Besides the information about peak intensity and pulse length, needed to ensure a minimum signal to noise ratio at a given distance, the key code of the remote control unit needs to be measured. With a 100 ns rise time and a sampling rate of 10 Msample/s the TR-9600-2 combined with a high-speed photodiode make it ideally suited to measure & evaluate IR remote control units for R&D purposes and for 100 % production control.
Detector calibrations are traceable to the ISO-EN 17025 accredited part of Gigahertz-Optik's calibration laboratory.

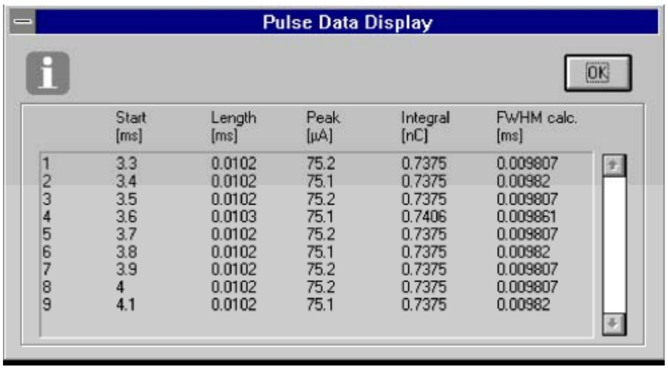


Radiant Intensity Measurement of Pulsed IR LEDs used in Optical Conveyor Control Switches

Infrared LEDs used in conveyor control sensors are operated with short pulses of high peak intensity. The high peak power enables these sensors to be used in long distance applications or with low reflectance objects.
Another strategy for operating LEDs at very short pulse lengths is used for battery operated devices where high peak power and short pulse length ensures low pulse energy which equals long battery life.
Real pulse shape data in absolute measurement quantities is needed to optimize the electronics that control LEDs in order to select LEDs with the shortest rise times and to do qualification measurements in production to ensure critical parameters.
The quantity used for LED measurement in this application is radiant intensity. The measurement of LED radiant intensity is described in CIE 127 –1997 standard.
The TR-9600-1 datalogger combined with PD-9304-1 and 100 mm length front tube can measure the class B radiant intensity of pulsed LED's with pulse length of equal or more than 10μs in reference to CIE 127 – 1997 standard.

Laser Classification EN 60825 (Peak Power, Half-Bandwidth, Pulse-Energy)

Laser are useful tools in measurement and production applications. Beside it's useful function such as high power, monochromatic and directional beam radiation, laser radiation takes also a risk for the human eye.
Because of it's high power, even laser stray-light may be a risk for the human eye. The EN 60825 standard describes the risk and measurements for risk classification. The common tool to measure laser stray-light are detector heads with a 7 mm dia. free aperture which represent the open pupil. Such a detector head combined with a TR-9600-1 is the right meter for risk classification of lasers with pulse length of larger that 10 μs.
The software supplied with the TR-9600 does offer the pulse-shape characteristic as well as the information about the peak intensity, pulse length and pulse energy.
The detector head which is calibrated in 10 nm steps does allow the measurement at the laser wavelength. The calibration is traceable to the ISO-EN 17025 accredited part of Gigahertz-Optik's calibration laboratory.


Pulse Data Display

OK

	Start [ms]	Length [ms]	Peak [µA]	Integral [nC]	FWHM calc. [ms]
1	3.3	0.0102	75.2	0.7375	0.009807
2	3.4	0.0102	75.1	0.7375	0.00982
3	3.5	0.0102	75.2	0.7375	0.009807
4	3.6	0.0103	75.1	0.7406	0.009861
5	3.7	0.0102	75.2	0.7375	0.009807
6	3.8	0.0102	75.1	0.7375	0.00982
7	3.9	0.0102	75.2	0.7375	0.009807
8	4	0.0102	75.2	0.7375	0.009807
9	4.1	0.0102	75.1	0.7375	0.00982

TR-9600 Operation Modes

Because of it's unique electronic design with a short rise time amplifier, high-speed data-logger and powerful microprocessor the TR-9600 is a highly useful tool to measure single light flashes and light pulse trains. Several modes of operation and functions allow the user to set-up the instrument to his specific measurement application. Because of it's fully remote controllable operation, the software supplied with the meter is an essential part of the system.

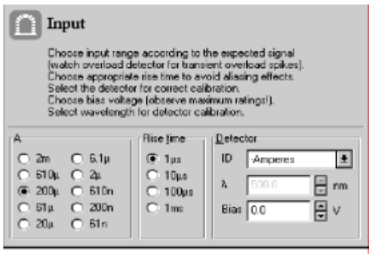
This page lists all functions available at the time of printing. If you do not see a desired function, ask for spec. updates or custom modification.

Set-up

There are three TR-9600 set-up windows labeled *Input, Time Base and Trigger*. Respectively they allow individual pre-set of the important parameters for the measurement task..

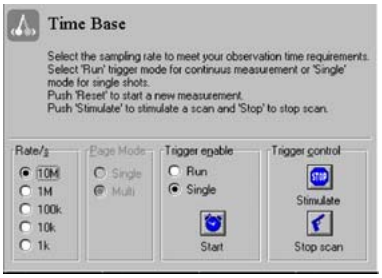
Input

The *Input* window allows set-up of the gain range and rise time (TR-9600-1 only).
The detector in-use calibration data can be selected as well as the wavelength of laser power detectors. In addition the user may specify a bias voltage for the detector, if required.



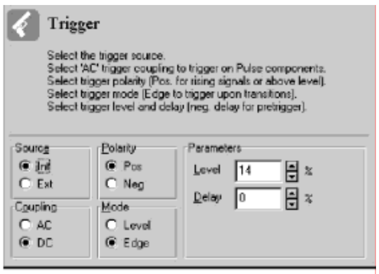
Time Base

The *Time Base* window allows the user to select the sampling rate of the data-logger. A high sampling rate means high time resolution and short measurement time.
The *Single Page-Mode* offers the complete 512 kilo sample data capacity for one measurement. The *Multi Page Mode* separates the memory into 16 pages to enable storage of up to 16 individually triggered measurements. This function allows the measurement of a chain of flashes with long repetition rates or sporadic flash events with high time resolution.
Trigger enable specifies the start mode of a measurement. *Trigger control* is used to manually start and stop a measurement.



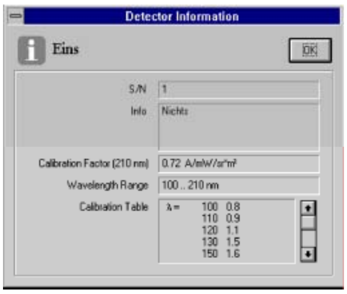
Trigger

High speed applications require variable trigger setting facilities. The TR-9600 software features this capability. Besides defining the trigger source, which can be externally connected to the special input of the TR-9600 device, AC or DC coupling and level or edge triggering can be selected separately.
In addition the user can individually set the trigger level and define a trigger delay or history.



Detector Calibration Data

The TR-9600 can be operated with several different detector heads. Serial number, calibration factor, wavelength range, wavelength dependent calibration data and comments (handling instructions, accessories, etc.) can be stored. The calibration data can be selected in the *Input* window or displayed in the Detector Information window as shown above.

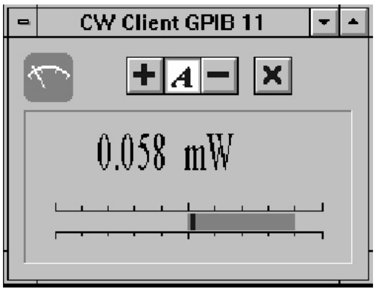


Measurement Mode

The TR-9600 basic software offers two measurement modes, the CW Client and Pulse Client.

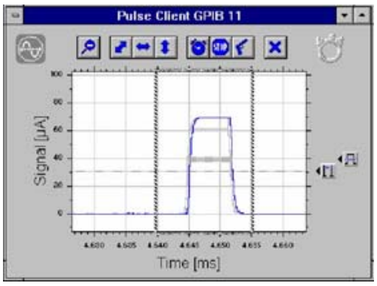
CW Client

The CW Client window with numeric data in the units of measurement based on detector calibration and a bar chart is continuously displayed. As shown in the screen shot to the right, radio buttons located at the top of the display allow manual or automatic ranging.

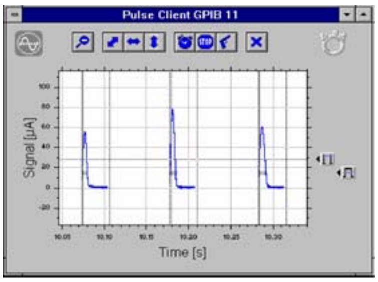


Pulse Client

Measurement of the pulse shape of single pulses or a pulse chain after a trigger incident or manually started.
The trigger is defined in the *Trigger* window.
The sample rate, which also defines the measurement time (512 ksample / 100 ns sample rate = 51.2 ms measurement time) is selected in the *Time Base* window.
Two different data storages modes can be selected in the *Time Base* window. In application with a long repetition rate between very short flashes the *Multi Page* mode should be selected. In this case each single flash is stored on a single page.



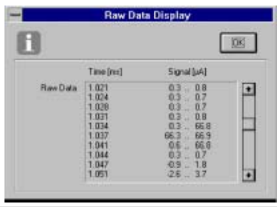
single page mode



multi page mode

Pulse Analysis

At the end of a measurement the pulse data of a single flash or a chain of flashes is shown on the *Pulse Data Display.*



Data Transfer

Data-logger measurements result in large numbers of data, e.g. 512 x 1024 = 542,288. For screen graphic display this number can be reduced to shorten the data transfer time. For external data analysis, *Single Point* resolution must be selected in the *Export data resolution* window which takes much longer for the data transfer.

TR-9600 Specification & Ordering Information

Specification:

Sensor Input	BNC-socket, max. +/-2 mA, +/-5 V
Detector Bias Voltage	Adjustable from –12 V to +12 V
Display LED's	POWER: device switched on. CONNECTED: remote command received. ERROR: error
Ext. Trigger Input	TTL/CMOS, positive edge or level triggered
Trigger Output	CMOS, positive level if triggered
ADC	12 Bit, sampling rate from 10 Msample to 1 ksample
Memory Capacity	512 kilo samples (optional 2 Msamples)
Measurement Ranges	1 µs version: 10 gain ranges from 1 mA/V to 30 nA/V
	100 ns version: 4 gain ranges 300 mA/V to 10 mA/V
Slew Rate	Switchable (only for 1 µs-version): 1 µs, 10 µs, 100 µs, 1 ms
Analog Output	BNC socket (-2 V to +2 V; Ri = 100 Ω)
Interfaces	RS232 (75-57600 Baud, 8 D, 1 S, N); IEEE488-1978 (AH1, SH1, L4, T4)
Power Supply	7.0 VDC / 1.2 A. Cavity plug 5.5/2.5 mm. Inner conductor positive. Built-in battery with approx. 3 hrs. operating time
Operation Temperature	+5 to +40 °C (+41 to +104°F)
Dim. / Weight	h=7 cm (2.8 in), b=25.5 cm (10 in), t=26.5 cm (10.4 in); 2.75 kg (6 lb) with battery, 2 kg (4.4 lb) without battery
Accessories	Plug-in AC power supply unit 230 V/50 Hz; 7.0 VDC/1.4 A; cavity plug 5.5/2.5 mm, inner conductor positive

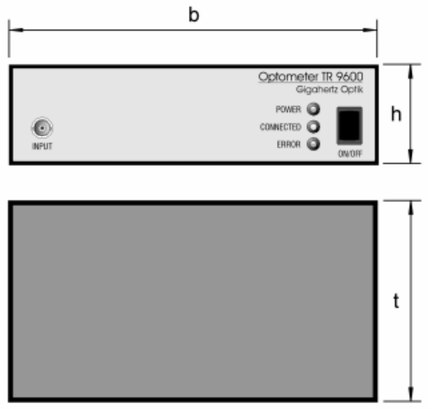
Range Specification TR-9600-1 (1 µs-Version)

Range A/V	Max. Input Value	Slew-Rate (10 - 90%)	Noise(p-p)	Error 1 year, 23°C ±5°C ±(% of reading + % of range),
1x10-3	±2 mA	1 µs	2 mV	1 % + 0.1 %
3x10-4	±600 µA	1 µs	3 mV	1 % + 0.1 %
1x10-4	±200 µA	1 µs	2 mV	1 % + 0.1 %
3x10-5	±60 µA	1 µs	3 mV	1 % + 0.1 %
1x10-5	±20 µA	1 µs	2 mV	1 % + 0.1 %
3x10-6	±6 µA	1 µs	4 mV	1 % + 0.1 %
1x10-6	±2 µA	3 µs	4 mV	1 % + 0.1 %
3x10-7	±600 nA	3 µs	10 mV	1 % + 0.1 %
1x10-7	±200 nA	30 µs	4 mV	1 % + 0.1 %
3x10-8	±60 nA	30 µs	10 mV	1 % + 0.1 %

Range Specification TR-9600-2 (100 ns-Version)

Range A/V	Max. Input Value	Slew-Rate (10 - 90%)	Noise(p-p)	Error 1 year, 23°C ±5°C ±(% of reading + % of range),
3x10-4	±600 µA	100 ns	2 mV	1 % + 0.1 %
1x10-4	±200 µA	100 ns	4 mV	1 % + 0.1 %
3x10-5	±60 µA	100 ns	4 mV	1 % + 0.1 %
1x10-5	±20 µA	100 ns	8 mV	1 % + 0.1 %

Dimension:



TR-9600 Specifications with Detector

In principle the TR-9600 can be combined with all Gigahertz-Optik detector heads. But because of it's high-speed characteristic the TR-9600 should only be used with detector heads with a short rise time. Those detector heads recommended for use with the TR-9600 are listed in the ordering information table below. Further to this, because of the unique nature of pulsed optical radiation measurement applications, the TR-9600 is very often set-up with detector heads specially suited for a specific measurement requirement. For this reason only a few example detectors designed for high speed pulse-form analysis are shown. Please contact our sales engineers to discuss your specific application requirements.

Ordering Information	
TR-9600-1	1 µs slew rate . Including manual and power supply
TR-9600-2	100 ns slew rate. Including manual and power supply
TR-9600Z	Memory expansion to 2 Msample
BHO-02	Hard case
VL-37 series	Photometric detector head, select / -1, BNC - type connector
PD-37 series	Modular detector head with 37 - type housing, select / -1, BNC - type connector
UV-37 series	UV - Irradiance detector head, select / -1, BNC - type connector
PD-11 series	Modular detector head with 11 - type housing, select / -1, BNC - type connector
LP-01 series	Laser power or irradiance detectors with integrating spheres, select / -1, BNC - type connector
LDM-9901-1	Luminance detector head with -1 type connector

P-9202 Current to Voltage Amplifier

- © **Single Channel Amplifiers for Laboratory Use or System Integration**
- © **Current to Voltage Converter**
- © **Low Offset Voltage for Photovoltaic Mode Operation**
- © **High Gain and High Speed Optimized Models**
- © **Eight Manually or Remote Controlled Gain Ranges**
- © **Simple Operation**
- © **Metal Shielded Package**
- © **Remote Control Interface with Opto-Coupler**
- © **AC operation**

Associated Parts / Service:
Chapter Detector Heads
Chapter Integrating Spheres
Chapter Calibration

Photodiodes (Si, InGaAs, Ge) generate current signals with an intensity that correlates to a wide dynamic range linear to the incident optical radiation.
This linear function is only achieved if the photodiodes are operated in the photovoltaic mode, which means almost in a short circuit condition.
In an open circuit configuration the photodiode would offer a voltage signal with a nearly logarithm characteristic.
The practical use of photodiodes requires amplifiers which offer the following features:

- current-to-voltage conversion
- lowest offset voltage for 'ideal' short circuit condition
- large dynamic range
- high gain for high sensitivity
- short slew rate for fast measurements.

Gigahertz-Optik's **P-9202 Amplifiers** offer optimum performance when used with state-of-the-art photodiodes. These amplifiers feature careful design of the input stage using high quality photocurrent amplifiers, the use of reed relays for switching between the high impedance amplification ranges and a remote control interface isolated by opto-couplers.
Due to its superior electronic and mechanical stability, the P-9202 series, originally designed for laboratory use, have found their way into industrial OEM applications.

Three standard versions are offered, differing in maximum sensitivity and bandwidth:

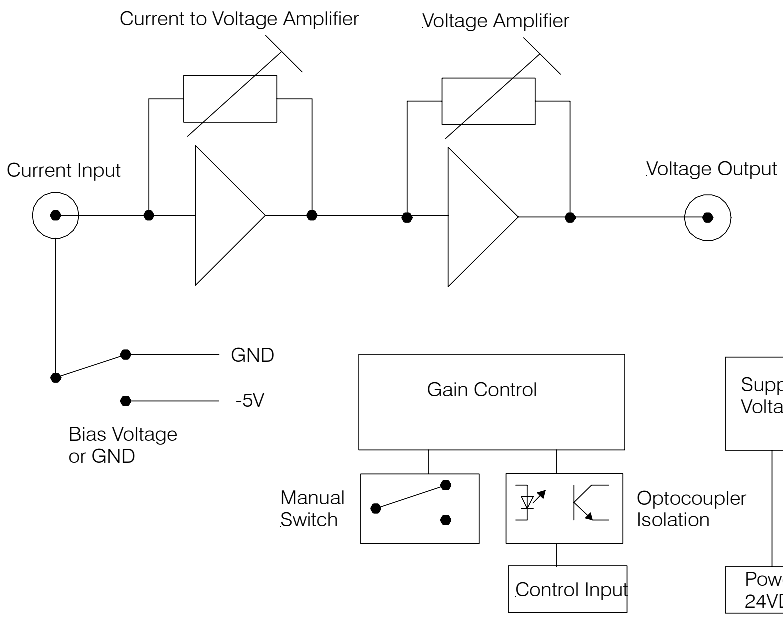
P-9202-4 Fast

Amplifier offers an 8-step switch-able sensitivity range from 300 nA/V to 1 μA/V and a nearly constant slew-rate of 1 μs in all gain ranges. Photodiodes can be operated in photovoltaic or photodiode mode (-5 V bias voltage). Useful in applications with need for high bandwidth up to 330 kHz or short, 1 μs rise time.

P-9202-5 Universal Amplifier offers an 8-step switchable sensitivity range from 100 pA/V to 1 mA/V and variable, gain dependent slew-rate. Photodiodes can be operated in photovoltaic or photodiode mode (0.5 V bias voltage). This model is suitable for use as a pre-amplifier for lock-in amplifier to extend their measurement range.

P-9202-6 High-sensitive

Amplifier with an 8-step switchable sensitivity range from **10 pA/V!** to 100 μA/V and variable, gain dependent slew-rates. This model is suited to applications involving very low signals from the photodiodes starting in the 10 femto ampere (0.01 pA) range.
Each amplifier is AC operated with an external power unit supplied.



Gigahertz-Optik

P-9202 Specifications & Ordering Instruction

Specifications

Limits:

max. input voltage:	+/-12 V
max. signal input current:	+/-5 mA
max. output current:	+/-5 mA
max. output voltage:	+/-9 V
Supply voltage:	min. 12 V, max. 24 V (80 mA)
Remote input voltage:	+5 V (25 mA)
Operating temperature:	+5 °C to +40 °C (+41 °F to +104 °F)

Technical data:

Housing:	Aluminum
Dimensions:	105 mm x 80 mm x 45 mm (4.1 in x 3.2 in x 1.8 in)
Weight:	approx. 400 g (0.9 lb)
Signal input:	BNC socket
Signal output:	BNC socket
Power supply:	24 V/80 mA, 2 pin FRIWO connector

Remote interface: D-SUB 9-pin (socket terminal strip)

Remote interface pin-out:
PIN 1: remote central point
PIN 2: Ranges 7/8
PIN 3: Ranges 5/6
PIN 4: Ranges 3/4
PIN 5: Ranges 1/2
PIN 6: Ground
PIN 7: Signal output (R_{out}=1 kΩ)
PIN 8: Remote COMMON
PIN 9: Not connected

Parts Supplied: amplifier, plug-in AC power supply unit (220 V/50 Hz, 24 VDC/80 mA)

Range Specifications

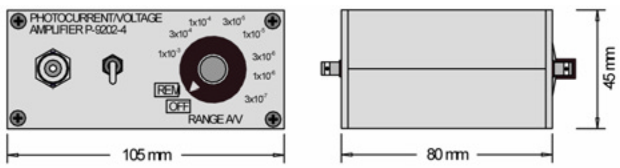
Model	Gain Stage	Sensitivity	Slew Rate	Error ± of Reading	Noise Voltage
P-9202-4	1	1 mA/V	1 µs	0.2 % +/-2 mV	1 mV p-p
	2	300 µA/V	1 µs	0.2 % +/-5 mV	1 mV p-p
	3	100 µA/V	1 µs	0.2 % +/-2 mV	1 mV p-p
	4	30 µA/V	1 µs	0.2 % +/-5 mV	1 mV p-p
	5	10 µA/V	1 µs	0.2 % +/-2 mV	1 mV p-p
	6	3 µA/V	1 µs	0.2 % +/-5 mV	3 mV p-p
	7	1 µA/V	3 µs	0.2 % +/-2 mV	3 mV p-p
	8	300 nA/V	3 µs	0.2 % +/-5 mV	10 mV p-p
P-9202-5	1	1 mA/V	5 µs	0.2 % +/-1 mV	1 mV p-p
	2	100 µA/V	5 µs	0.2 % +/-1 mV	1 mV p-p
	3	10 µA/V	30 µs	0.2 % +/-1 mV	1 mV p-p
	4	1 µA/V	30 µs	0.2 % +/-1 mV	1 mV p-p
	5	100 nA/V	500 µs	0.2 % +/-1 mV	1 mV p-p
	6	10 nA/V	500 µs	0.2 % +/-1 mV	2 mV p-p
	7	1 nA/V	20 ms	0.7 % +/-1 mV	1 mV p-p
	8	100 pA/V	20 ms	0.7 % +/-1 mV	4 mV p-p
P-9202-6	1	100 µA/V	25 ms	0.2 % +/-1 mV	0.5 mV eff
	2	10 µA/V	25 ms	0.2 % +/-1 mV	0.5 mV eff
	3	1 µA/V	250 ms	0.2 % +/-1 mV	0.5 mV eff
	4	100 nA/V	250 ms	0.2 % +/-1 mV	0.5 mV eff
	5	10 nA/V	250 ms	0.5 % +/-1 mV	0.5 mV eff
	6	1 nA/V	250 ms	0.5 % +/-1 mV	0.5 mV eff
	7	100 pA/V	2.5 s	1 % +/-1 mV	0.5 mV eff
	8	10 pA/V	2.5 s	1 % +/-1 mV	0.5 mV eff

Amplifier Input Specifications

Model	Max. Bias Current	Bias Voltage	Offset Voltage Drift	Input Impedance
P-9202-4	5 pA	0 V or –5 V [1)]	1 µV/°C	Virtual short circuit
P-9202-5	2 pA	0 V or –5 V [1)]	1 µV/°C	
P-9202-6	0.2 pA	-	5 µV/°C	

1) on the outer contact of the BNC signal input socket

Dimensions



Calculation of the Input Noise Voltage

Noise voltage

Input noise voltage

$$N_{eff\left(\sqrt{Hz}\right)} = \frac{N_{p-p} * \sqrt{t_{(10-90)}} * 1{,}5 * sensitivity\ (A/V)}{6} \left(A/\sqrt{Hz}\right)$$

Ordering Information

P-9202-4	Amplifier, 300 nA/V to 1 mA/V. Including external power supply
P-9202-5	Amplifier, 100 pA/V to 1 mA/V. Including external power supply
P-9202-6	Amplifier, 10 pA/V to 100 µA/V. Including external power supply

BHO Carrying Cases for Optometers, Detectors & Accessories

Optical radiation measurements instruments are built with precision optical, electro optical and high tolerance electronic components for low level current measurements. As such, they should be protected, carried and stored carefully.
Gigahertz-Optik offers specially designed carrying cases for its instruments. Besides the standard models shown on this page, custom design carrying cases for private label instruments in different sizes, colors, inserts and company logo are available.

BHO-01

Hard case for the P-9710 optometer with 37-type standard detector heads and accessories such as plug-in power supply.

BHO-02

Hard case for the P-9710 optometer with LDM-98 detector head or the P-9801 optometer with CT-3701 color detector head. Additional space for plug-in power supply.

BHO-04

Hard case for the X1[1] or X9 Type optometer with one 37 type and LDM-99 type detector heads and additional accessories.

BHO-05

Hard case for the X1[1] or X9[2] optometer with up to two RCH-0 or RCH-1 detector heads. Additional space for up to three RCH-Z light guide adapters.

BHO-06

Hard case for one X-2000 with RS232 interface cable and spare battery or one HCT-99 color meter or X1[1] optometer with CT-4501 ordetector head and spare batteries.

BHO-08

Aluminum hard case with universal partitionable foam rubber to store meter, detector heads and accessories which do not fit into the fixed partitioned BHO series hard cases.

BHO-09

Aluminum hard case with universal partitionable foam rubber to store meter, detector-heads and accessories which do not fit into the fix partitioned BHO series hard cases.

Dimensions & Weight:

Model	Outside (mm)	Outside (inch)	Inside (mm)	Inside (inch)	Weight (kg)	Weight (lb.)
BHO-01	400 x 350 x 90	16 x 14 x 4	380 x 280 x 50	15 x 11 x 2	1.10	2.42
BHO-02	540 x 430 x 130	21 x 17 x 5	530 x 360 x 55	21 x 14 x 2	2.50	5.50
BHO-04	330 x 280 x 70	13 x 11 x 2.7	320 x 230 x 35	13 x 9 x 1.4	0.65	1.43
BHO-05	330 x 280 x 70	13 x 11 x 2.7	320 x 230 x 35	13 x 9 x 1.4	0.65	1.43
BHO-06	240 x 210 x 55	9.5 x 8 x 2	230 x 170 x 30	9 x 7 x 1.2	0.30	0.66
BHO-08	370 x 310 x 145	15 x 12 x 6	350 x 265 x 90	14 x 11 x 3.5	1.75	3.85
BHO-09	460 x 360 x 170	18 x 14 x 7	440 x 320 x 100	17 x 13 x 4	2.30	5.06

Ordering Information

BHO-01	Hard Carrying Case.
BHO-02	Hard Carrying Case
BHO-04	Hard Carrying Case
BHO-05	Hard Carrying Case
BHO-06	Hard Carrying Case
BHO-08	Hard Carrying Case
BHO-09	Hard Carrying Case

General Information

Gigahertz-Optik manufactures light detectors for use in combination with Gigahertz-Optik optometers and accessories to form complete radiometric and photometric measurement systems. Detectors can also be used with integrating spheres to form the basis of uniform light sources and reflectance/transmittance instruments. A typical sensor head may consist of a photodiode, optical bandpass filter, diffuser, lens assembly or other optical elements. A complete range of detector head housings and configurations designed around the specific application demands of dynamic range, spectral range, physical size and measurement environment are available. All optical radiation detectors are calibrated and certified by Gigahertz-Optik's calibration laboratory with both absolute sensitivity data and spectral responsivity plot provided.

Table of Contents

Model	Spectral Function	Wavelength Range (nm)	Diffuser Diameter (mm)	Aperture (mm) (F.O.V.)	Sphere Diameter (mm)	Unit	Package Type	Package Page	Specifications Page
Compact Size Illuminance Detectors									
VL-1101	Photopic; $f_1 \leq 5\%$	380-780	-	1,1 mm ∅	-	lx, fc	11	90	63
Photopic & Scotopic Illuminance Detectors									
VL-3701	Photopic; $f_1 \leq 3\%$	380-780	7	Cosine	-	lx, fc	37/20	90	64
VL-3702	Photopic; $f_1 \leq 5\%$	380-780	7	Cosine	-	lx, fc	37/20	90	64
VL-3704	Photopic; $f_1 \leq 5\%$	380-780	7	Cosine	-	lx, fc	37/20	90	64
VL-3705	Scotopic; $f_1 \leq 5\%$	380-780	7	Cosine	-	lx, fc	37/20	90	64
PD-9310	Photopic; $f_1 \leq 3$ or 6%	380-780	30	Cosine	-	lx, fc	PD93	91	64
Temperature Controlled Illuminance Detectors									
TD-11VL01	Photopic; $f_1 \leq 3\%$	380-780	-	-	-	lx, fc	TD-11	90	65
Compact Size Broadband Irradiance Detectors									
RW-1103	Radiometric *VISIBLE*	400-800	-	1.1 x 1.1	-	W/m²; W/cm²	11	90	66
RW-1104	Radiometric *NIR*	800-1000	-	1.1 x 1.1	-	W/m²; W/cm²	11	90	66
RW-1105	Radiometric *VISNIR*	400-1000	-	1.1 x 1.1	-	W/m²; W/cm²	11	90	66
Temperature Controlled Broadband Irradiance Detectors									
TD-11RW03	Radiometric *VISIBLE*	400-800	-	2.8 x 2.8	-	W/m²; W/cm²	TD-11	90	66
TD-11RW04	Radiometric *NIR*	800-1000	-	2.8 x 2.8	-	W/m²; W/cm²	TD-11	90	66
TD-11RW05	Radiometric *VISNIR*	400-1000	-	2.8 x 2.8	-	W/m²; W/cm²	TD-11	90	66
High Sensitive Broadband Irradiance Detectors									
RW-3701	Radiometric *BLUE*	400-500	11	Cosine	-	W/m²; W/cm²	37/32	90	67
RW-3702	Radiometric *RED*	700-800	11	Cosine	-	W/m²; W/cm²	37/32	90	67
RW-3703	Radiometric *VISIBLE*	400-800	11	Cosine	-	W/m²; W/cm²	37/32	90	67
RW-3704	Radiometric *NIR*	800-1000	11	Cosine	-	W/m²; W/cm²	37/32	90	67
RW-3705	Radiometric *VISNIR*	400-1000	11	Cosine	-	W/m²; W/cm²	37/32	90	67
Compact Size Broadband UV Irradiance Detectors									
UV-1101	Radiometric *UV-A*	315-400	-	2.5 x 2.5	-	W/m²; W/cm²	11	90	68
UV-1102	Radiometric *UV-B*	280-315	-	1.1 x 1.1	-	W/m²; W/cm²	11	90	68
Temperature Controlled Broadband UV Irradiance Detectors									
TD-11UV01	Radiometric *UV-A*	315-400	-	2.5 x 2.5	-	W/m²; W/cm²	TD-11	90	68
TD-11UV02	Radiometric *UV-B*	280-315	-	1.1 x 1.1	-	W/m²; W/cm²	TD-11	90	68
High Sensitivity Broadband UV Irradiance Detectors									
UV-3701	Radiometric *UV-A*	315-400	11	Cosine	-	W/m²; W/cm²	37/32	90	69
UV-3702	Radiometric *UV-B*	280-315	11	Cosine	-	W/m²; W/cm²	37/50	90	69
UV-3703	Radiometric *UV-C*	250-280	11	Cosine	-	W/m²; W/cm²	37/32	90	69

Table of Contents

Model	Spectral Function	Wavelength Range	Diffuser Diameter	Aperture (mm)	Sphere Diameter	Unit	Package		Specification
		nm	mm	F.O.V.	mm		Type	Page	Page
Luminance & Radiance Detectors									
PD-16-RTH	Retinal Thermal Hazard	500-1200	-	5.8 x 5.8	-	W/m²sr	PD16	92	77/78
PD-16-RTHA	RTH IR-A	800-1200	-	5.8 x 5.8	-	W/m²sr	PD16	92	77/78
PD-16-RW05	Radiometric *VIS-NIR*	400-1000	-	5.8 x 5.8	-	W/m²sr	PD16	92	77/78
PD-16-VL01	Photopic, f1≤3%	380-780	-	5.8 x 5.8	-	cd/m²	PD16	92	77/78
LDM-98Z-NL	-	380 - 1000	-	50	-	-	LDM98	92	77/78
LDM-98Z-FC	-	Fiber Coupler for flexible light guide bundles						92	77/78
LDM-9901	Photopic, f1≤5%	380-780	-	1°	-	cd/m²	LDM99	92	79
SRT-M37	A Range of Front Lenses is Offered for the VL, RW and UV Detectors for Luminance & Radiance Set-ups							89	80
Luminous Flux & Radiant Power Detectors									
LSM-9901	Photopic, f1≤5%	380-780	-	12.5 ∅	50	lm	11/50	91	81
PRW-0505	Radiometric *VIS-NIR*	400-1000	-	12.5 ∅	50	W	11/50	91	81
Integrating Spheres	Spheres from 100 mm (4 inch) to 500 mm (20 inch) Diameter are Offered which can be Combined with VL, RW, UV & PS Detectors for Luminous Flux and/or Radiant Power Measurement Set-ups							See Integrating Spheres	
Laser Stray-light and Laser Power Detectors									
LP-9901	Si Photodiode	350-1100	-	7 ∅	-	W/m² nm / W nm	37/8.5	91	82
Laser Power Detectors with Integrating Spheres									
LP-0101	InGaAs Photodiode	800-1800	-	5 ∅	30	W nm	11/30	91	82/83
LP-0102	Si & InGaAs Photodiode	350-1800	-	5 ∅	30	W nm	11/30	91	82/83
LP-0103	Si Photodiode	350-1100	-	5 ∅	30	W nm	11/30	91	82/83
LP-0201	Si LP Photodiode	400-1100	-	2 ∅	8	W nm	11/8	91	82/83
LP-9910	Si Photodiode	400-1100	-	12.5 ∅	50	W nm	11/50	91	83
LP-9920	InGaAs Photodiode	800-1800	-	12.5 ∅	50	W nm	11/50	91	83
LP-9930	Si & InGaAs Photodiode	400-1800	-	12.5 ∅	50	W nm	11/50	91	83
Laser Pulse Shape Radiant Power Detector									
LPPA-9901	Si LP Photodiode	400-1060	-	12.5 ∅	50	V / W nm	LPPA	91	84
Compact Size Modular Detectors									
PD-1101	Si Photodiode	200-1100	-	3.6 x 3.6	-	With Accessory	11	90	85
PD-1102	InGaAs Photodiode	800-1800	-	0.3 ∅	-	With Accessory	11	90	85
PD-1103	InGaAs Photodiode	800-1800	-	1 ∅	-	With Accessory	11	90	85
PD-1104	InGaAs Photodiode	800-1800	-	3 ∅	-	With Accessory	11	90	85
PD-1105	SiC Photodiode	200-400	-	1.1 x 1.1	-	With Accessory	11	90	85
PD-1106	Si LP Photodiode	400-1050	-	0.5 x 0.5	-	With Accessory	11	90	85
PD-1107	Si LP Photodiode	400-1050	-	1.9 x 1.9	-	With Accessory	11	90	85
PD-1108	Si LP Photodiode	400-1050	-	3.4 x 3.4	-	With Accessory	11	90	85
PD-1109	GaP Photodiode	250-550	-	1.1 x 1.1	-	With Accessory	11	90	85
PD-1110	GaAsP Photodiode	200-760	-	2.3 x 2.3					
Integrating Spheres	Spheres from 100 mm (4 inch) to 500 mm (20 inch) Diameter are Offered which can be Combined with PD-11 Detectors for Radiant Power Measurement Set-ups							See Integrating Spheres	
Temperature Controlled Modular Detectors									
TD-1101	Si Photodiode	200-1100	-	3.6 x 3.6	-	With Accessory	TD11	90	86
TD-1102	InGaAs Photodiode	800-1800	-	0.3 ∅	-	With Accessory	TD11	90	86
TD-1103	InGaAs Photodiode	800-1800	-	1 ∅	-	With Accessory	TD11	90	86
Integrating Spheres	Spheres from 100 mm (4 inch) to 500 mm (20 inch) Diameter are Offered which can be Combined with TD-11 Detectors for Radiant Power Measurement Set-ups							See Integrating Spheres	
Modular Detectors									
MD-37-GP6	GaP Photodiode	250-550	-	2.5 x 2.5	-	With Accessory	MD37	90	86

Gigahertz-Optik

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Optometer Model Depending Plug Types:

Gigahertz-Optik light detectors come equipped with a plug type compatible with the particular optometer it will used with (see table).
The -2 calibration data plug contains an Eeprom that stores the detectors serial number, model, units and calibration data or data table for automatic information transfer to the meter when connected.
Both standard BNC (-1) and ITT-9PIN (-4) connectors are straight forward plugs without internal Eeprom.

- 1 BNC Connector

- 2 Calibration Data Connector

- 4 ITT Type Connector

Plug Type		Meter
BNC	-1	P-9202, P9801, P-9802, TR-9600
Calibration Data	-2	P-9710, P-2000
ITT (MSDM9)	-4	X9, X1, HCT-99

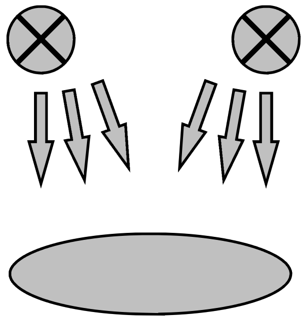
Measurement Range Calculation; Illuminance & Irradiance

Calculation of the Maximum Measurable Intensity and Resolution:

Typical sensitivity factors for each light detector in its calibrated units are included in the specifications listed on the following pages. The maximum measurable intensity and attainable resolution with the different models of optometer offered can be calculated as follows

Maximum Resolution
= Meter Current Signal Resolution / Detector Sensitivity
e.g. 0.1 pA / 3 nA / (mW / cm²) = 0.33 nW / cm²
Maximum Signal = Max Meter Signal Current / Detector Sensitivity
e.g. 20 µA / 3 nA / (mW / cm²) = 6.66 W / cm²

Illuminance E



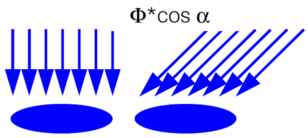
Illuminance refers to the luminous flux per unit area impinging on a particular surface from one or more sources of light. Illuminance is measured horizontally and vertically in the units of lux (lx) or footcandles (fc). When the incident light is not parallel, which in practice is normal, a cosine diffuser must be used as the measurement geometry for "lux detector heads".

lx = lm / m²
fc = lm / ft²

Irradiance E

Irradiance refers to the radiant power impinging on a particular surface from one or more sources of optical radiation. Irradiance is measured horizontally and vertically in the units of watts per square meter (W/m²).
When the incident optical radiation is not parallel, which in practice is normal, a cosine diffuser must be used to correct the measurement geometry for irradiance detector heads.

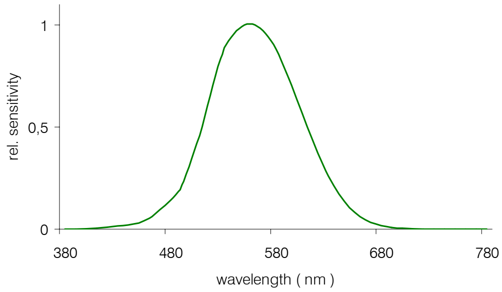
Cosine Corrected Field of View



Each optical radiation quantity calls for its own measurement geometry for the proper reception of the radiation. Illuminance and irradiance measurement systems require a cosine corrected field of view. Only then can the laws for the incidence of diffuse radiation from one or more sources be satisfied.
If the incident radiation is not parallel, the accuracy of the cosine function is critically important to the result of the measurement.

VL-1101: Compact Size Illuminance Detector

VL-1101 with UPB-50-L



Photopic Spectral Response

The VL-1101 detector offers a compact package with flange mount that allows arrangement of discrete linear arrays (11 mm grid size) to measure the luminous intensity distribution of spot lamps.
The detector can be combined with integrating spheres with 11-type adapter for luminous flux measurements.
Calibration is offered with or without accessory.

Ordering Information & typical Specifications

Model	λresp InGaAs	f_1	Typical Sensitivity	Imax	Sensing Area	cable	Temp.	plug	package
		≤ %	nA/lx	mA	photodiode	m	°C		page
VL-1101	V(λ)	5	0.3	1	1.1 mm Ø	2	5 - 40	1,2,4	90
K-VL1101-I	Calibration of the illuminance sensitivity in lx or fc. Including K-SR in order with new detector								
KDW-S	Calibration of the spectral sensitivity in combination with accessory								
KDW-P	Calibration of the integral photometric sensitivity in combination with accessory								

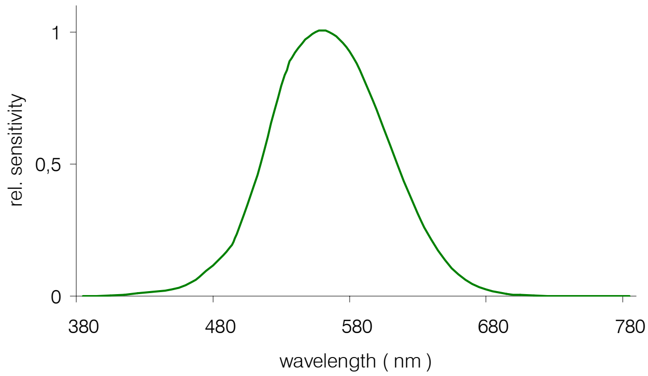
VL-3701, VL-3702, VL-3704 & VL-3705: Photopic & Scotopic Illuminance Detectors

Illuminance is one of the most important measurements in the field of commercial or industrial lighting. It enables us to see things properly and comfortably.
Illuminance detector's spectral responsiveness must be equal the photopic vision characteristic V(λ), as defined by the CIE. The very best matching of the detector spectral response to the photopic vision function is necessary especially if the measurements involve different kinds of light sources such as daylight, tungsten, fluorescent lamps, LED's etc.
Illuminance detectors require a cosine field-of-view characteristic. This spatial response properly 'weights' the effects of the illumination reaching the detector from different angles of incidence. The accuracy of the cosine correction is as equally important as the photometric responsivity for illuminance detectors.
The height of the detector is an other important factor, since the illuminance should be measured close to the subject surface. To measure the ANSI Lumen rating of projectors a max. height of 20 mm is specified.

Illuminance

VL-3701: Photopic with DIN Class A Parameters

The VL-3701 is a high quality detector for the measurement of illuminance. Its specifications satisfy the requirements for lux detector heads according to DIN 5032 Part 7.
The VL-3701's spectral adaptation to the **V(λ)** function for daylight vision is better than 3%. The precise adaptation of its spectral sensitivity to the ideal V(λ) function makes this detector head appropriate where sharply different spectra need to be measured (arc lamps, color monitors, LEDs, etc.). The deviation from the cosine function is < 1.5 %.
The low detector profile of 20 mm allows its use in applications where the height of the detectors surface over the illuminated surface is restricted.
Calibration of the illuminance, in lux or fc is performed at Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities, and is supported by a factory certificate.



Photopic Spectral Response

VL-3702: Photopic with DIN Class B Parameters

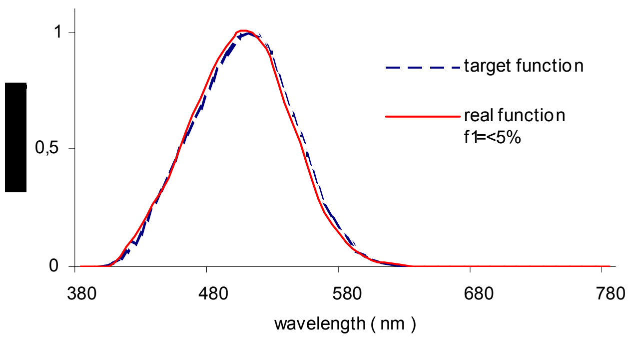
The VL-3702 detector is constructed the same as the VL-3701 model, but has a lower precision of photometric adaptation, at 6 %, sufficient for DIN quality class B, and a maximum deviation of 3 % from the cosine function. Available versions and calibration are the same as model VL-3701.

VL-3704: Photopic with DIN Class B Parameters

The VL-3704 detector specifications are equal to that of the VL-3702 detector except that it is less sensitive. This allows the VL-3704 detector to be used with optometers like the X11, X91 and P-9802 with amplifiers having a limited signal range.

VL-3705: Scotopic

The spectral response of the human eye changes with light intensity. In daylight conditions >0.1 lx the photopic action spectrum applies. In low brightness applications 0.01 to 0.0001 lx the spectral eye response changes to the scotopic (dark adapted) action spectrum. Light intensities below 0.0001 lx can not be detected by the human eye.
The VL-3705 detector offers a precise scotopic spectral match



Scotopic Spectral Response

with an f_1 =< 5%. This is within DIN class B specifications qualifying the VL-3705 for use in most low light level application.

Ordering Information & typical Specifications										
Model	λresp	f_1	Typical Sensitivity		Imax	Sensing Area	cable	Operation	plug	package
		≤ %	nA/lx	nA/fc	mA	Diffuser	m	Temp.		page
VL-3701	V(λ)	3	0.5	5	1	7 mm Ø	2	5 - 40	1,2,4	90
VL-3702	V(λ)	5	0.5	5	1	7 mm Ø	2	5 - 40	1,2,4	90
VL-3704	V(λ)	5	20 pA/lx	200 pA/fc	1	7 mm Ø	2	5 - 40	4	90
VL-3705	V'(λ)	5	0.5	5	1	7 mm Ø	2	5 - 40	1,2,4	90
K-VL37xx-I	Calibration of illuminance sensitivity in lx or fc. Including K-SR with new detector order. xx = model number									
KDW-S	Calibration of spectral sensitivity with accessory components									
KDW-P	Calibration of integral photometric sensitivity in combination with accessory									
K-FOV	Calibration of cosine field of view function. Included with new detector order									

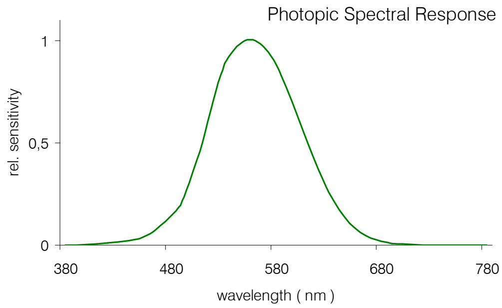
VL-37xx Illuminance Detectors comparison DIN 5032 Class Limits (%)						
Characteristic	**Symbol**	**DIN 5032 Class A**	**DIN 5032 Class B**	**VL-3701**	**VL-3702**	**VL-3704**
Calibration Uncertainty	U_{kal}	1.5	3	1.1	1.1	1.1
V(λ) Match Characteristic	f_1	3	6	3	5	5
UV Response Characteristic	u	1	2	0.01	0.01	0.01
IR Response Characteristic	r	1	2	0.01	0.01	0.01
Directional Response (Cosine)	f_2	1.5	3	1.5	3	3
Linearity Characteristic	f_3	1	2	0.2	0.2	0.2
Fatigue Characteristic (at 1 klx)	f_5	0.5	1	0.1	0.1	0.1
Temperature Dependence Characterist.	f_6	2	10	1	1	1

Accessories:

Mating SRT-M37 front lens adapters allow VL-37 detectors to be adapted for luminance measurements. See page 89 for specifications.

VL-37 detectors can be combined with integrating spheres for luminous flux measurements. See integrating sphere chapter .

PD-9310: High Sensitivity Photopic Illuminance Detector

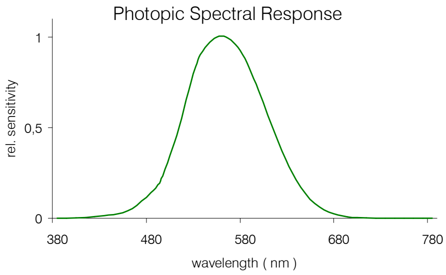


The PD-9310 detector offers a large 30 mm diameter diffuser window combined with a large 100 mm² area photodiode. It's high sensitivity makes this detector ideal for all applications in which very low light levels needs to be measured.
The detector can be combined with the PD-93 modular detector accessories and with integrating spheres with 37-type adapters. Calibrations are offered with or without accessory.

Ordering Information & typical Specifications

Model	λresp	f_1	Typical Sensitivity	Imax	Sensing Area	cable	Operation Temp.	plug	package
		≤ %	nA/lx	mA	Diffuser	m			page
PD-9310A	V(λ)	3	2.8	1	30 mm Ø	2	5-40 °C	1,2,4	91
PD-9310B	V(λ)	6	2.8	1	30 mm Ø	2	5-40 °C	1,2,4	91
K-PD9310-I	Calibration of the photometric sensitivity in lx or fc. Including K-SR in order with new detector								
KDW-S	Calibration of the spectral sensitivity in combination with accessory								
KDW-P	Calibration of the integral photometric sensitivity in combination with accessory								

TD-11VL01: Temperature Controlled Illuminance Detector



TD-11VL-01 with UMB

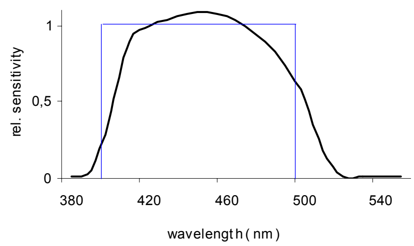
The TD-11VL01 detector offers a unique temperature control for filter and photodiode by precise heating to a higher operation temperature than the ambient temperature. The control electronic is supplied in an external housing with plug-in power supply. The detector can be combined with integrating spheres with 11-type adapter for luminous flux measurements.
Calibrations are offered with or without accessory.

Ordering Information & typical Specifications

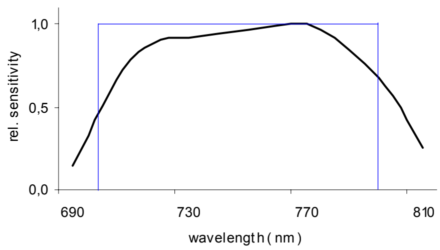
Model	λresp	f_1	Typical Sensitivity	Imax	Sensing Area	cable	Operation Temp.	plug	package
		≤ %	nA/lx	mA	photodiode	m			page
TD-11VL01	V(λ)	5	tbc with sphere	1	2.77 mm x 2.77 mm	2	55°C	1,2,4	90
K-TD11VL01-I	Calibration of the photometric sensitivity in lx or fc. Including K-SR in order with new detector								
KDW-S	Calibration of the spectral sensitivity in combination with accessory								
KDW-P	Calibration of the integral photometric sensitivity in combination with accessory								

VISIBLE-NIR Polychromatic Radiometric Light Detectors

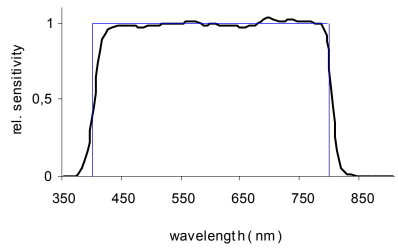
Polychromatic radiometric detectors are primarily used for integral intensity measurements in a defined range of wavelengths. Correction filters are used to shape the bare detector response to the desired bandpass function, and ensure a radiometric responsiveness function.
The plots below and on the following page summarizes the standard measurement heads offered with correction filters and spectral responses. Customer-specific solutions with respect to spectral range, measurement geometry and other design features are available along with full assistance from our sales engineers.



RW-01 ***BLUE***$_{400\text{-}500\ nm}$ Spectral Response



RW-02 ***RED***$_{700\text{-}800\ nm}$ Spectral Response

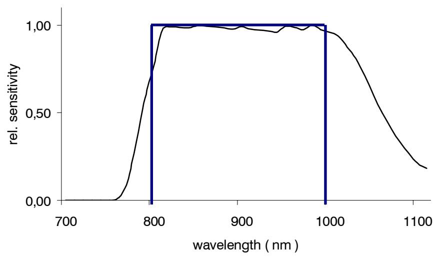


RW-03 ***VISIBLE***$_{400\text{-}800\ nm}$ Spectral Response

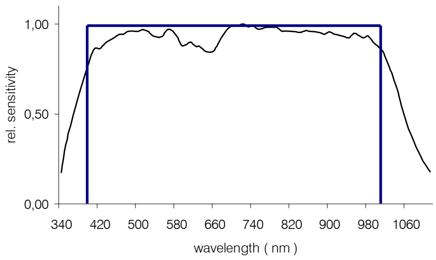
Gigahertz-Optik

Irradiance

VISIBLE-NIR Polychromatic Radiometric Light Detectors



RW-04 ***NIR****800-1000 nm* Spectral Response



RW-05 ***VISNIR****400-1000 nm* Spectral Response

RW-11: Compact Size *VISIBLE-NIR* Polychromatic Radiometric Detectors

The RW-11 detectors offer a compact package with flange mount which allows arrangement of discrete linear arrays with a grid of 11 mm to measure the radiant intensity distribution of light sources.
The detector can be combined with integrating spheres with 11-type adapter for radiant power measurements.
Calibrations are offered with or without accessory.

RW-11 assembled
to UM series sphere

Ordering Information & typical Specifications										
Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Operation Temp.	plug	package
	polychromatic	Page	nA/W/m²	nA/W	mA	photodiode	m			page
RW-1103	VISIBLE 400-800 nm	65	tbc with sphere		1	1.1 x 1.1 mm	2	5-40 °C	1,2,4	90
RW-1104	NIR 800-1000 nm	66			1	1.1 x 1.1 mm	2	5-40 °C	1,2,4	90
RW-1105	VISNIR 400-1000 nm	66			1	1.1 x 1.1 mm	2	5-40 °C	1,2,4	90
K-RW11xx-I	Calibration of the irradiance sensitivity in A/W/m² and A/W/cm². Including K-SR in order with new detector. xx = detector model									
KDW-S2	Calibration of the spectral irradiance sensitivity at one or a chain of wavelength without or in combination with accessory									
KDW-R	Calibration of the integral radiometric sensitivity in combination with accessory									

TD-11RW: Temperature Controlled *VISIBLE-NIR* Polychromatic Radiometric Light Detectors

The TD-11RW detectors offers a unique temperature control for filter and photodiode by precise heating to a higher operation temperature than the ambient temperature.
The control electronic is supplied in an external housing with plug-in power supply.
The detector can be combined with integrating spheres with 11-type adapter for radiant power measurements.
Three different kinds of spectral responses e.g. TD-11RW03, TD-11RW04 and TD-11RW05 are offered which fulfill the need of most radiometric applications for integral detectors.
Calibrations are offered with or without accessory.

Ordering Information & typical Specifications										
Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Operation Temp.	plug	package
	polychromatic	Page	nA/W/m²	nA/W	mA	photodiode	m			page
TD-11RW03	VISIBLE 400-800 nm	65	tbc with sphere		1	2.8 x 2.8 mm	2	55°C	1,2,4	90
TD-11RW04	NIR 800-1000 nm	66			1	2.8 x 2.8 mm	2	55°C	1,2,4	90
TD-11RW05	VISNIR 400-1000 nm	66			1	2.8 x 2.8 mm	2	55°C	1,2,4	90
K-TD-11RWxx-I	Calibration of the irradiance sensitivity in A/W/m² and A/W/cm². Including K-SR in order with new detector									
KDW-S	Calibration of the spectral sensitivity in combination with accessory									
KDW-R	Calibration of the integral radiometric sensitivity in combination with accessory									

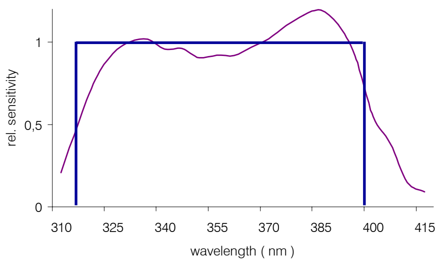
RW-37: High Sensitivity *VISIBLE-NIR* Broadband Irradiance Detectors

The RW-37 irradiance detectors are for use in radiometric applications requiring high sensitivity. The diffuser window offers a cosine corrected field-of-view. The compact 37-type package fits into tight spaces in end-on viewing set-up. A side M6 tapped hole allows post mounting or fixturing into the application.
The detector can mounted to integrating spheres using 37-type adapters and calibrated for radiant power measurements. See Integrating Spheres chapter. For simple radiometric radiance measurements the RW-37 detectors can be combined and calibrated with SRT-M37 front lenses. Calibrations are offered with or without components attached.

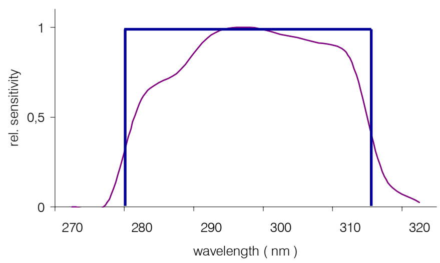
Ordering Information & typical Specifications										
Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Temp. °C	plug	package
	Broadband	Page	nA/W/m²	mA/W/cm²	mA	Diffuser	m			page
RW-3701	BLUE $_{400\text{-}500\ nm}$	65	70	0.7	1	11 mm Ø	2	5-40	1,2,4	90
RW-3702	RED $_{700\text{-}800\ nm}$	65	70	0.7	1	11 mm Ø	2	5-40	1,2,4	90
RW-3703	VISIBLE $_{400\text{-}800\ nm}$	65	1.7	0.017	1	11 mm Ø	2	5-40	1,2,4	90
RW-3704	NIR $_{800\text{-}1000\ nm}$	66	200	2	1	11 mm Ø	2	5-40	1,2,4	90
RW-3705	VISNIR $_{400\text{-}1000\ nm}$	66	400	4	1	11 mm Ø	2	5-40	1,2,4	90
K-RW37xx-I	Calibration of radiometric sensitivity in A/W/m² and A/W/cm². Includes K-SR in new detector order. xx = detector model									
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components									
KDW-R	Calibration of integral radiometric sensitivity in combination with accessory components.									

ULTRAVIOLET Polychromatic Irradiance Light Detectors

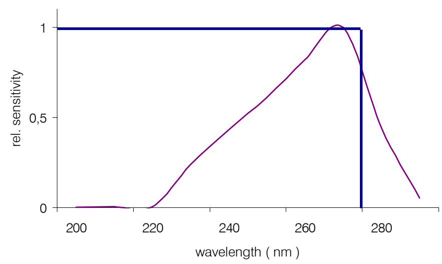
ULTRAVIOLET broadband radiometric detectors are primarily used for integral intensity measurements in defined UV band pass ranges of wavelengths. Correction filters are used to shape the bare detector response to the desired spectral response.
The plots below and on the following page summarize the standard measurement heads offered with correction filters and spectral responses. Customer-specific solutions with respect to spectral range, measurement geometry and other design features are available along with full assistance from our sales engineers.



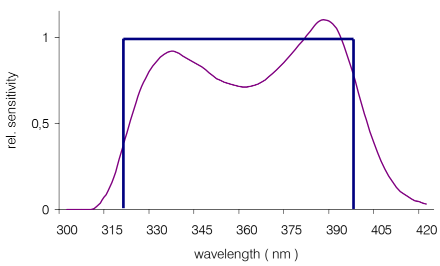
UV-01 Spectral Response: UV-A $_{315\text{-}400\ nm}$



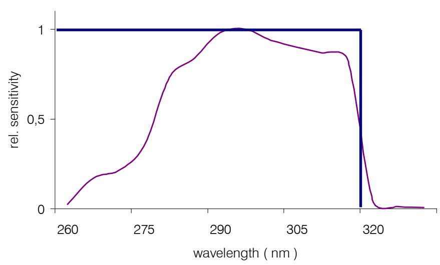
UV-02 Spectral Response: UV-B $_{280\text{-}315\ nm}$



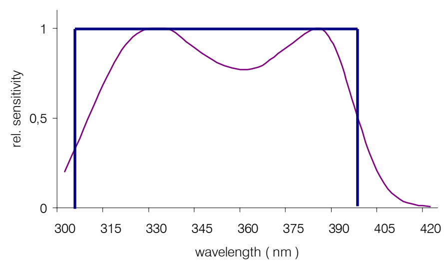
UV-03 Spectral Response: UV-C $_{200/250\text{-}280\ nm}$



UV-10 Spectral Response: UV-A $_{320\text{-}400\ nm}$



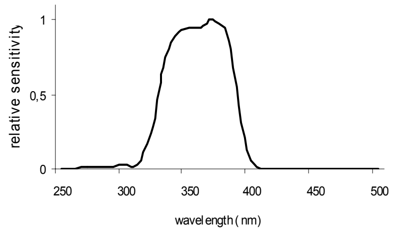
UV-11 Spectral Response: UV-B $_{280\text{-}320\ nm}$



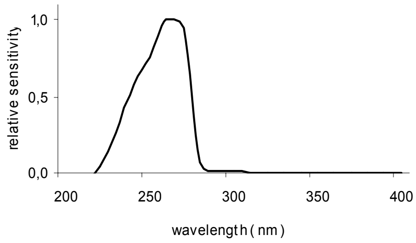
UV-16 Spectral Response: UV-A $_{305\text{-}400\ nm}$

Irradiance

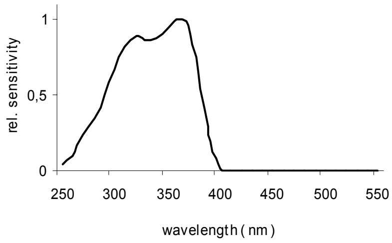
ULTRAVIOLET Broadband Irradiance Detectors



UV-17 Spectral Response: UV-A 320-400 nm



UV-18 Spectral Response: UV-C 254 nm peak



UV-19 Spectral Response: UV-Broad-band

UV-11: Compact Size UV Broadband Irradiance Detectors

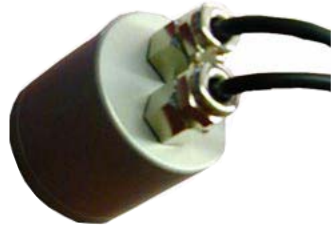
UV-A/UV-B are the most frequently used wavelength ranges in the qualification procedure of light sources used in photobiological and industrial application. Besides standard narrow band detectors, Gigahertz-Optik offers real broadband detectors. **The UV-11** detectors offer a compact package with flange mount to arrange detector arrays with only a grid size of 11 mm. Or they can be combined with integrating spheres using 11-type adapters for radiant power measurements.
Calibrations are offered with or without accessory components.

Ordering Information & typical Specifications

Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Temp. °C	plug	package
	Broadband	Page	nA/W/m²	nA/W	mA	photodiode	m			page
UV-1101	UV-A 315-400 nm	67	tbc	tbc with sphere	0.2	2.5 x 2.5 mm	2	5-40	1,2 or 4	90
UV-1102	UV-B 280-315 nm	67	tbc		0.05	1.1 x 1.1 mm	2	5-40	1,2 or 4	90
K-UV11xx-I	Calibration of radiometric sensitivity in A/W/m² and A/W/cm². Includes K-SR in with new detector order. xx = detector model									
KDW-S	Calibration of spectral sensitivity at one or a chain of wavelength without or in combination with accessory components.									
KDW-R	Calibration of integral radiometric sensitivity with accessory components									

TD-11UV: Temperature Controlled UV Broadband Radiometric Detectors

The TD-11UV detectors offer a unique temperature control feature where the filter and photodiode are heated to a higher operating temperature than the ambient temperature.
The control electronics are supplied in an external housing with a plug-in power supply.
The detector can be combined with integrating spheres with 11-type adapter for radiant power measurements.
Two different kinds of spectral responses, UV-A315-400 nm and UV-B280-315 nm are offered which fulfill the need of most radiometric applications for integral detectors.
Calibrations are offered with or without accessory components.



Ordering Information & typical Specifications

Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Operation Temp.	plug	package
	Broadband	Page	nA/W/m²	nA/W	mA	photodiode	m			page
TD-11UV01	UV-A 315-400 nm	67	tbc	tbc with sphere	0.2	2.5 x 2.5 mm	2	55°C	1,2,4	90
TD-11UV02	UV-B 280-315 nm	67	tbc		0.05	1.1 x 1.1 mm	2	55°C	1,2,4	90
K-TD11UVxx-I	Calibration of radiometric sensitivity in A/W/m² and A/W/cm². Includes K-SR in new detector order. xx = detector									
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components									
KDW-R	Calibration of integral radiometric sensitivity with accessory components									

UV-37: High Sensitivity Broadband UV Irradiance Detectors

UV-3701, UV-3702, UV-3703

These detectors represents the classic DIN and CIE ultraviolet radiation wavelength bands UV-$A_{315\text{-}400\ nm}$, UV-$B_{280\text{-}315\ nm}$ and UV-$C_{100\text{-}280\ nm}$. Deep UV in the range of 100 to 250 nm is very rarely observed in radiometry. So the UV-3703 offers a practical UV-C solution with a sensitivity range from 250 to 280 nm.

UV-3710, UV-3711

Some non-biological disciplines specify the wavelength ranges 320 to 400 and 280 to 320 nm for the evaluation of UV-A and UV-B radiation. The UV-3701 and UV-3702 irradiance detectors are designed for this application.

UV-3716

The sharply increasing short-wave spectral component of modern lamps creates a potential risk of exposure of the eyes to excessive UV-A radiation. The limit values for $E_{305\text{–}400\ nm}$ irradiance were established to limit the intensity this radiation on the retina as when optical fibers are used in eye operations (aphakic eye operation).

UV-3717

In applications where the UV-A irradiance must measured amidst intense blue & visible light, the UV-3701 and UV-3710 may not offer sufficient visible wavelength range signal rejection. This will produce an inaccurately high UV-A reading. A good example of this is fluorescent lamps which generate significant mercury lines at 405, 436, 546 and 577 nm. The UV-3717 is visible blind for best stray light rejection >400 nm..

UV-3718

The model UV-3718 is designed for narrow band UV-light sources with distinct 254 nm peak emission spectrum. The RADIN type diffuser offers high UV stability under UV-C irradiation. The detector is calibrated with a narrow band light source at 254 nm.

UV-3719

The model UV-3719 offers a broadband spectral sensitivity from 250 to 390 nm. This detector is typically used in applications where the lamp emission spectrum is known allowing an a (z) calibration correction.

UV-37

The UV-37 detectors are high sensitivity irradiance detectors for radiometric applications involging polychromatic optical radiation. The diffuser window provides a cosine corrected field-of-view for diffuse light signals. The compact 37-type package fits into tight spaces with a vertical end-on view. An M6 tapped hole allows post mounting or fixturing in the application. The detectors can be combined and calibrated with integrating spheres or SRT-M37 quartz front lenses.

Ordering Information & typical Specifications

Model	λresp	Response	Typical Sensitivity		Imax	Sensing Area	cable	Temp. °C	plug	package
	Broadband	Page	nA/W/m²	µA/W/cm²	mA	Diffuser	m			page
UV-3701	UV-A $_{315\text{-}400\ nm}$	67	4	40	0.1	11 mm Ø	2	5-40	1,2 or 4	90
UV-3702	UV-B$_{280\text{-}315\ nm}$	67	1.7	17	0.05	11 mm Ø	2	5-40	1,2 or 4	90
UV-3703	UV-C $_{200/250\text{-}280\ nm}$	67	2	20	0.05	11 mm Ø	2	5-40	1,2 or 4	90
UV-3710	UV-A $_{320\text{-}400\ nm}$	67	7	70	0.1	11 mm Ø	2	5-40	1,2 or 4	90
UV-3711	UV-B $_{280\text{-}320\ nm}$	67	3	30	0.05	11 mm Ø	2	5-40	1,2 or 4	90
UV-3716	UV-A $_{305\text{-}400\ nm}$	67	10	100	0.1	11 mm Ø	2	5-40	1,2 or 4	90
UV-3717	UV-A $_{325\text{-}400\ nm}$	68	1	10	0.1	11 mm Ø	2	5-40	1,2 or 4	90
UV-3718	UV-C $_{254\ nm}$	68	2	20	0.05	11 mm Ø	2	5-40	1,2 or 4	90
UV-3719	UV-A $_{250\text{-}400\ nm}$	68	3	30	0.1	11 mm Ø	2	5-40	1,2 or 4	90
K-UV37xx-I	Calibration of radiometric sensitivity in A/W/m² and A/W/cm². Includes K-SR in new detector order. xx = detector model									
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths without or in combination with accessory components									
KDW-R	Calibration of radiometric sensitivity with accessory components									

UV-37: High Sensitivity Photobiologically Actinic UV Irradiance Detectors

Photobiology is concerned with the interaction of optical radiation and living organisms. Photobiological radiometric measurement systems are essential tools used for the evaluation of sources of optical radiation in cosmetics, medical and therapeutic, health and safety and other areas. The photodetectors used in these various application areas require spectral sensitivities corresponding directly to a particular photobiological response function. This enables direct measurement of the photobiological dose of a radiation source.

The spectral response function of the sensor is generated by optical correction filters used to tailor the bare detector response. Since the ideal target function cannot be perfectly duplicated, it is necessary to find the best possible compromise through extensive computer simulation taking a great variety of lamp spectra into account to minimize error. The associated series of measurements, which are an essential part of this engineering process, are carried out at Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities.

On the following page, irradiance light detectors available from Gigahertz-Optik that are primarily intended for applications in the fields of radiation protection and of radiation therapy are presented. For a specific response function not shown, or if you should require more detailed information, please contact our technical sales department directly.

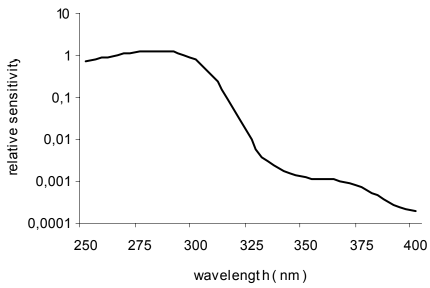
Gigahertz-Optik

Actinic Irradiance

UV-3704: UV-Erythemal Actinic Irradiance Detector

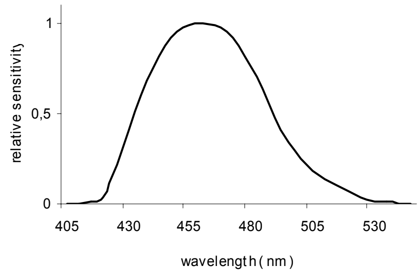
The typical symptom of UV erythema is acute skin inflammation caused by UV radiation (sunburn) which has been linked to skin cancer over prolonged exposure times.
The UV-3704 detector permits direct measurement of the UV Erythema effective irradiance by means of it's spectral sensitivity adaptation to the nominal CIE Erythemal spectral function.

Measurement uncertainty can be evaluated and reduced using Gigahertz-Optik's a(z) method when the lamp emission spectra is known with dataset provided.



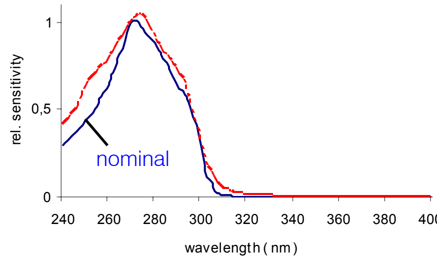
UV-3706: Bilirubin Actinic Irradiance Detector

Newborn jaundice or neonatal hyperbilirubinaemia, a yellowish appearance of the skin and whites of the eyes, is present to some degree in almost all newborn infants. This is caused by an elevated level of bilirubin molecule in the blood which results from immaturity of the liver function combined with the destruction of red blood cells present. When these levels are very high, one method of clearing the jaundice is by exposing the newborn to light in the blue spectral region between 400 to 550 nm.
The UV-3706 detector allows the direct measurement of phototherapeutically effective irradiance employed for lowering the bilirubin level in newborn infants.



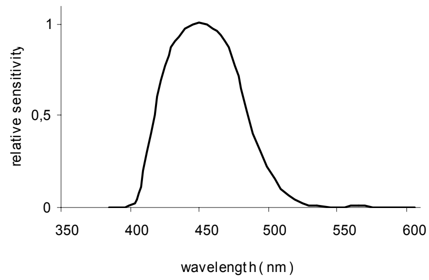
UV-3708: ACGIH/ICNIRP Actinic Irradiance Detector

The spectral weighting function for the acutely harmful effects of UV radiation, was developed by the *American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Non-Ionising Radiation Protection (ICNIRP).*
The spectral effectiveness in the UV-C and UV-B ranges is very high as compared to the UV-A range.
The UV-3708 detector permits direct measurement of effective irradiance according to ACGIH/ICNIRP guidelines.
Measurement uncertainty can be evaluated and reduced using Gigahertz-Optik's a(z) method when the lamp emission spectra is known with dataset provided.



UV-3709: Blue-Light Hazard Actinic Irradiance Detector

If optical radiation in the wavelength range between 380 and 550 nm of sufficient intensity reaches the retina it can cause photochemical injury. Radiation in the "blue" part of the spectrum triggers photochemical reactions, if the photon energy in the radiation is high enough, converting chemically unstable molecules into one or more other molecule types. BLH irradiance is relevant exclusively in connection with ophthalmic instruments (microscopes, observation devices used in optician's practices). Otherwise the measurement of radiance applies.
The UV-3709 detector head is designed for direct measurement of the effective irradiance for blue light hazard, responsible for retinal damage.



Ordering Information & Specifications

Model	λresp	Wavelength Range	Typical Sensitivity		Imax	Sensing Area	cable	Temp. °C	plug	package
	Biological Effective		nA/W/m²	µA/W/cm²	mA	Diffuser	m			page
UV-3704	Erythema	250-400 nm	3	30	0.05	11 mm Ø	2	5-40	1, 2, 4	90
UV-3706	Billirubin	400-550 nm	200	2000	1	11 mm Ø	2	5-40	1, 2, 4	90
UV-3708	ACGIH/ICNIRP	250-400 nm	1,5	15	0.05	11 mm Ø	2	5-40	1, 2, 4	90
UV-3709	Blue-light Hazard	400-520 nm	150	15000	1	11 mm Ø	2	5-40	1, 2, 4	90
K-UV37xx-I	Calibration of actinic irradiance sensitivity in A/W/m² and A/W/cm². Includes K-SR in new detector order. xx = detector									
KDW-S	Calibration of spectral sensitivity with accessory components									
KDW-R	Calibration of radiometric sensitivity with accessory components									

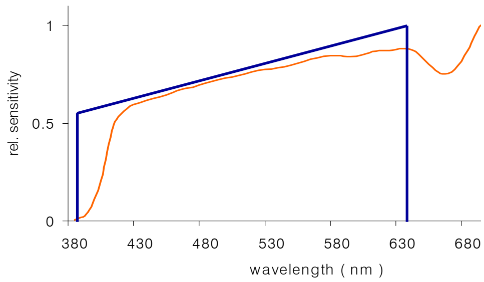
PS-37: Plant Physiology Actinic Irradiance Detectors

The radiation conditions used in determining the rate of photosynthesis and the photosynthetic potential of various plant or algae types are not the same in all research institutions. Results obtained under very different radiation conditions, using detector heads with non-uniform rectangular (radiometric) characteristics, and then relating them to one another, may lead to false conclusions. This is because the varying spectra of the radiation sources in use are ignored in obtaining the measurement.
The solution is to evaluate the irradiance with a sensor with an appropriate spectral response function. It is presently assumed that the number of light quanta absorbed is responsible for plant growth, which implies that it is quantum magnitudes effective in plant biology that need to be measured. The most important magnitude is the photosynthetic photon irradiance $E_{p,sy}$.
The wavelength limits of integration band pass need to be specified. If, for example, the photosynthetic photon irradiance is to be measured in the range of wavelengths between 400 nm and 700 nm, 320 nm and 500 nm and 590 nm to 900 nm, the integration is carried out in the corresponding spectral segments.
This numerical integration can be performed implicitly by means of a cosine corrected integral detector such as the PS-37 series.

Waterproof version of the PS-37 type detector head with dome cover

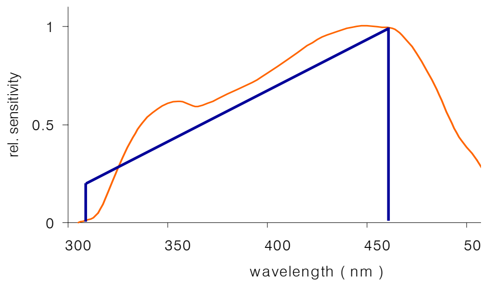
PS-3701: PAR Irradiance Detector

Photosynthesis is one of the most important biochemical processes on the planet. In the process of photosynthesis green plants absorb carbon dioxide from the atmosphere and water from the soil, combining them with the aid of radiation energy to build sugar, releasing oxygen and water into the atmosphere.
In general plant physiology, the term **P**hotosynthetically **A**ctive **R**adiation (**PAR**) refers to the radiation in the range of wavelengths between 400 nm and 720 nm.
The PS-3701 detector is designed for direct evaluation of **P**hotosynthetically **A**ctive **R**adiation in the 400 to 700 nm wavelength range. This detector can also be supplied with an optional water proof dome cover.



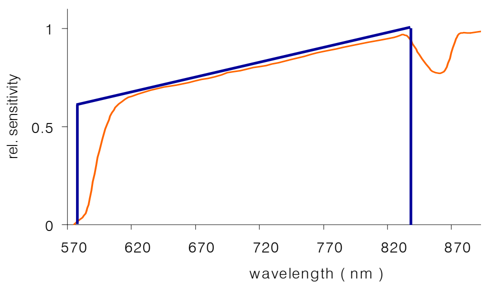
PS-3702: BLUE$_{320\text{-}500\ nm}$ Plant Physiology Irradiance Detector

Phototropism describes the effect of optical radiation on the direction of plant growth. The regions of maximum effect lie in the blue range between 380 nm and 520 nm. Radiation can have the effect of causing parts of plants to move.
The PS-3702 detector is designed for direct evaluation of the **phototropism** effective irradiation over the spectral range from 320 to 500 nm for UV-A to green/visible assessment.
This detector can also be supplied with an optional water proof dome cover.



PS-3703: RED$_{560\text{-}900\ nm}$ Plant Physiology Irradiance Detector

Photomorphogenesis describes the way in which plants are formed under the influence of optical radiation. Radiation in the red region of the spectrum encourages linear growth, while blue radiation yields small, strong plants. To be more precise, the ratio of the radiation intensities in the range of wavelengths from 690 nm to 780 nm (long wavelength red) to the range of wavelengths from 560 nm to 680 nm (short wavelength red) is of great importance for the plant's biological processes. The PS-3703 detector evaluates photomorphogenesis effective radiation in the wavelength range from 590 to 900 nm.
This detector can also be supplied with an optional water proof dome cover.



Ordering Information & typical Specifications

Model	λresp	Wavelength Range	Typical Sensitivity	Imax	Sensing Area	cable	Operation Temp.	plug	package
	Plant Physiology		nA / µMol*m^{-2}*s^{-1}	mA	Diffuser	m			page
PS-3701	PAR	400-700 nm	100	1	11 mm Ø	2	5-40°C	1, 2, 4	90
PS-3702	BLUE	320-500 nm	2	1	11 mm Ø	2	5-40°C	1, 2, 4	90
PS-3703	RED	590-900 nm	100	1	11 mm Ø	2	5-40°C	1, 2, 4	90
K-PS37xx-I	Calibration of PAR sensitivity in A/µMol*m^{-2}*s^{-1}. Includes K-SR in new detector order. xx = detector model								
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components								
KDW-R	Calibration of integral radiometric sensitivity in combination with accessory components								

High Intensity Irradiance / UV-Curing

High Intensity Irradiance Detectors for UV-Curing Applications

Gigahertz-Optik offers irradiance detectors specially designed for hostile ambient conditions involving high intensity irradiation and high temperature.
The detectors consist of two main components, the passive RADIN element and the detector that are connected by a flexible or rigid light guide.
The light guide protects the detector and corrective band pass filter from heat damage and also reduces measurement errors due to the temperature coefficient (drift) of the photodiode.
RADIN itself is high UV irradiation and temperature stable up to 100°C with short peak measurements to 200°C. The low profile (9 mm) RADIN sensor element permits irradiance measurement close to the sample surface of the probe and offers a cosine adapted field-of-view.
Irradiances of up to 40 W/cm^2 can be measured.
For spot curing applications, adapters are available for simple positioning of different size light guide nozzles in front of the RADIN sensor.

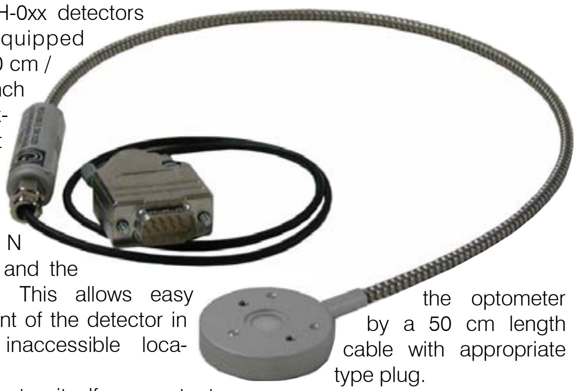
Three Different Package Designs

The RCH type detectors are offered in three different packages for use in the most common UV curing applications.

Three Different Spectral Sensitivities

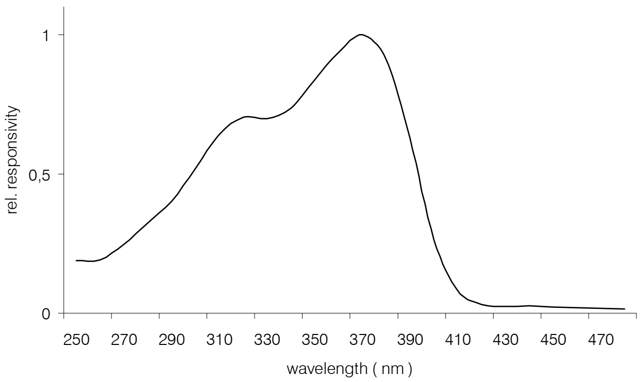
Detector spectral responses are available for the most common 365 nm peak UVA as well as UV broadband and BLUE ranges.

RCH-0: Low Profile with Flexible Light Guide

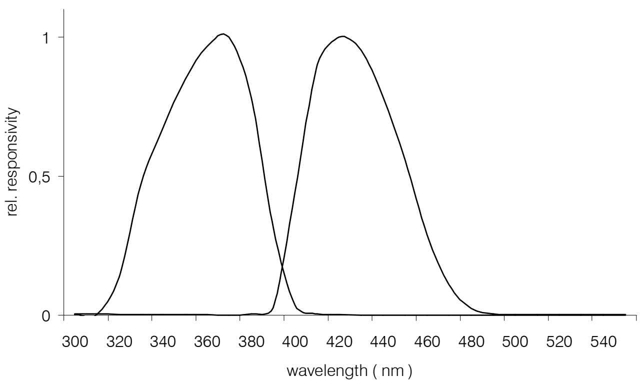


The RCH-0xx detectors are equipped with a 50 cm / 20 inch long flexible light guide between the RADIN element and the detector. This allows easy placement of the detector in remote inaccessible locations.
The detector itself connects to the optometer by a 50 cm length cable with appropriate type plug.

06: UV Broadband Sensitivity



08/09: UVA 365 nm Peak & BLUE Sensitivity



RCH-1: Low Profile with Rigid Light Guide

The RCH-1xx detectors are supplied with a 22 cm / 8.7 inch long rigid (non-flexible) light guide between the RADIN element and the detector.
The detector is connected to the optometer by a 50 cm long cable with appropriate type plug.

RCH-5: In-Line Detector

The RCH-5xx detectors are designed for applications where the active detector RADIN surface must be positioned at the same height and location of the test sample surface. To accomplish this, the RADIN element is recessed in the probe housing. The sensor housing is made of stainless steel to avoid any temperature problems. The detector connects to the meter via a 2 m long cable with appropriate plug. type .

***X9 2 with RCH-1xx** detector and light-guide adapter. Specifications and description in chapter Optometer*

High Intensity & UV-Curing Actinic Irradiance / 360 Deg. F.O.V. Irradiance

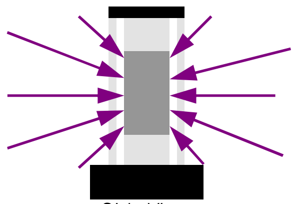
RCH-1xx, RCH-1xx & RCH-5xx: High Intensity Irradiance Detectors

Ordering Information & typical Specifications

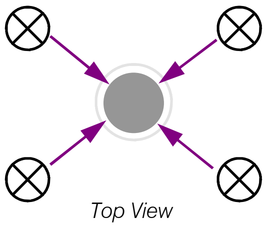
Model	λresp	Resp.	Max. E & T		Typ. Sensitivity	Imax	Sensing Area	Light Guide	cable	Front adapter		plug	package
	Broadband	Page	W/cm²	°C	nA/mW/cm²	mA	Diffuser	cm / inch	m	Dia.	Page		page
RCH-006	UV Broadband	14	40	100	0.3	0.1	9 mm Ø	50 / 20	0.5	5,7,10	91	1,2,4	91
RCH-008	UVA Peak 365 nm	14	40	100	0.3	0.1	9 mm Ø	50 / 20	0.5	5,7,10	91	1,2,4	91
RCH-009	BLUE Peak 430 nm	14	40	100	0.2	0.1	9 mm Ø	50 / 20	0.5	5,7,10	91	1,2,4	91
RCH-106	UV Broadband	14	40	100	0.3	0.1	9 mm Ø	22 / 8.7	0.5	5,7,10	91	1,2,4	91
RCH-108	UVA Peak 365 nm	14	40	100	0.3	0.1	9 mm Ø	22 / 8.7	0.5	5,7,10	91	1,2,4	91
RCH-109	BLUE Peak 430 nm	14	40	100	0.2	0.1	9 mm Ø	22 / 8.7	0.5	5,7,10	91	1,2,4	91
RCH-506	UV Broadband	14	40	100	0.065	0.05	6 mm Ø	-	2	-	-	1,2,4	91
RCH-508	UVA Peak 365 nm	14	40	100	0.096	0.1	6 mm Ø	-	2	-	-	1,2,4	91
RCH-509	BLUE Peak 430 nm	14	40	100	0.065	0.1	6 mm Ø	-	2	-	-	1,2,4	91
K-RCHxxx-I	Calibration of irradiance sensitivity in A/W/cm². Includes K-SR in new detector order. xxx = detector model												
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths without or in combination with accessory components												
KDW-R2	Calibration of integral irradiance sensitivity with accessory components.												

ROD-360-UV18: 360 Degree F.O.V. UV-C$_{254nm}$ Irradiance Detectors

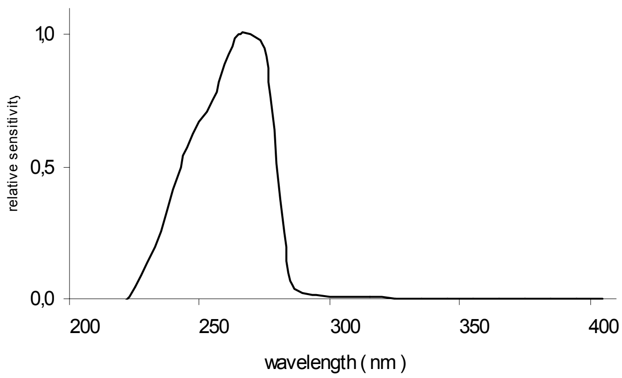
The ROD-360 is an unique irradiance detector which offers a 360 degree field-of-view.
A quartz-rod is used to collect all light irradiating it's diffuse detection window independent of the horizontal incident angle within the round angle. The vertical axis exhibits a diffuse viewing characteristic.

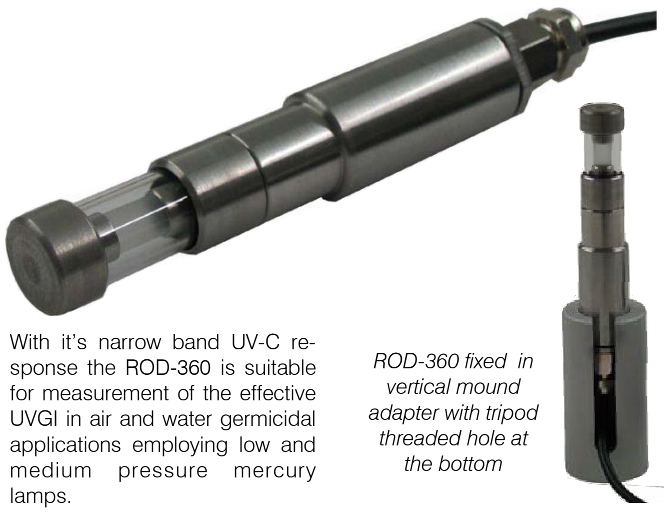


Side View



Top View





ROD-360 fixed in vertical mound adapter with tripod threaded hole at the bottom

With it's narrow band UV-C response the ROD-360 is suitable for measurement of the effective UVGI in air and water germicidal applications employing low and medium pressure mercury lamps.
Calibration is done using a 254 nm low pressure mercury light source.
The ROD-360 features a waterproof housing which allows measurements in humid or underwater applications. The 10 mm diameter clear quartz tube not only seals the detector rod but along with it's stainless steel housing the probe and active window can be easily cleaned. This makes the ROD-360 usable in gray water or other dirty measurement environments and also in medical applications.
A protective cap and mounting adapter is supplied to fixture the probe for vertical or horizontal use on a standard tripod or for integration into the application.

Ordering Information & typical Specifications

Model	λresp	Wavelength Range	Typical Sensitivity		Imax	Sensing Area	cable	Operation Temp.	plug	package
	Narrow Band		nA/W/m²	µA/W/cm²	mA	Rod	m			page
ROD-360-UV18	UV-C	220-280 nm	0.8	8	0.1	5 Ø x 6.5 mm	2	0-40°C	1,2,4	92
K-ROD360-UV18-S	Calibration of the irradiance sensitivity in A/W/m² and. A/W/cm² Including K-SR in order with new detector.									
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths									

Gigahertz-Optik

Multi-Channel Illuminance & Irradiance

XD-95: Single & Dual Channel Illuminance & Irradiance Detector

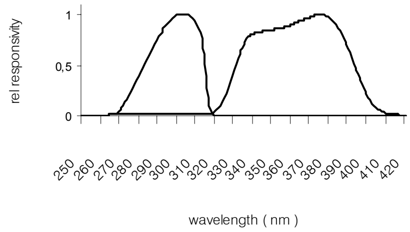
The XD-95 detectors are designed for use with Gigahertz-Optik's multi-channel X1 and X9 hand-held optometers. The ability to measure two wavelength ranges without having to change and replace the detector head greatly simplifies the measurement procedure.

Several detectors are offered covering common applications. A short overview describing the various models is shown here. More information is available in the X9 and X11 optometer data descriptions.

The XD-95 detectors are supplied in a compact lightweight and low profile plastic housing with a 2 m long cable with –4 type plug for use with the X9 and X1 meters.

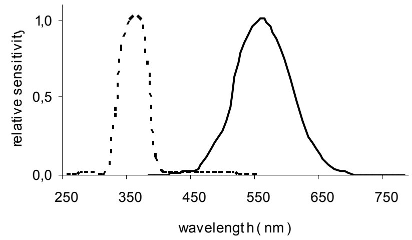
XD-9501: UV-A & UV-B Irradiance

Ultraviolet radiation is used in the treatment of certain skin diseases like Psoriasis and for photobiological studies like SPF testing. The phototherapist needs to monitor the source irradiance or energy for accurate dosimetry. Typical wavelength ranges of interest are UV-A$_{320\text{-}400nm}$, UV-B$_{280\text{-}320nm}$ and UV-B$_{311nm}$. The XD-9501 detector offers a real polychromatic radiometric spectral match to the UV-A and UV-B spectral ranges and a precise cosine corrected field of view.



XD-9502: UV-A Irradiance & V(λ) Illuminance

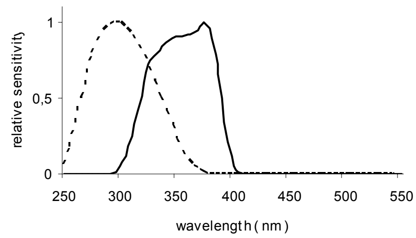
Liquid Penetrant Testing of surface defects using the dye penetration process (**DIN EN 1956, ASTM and MIL Standards)** and **Photostability** testing of drug and drug products as stated in ICH guidelines (International Conference for Harmonization) requires the intensity or dose control of the light sources used for test sample irradiation. The XD-9506 detector offers a real broadband radiometric UV-A$_{315\text{-}400nm}$ detector and a illuminance detector (f1' ≤6%), both with cosine diffuser for precise readings in both applications.



XD-9503: UV-B$_{240\text{-}340nm}$ & UV-A$_{315\text{-}400nm}$ Irradiance

TL01 and TL12 light sources are widely used in phototherapy applications. The phototherapeutic effective radiation of the TL01 and TL12 source falls within the 240 to 340 nm bandpass with peak at 313 nm.

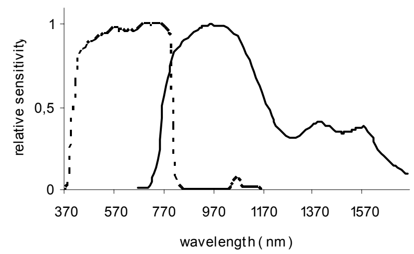
The XD-9503 is specially designed to measure the therapeutic effective UV-B and UV-A irradiance of TL01 and TL12 light sources. The detectors spectral sensitivity functions and calibration using TL1 and TL12 light sources ensure precise readings.



XD-9504: VISIBLE$_{400\text{-}800nm}$ & NIR$_{800\text{-}1200nm}$ Irradiance

Light has therapeutic effects in many different wavelength ranges. However broadband light sources will emit light at wavelengths outside the phototherapeutic wavelength range. This 'stray light' can interfere with the treatment or even cause harm in terms of heat for example, so must be measured in order to be kept to minimal levels.

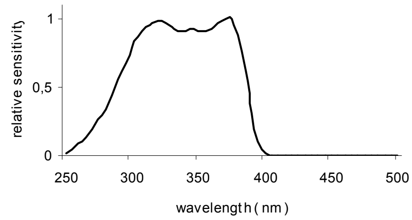
The XD-9504 is designed to measure irradiance in the 'signal' wavelength range (400-800 nm) and 'noise' range (800-1200 nm). Both detectors offer a 'flat' broadband spectral response

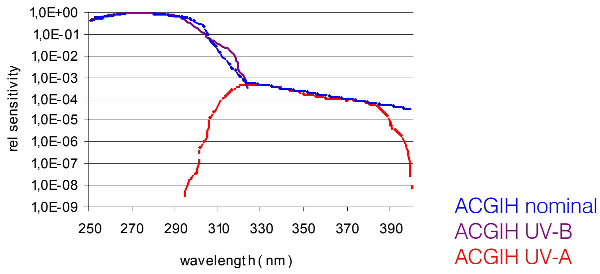


XD-9505: UV-Broadband$_{240\text{-}400nm}$ Irradiance

In some applications the total UV irradiance of broadband light sources needs to be measured. But because of the unavailability of ultraviolet detectors with radiometrically 'flat' spectral sensitivities across the entire UV range, relative measurements are normal. The XD-9505 can be used for relative broadband UV assessment and can provide more precise UV measurement through calibration correction when the emission spectrum of the light source is known.

The single detector offers a cosine diffuser for precise readings in diffuse irradiation zones.

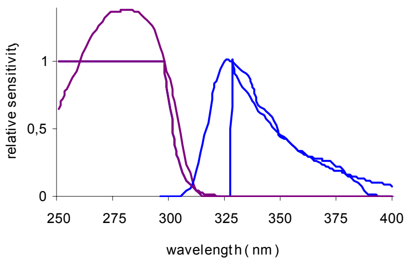




XD-9506: EM6 & EN14255 ACGIH Irradiance

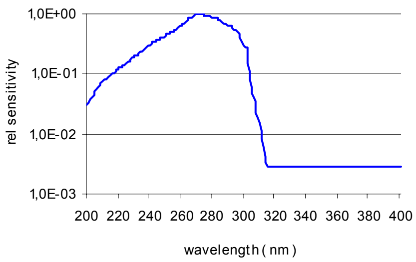
Several guidelines and standards concerning UV hazard risk assessment exist today. Most often the ACGIH/ICNIRP spectral weighting function for the acutely harmful effects is recommended as reference for irradiance measurements *(American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Non-Ionising Radiation Protection (ICNIRP).* The XD-9506 ACGIH detector is designed to meet EM 6, DIN-EN 14255 and BGV B9 regulations. It's two cell design offers best possible isolation between UV-A and UV-B.

As part of these requirements an additional UV-A irradiance detector like the XD-9502, XD-9511 or UV-3717 is needed.



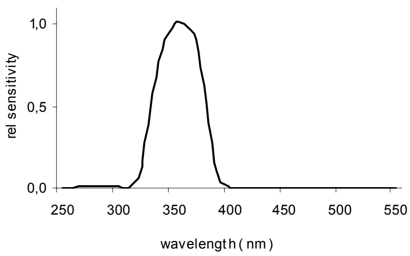
XD-9509: 2-Channel Erythema Effective Irradiance

The typical symptom of UV erythema is acute skin inflammation caused by UV radiation (sunburn) which may be linked to skin cancer over prolonged exposure times. The XD-9509 detector permits direct measurement of the UV Erythemal effective irradiance by means of it's spectral sensitivity adaptation to the nominal CIE Erythemal spectral function. It's two cell design offers best possible isolation between the UV-A and UV-B range.



XD-9510: DIN EN 12198 ACGIH Irradiance

The XD-9510 detector is a modified version of the XD-9506 ACGIH irradiance detector. The difference is the spectral response of the UV-A cell which simulates the *flat UV-A response* specification for DIN EN 12198. Both detectors offer a cosine diffuser.



XD-9511: UV-A & EN 14255 UV-A$_{315\text{-}400nm}$ Irradiance

The XD-9511 offers a single detector with UV-A spectral response from 315 to 400 nm.

Because of it's good blocking of the visible spectrum above 400 nm, this detector can also be used in combination with the XD-9506 for measurement of UV-A irradiance following DIN EN 14255 and BGV B9.

The detector offers a cosine diffuser for precise measurements in diffuse light incident conditions.

Ordering Information & typical Specifications

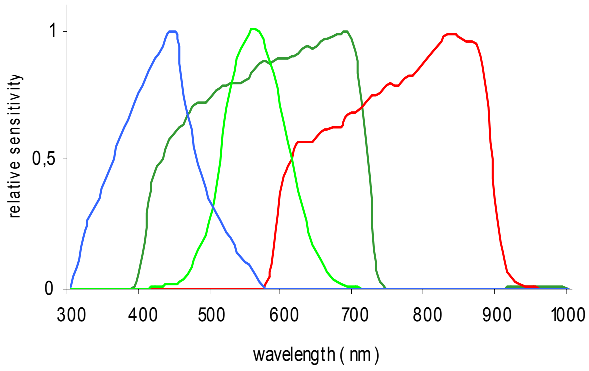
Model	Ch1 λresp	Ch2 λresp	Typical Sensitivity		Sensing Area	cable	Operation Temp.	Optometer		plug	package
			nA/..	nA/..	Diffuser	m		X9 type			page
XD-9501	UVA$_{320\text{-}400nm}$	UVB$_{280\text{-}320nm}$	17 W/m^2	2.5 W/m^2	8 mm Ø	2	5-40°C	X96	X11	4	91
XD-9502	UVA$_{315\text{-}400nm}$	V(λ)	10 W/m^2	0.05 lx	8 mm Ø	2	5-40°C	X98	X11	4	91
XD-9503	UVA $_{315\text{-}400nm}$	UV$_{Peak\ 311nm}$	4 W/m^2	2 W/m^2	8 mm Ø	2	5-40°C	-	X11	4	91
XD-9504	VIS$_{400\text{-}800nm}$	NIR$_{800\text{-}1200nm}$	0.7 W/m^2	130 W/m^2	8 mm Ø	2	5-40°C	-	X11	4	91
XD-9505	UV$_{Broadband}$	-	13 W/m^2	-	8 mm Ø	2	5-40°C	X97	X11	4	91
XD-9506	UVA$_{ACGIH}$	UVB$_{ACGIH}$	4000 W/m^2	1.5 W/m^2	8 mm Ø	2	5-40°C	-	X11	4	91
XD-9509	UVA$_{Erythema}$	UVB$_{Erythema}$	tbc W/m^2	tbc W/m^2	8 mm Ø	2	5-40°C	-	X11	4	91
XD-9510	UVA$_{ACGIH}$	UVB$_{ACGIH}$	4000 W/m^2	1.5 W/m^2	8 mm Ø	2	5-40°C	-	X11	4	91
XD-9511	UVA$_{315\text{-}400nm}$	-	4 W/m^2	-	8 mm Ø	2	5-40°C	X97	X11	4	91
K-XD95xx-I	Calibration of integral illuminance/irradiance sensitivity in A/lx or A/W/cm^2. Includes K-SR in new detector order. xx = detector model										
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths										

Gigahertz-Optik

Multi-Channel Illuminance, Irradiance & Luminous Color

TP-4501: Triple PAR Irradiance Detectors

The TP-4501 is a unique detector head designed for use with the X1$_1$ hand-held optometer to measure on-site lighting conditions in greenhouses, plant growth studies, soil and seed science.
The compact detector houses four different detectors:
PAR: Measures the **photosynthetically** effective radiation in the 400 to 700 nm wavelength range actinic for green growth.
BLUE: Measures the **phototropism** effective radiation within the 320 to 500 nm wavelength range actinic for directional plant growth.
RED: Measures the **photomorphogensis** effective radiation within the 560 to 900 nm wavelength range actinic for plant growth formation.
V(λ): Measures the **photometric** illuminance which specifies the ambient lighting condition.
The low profile detector housing



is only 20 mm high with a central 10 mm diameter diffuser which ensures the cosine corrected field of view required in illuminance & irradiance applications.

Ordering Information & Specifications

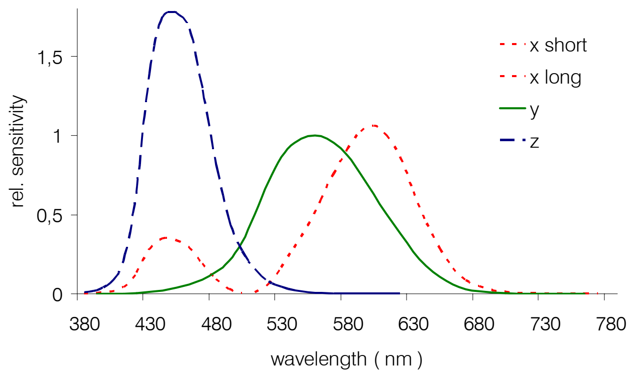
Model	λresp	λresp	λresp	λresp	Typical Sensitivity				Sensing Area	cable	Operation Temp.	Meter Type	plug	package
	Ch1	Ch2	Ch3	Ch4	CH1	CH2	CH3	CH4		m	°C			page
	photometric	Plant Physiology Effective			pA/lx	pA/μMol*m^{-2}*s^{-2}			Diffuser					
TP-4501	V(λ)	PAR$_{400\text{-}700\ nm}$	BLUE$_{320\text{-}500\ nm}$	RED$_{560\text{-}900\ nm}$	40	0.1	2	70	10 mm Ø	2	5-45	X1$_1$	4	90
K-TP4501-I	Calibration of photometric & plant physiology effective sensitivity in A/lx & A/μMol*m^{-2}*s^{-2}. Includes K-SR in new detector order.													
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths without or in combination with accessory components.													

CT-3701 & CT-4501: Luminous Color and Illuminance Detectors

CT-3701

CT-4501-4

The CT-3701 and CT-4501 luminous color detectors are designed with precise x,y,z tristimulus matching functions to measure the illuminance, x,y chromaticity values and color temperature of broad band emitting light sources. Four detectors mounted in one compact housing are used to form the x_{short}, x_{long}, y and z spectral tristimulus values for the 2 degree viewer.
Both probes feature two separate x_{short} and x_{long} functions to provide more accurate readings in the blue region over detectors with only the x_{long} function and a simulated x_{short} using the z values.
Sandwich filtering technology allows a very compact housing design with a only 10 mm diameter diffuser window. This ensures a uniform illumination of the dif-



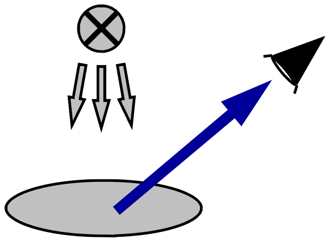
fuser as required for the measurement of illuminance.
A special feature of the CT-3701 detector is temperature control of it's photodiodes and filters for ambient temperature independent operation. This allows the CT-3701 to be integrated into industrial qualification process control applications where long term stability is essential. CT-3701 and CT-4501 can be combined with other components like luminance steradian tubes.

Ordering Information & Specifications

Model	λresp	λresp	λresp	λresp	Typical Sensitivity				Sensing Area	cable	Operation Temp.	Meter Type	plug	package
	Ch1	Ch2	Ch3	Ch4	CH1	CH2	CH3	CH4		m				page
	380-500 nm	500-730 nm	380-780 nm	380-580 nm	nA/lx at 2856 K				Diffuser					
CT-3701	x short	x long	y	z	0.07	0.03	0.08	0.02	10 mm Ø	2	+40°C	P-9801	1	92
CT-4501	x short	x long	y	z	0.07	0.03	0.04	0.01	10 mm Ø	2	5-40°C	X1$_1$	4	90
K-CT3701	Calibration of illuminance sensitivity A/lx, x,y chromaticity values and color temperature. Includes K-SR in new detector order.													
K-CT4501	Calibration of illuminance sensitivity A/lx, x,y chromaticity values and color temperature. Includes K-SR in new detector order.													
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components													

Luminance & Radiance

Radiance L is described as the intensity of optical radiation from an irradiated or irradiating surface in a particular direction measured with a specified solid angle.
The units of radiance are W/(m^2*sr). Light detectors with a defined angle of view are used to measure radiance.



Luminance L is described as the measurable photometric brightness of an illuminated or illuminating surface. In many cases luminance describes the quality of illumination much better than illuminance. The units of luminance are candela per unit area (cd/m^2) or nit and foot-lamberts (fL). Detector heads with a defined angle of view are used to measure luminance so that a small area within a larger uniform field is sampled.

$$cd/m^2 = nit = lm/(m^2 * sr)$$
$$fL = lm/(ft^2 * sr)$$
$$1\ cd/m^2 = 2.919 \times 10^{-1}\ fl$$

LDM-9810 & LDM-9811: Luminance & Radiance Detectors

LDM-9810 and LDM-9811 are modularly designed viewer modules that are combined with PD-16 detectors to form luminance and radiance measurement heads offering flexible spot size diameter selection. Both units are built with stable aluminium housings to ensure precise measurement in laboratory or field use.
The unit's wide aperture focussing objective is achromatically corrected, and satisfies the tightest requirements for the suppression of stray light and image formation.
Both viewer modules offer three selectable fields of view:

- **LDM-9810**:
  20', 1° and 6°
- **LDM-9811**:
  1.7, 11 and 100 mrad

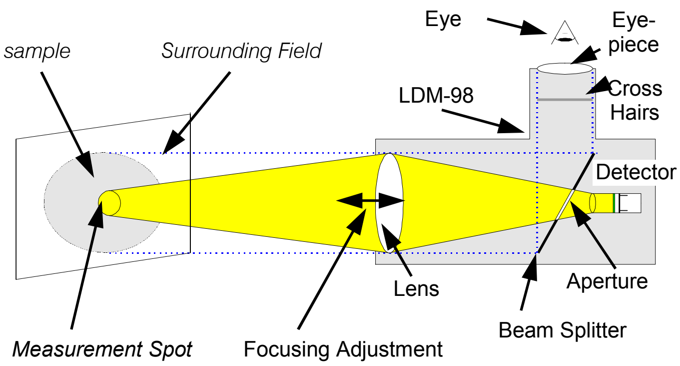
A f.o.v. selector knob is located on the rear of the device. The resultant size measurement spot is visible through the ocular viewfinder. In combination with the cross-hair targeting aid alignment of the LDM-98 to the zone of interest is simple.
Focussing is achieved by adjusting the sharpness of the image on the viewfinder screen.
The useable measurement distance of the LDM-98 spans from 0.3m to ∞. The area of the measured surface depends on the distance to the target and on the angle chosen for the field of view.

Photometric and Radiometric detectors from the PD-16 series combine with the LDM-9810 and LDM-9811 viewing module to set up a luminance or radiance measurement device.

Luminance Measurement:

The **PD-16VL01** photometric detector has been adapted with great care to the ideal V(λ) function, and in combination with the LDM-98 meets the DIN class A specification for the adaptation error of f_1 ' less than or equal to 3%. Typical applications of the luminance detector LDM-98/PD-16VL01 include photometric brightness measurement of:

- Luminous surfaces such as monitor screens, alphanumeric displays, information signs, emergency lighting and illuminated control panels
- Reflecting surfaces such as walls and workplace equipment, projection screens, traffic and information signs, roadways and roller tracks
- Light emission in accordance with Federal Emissions Statutes
- Fluorescent pigments with long afterglow decay
- In lighting design stage of workplace and office design



Radiance Measurement:

The PD-16RW05 radiometric detectors with spectral sensitivity within the wavelength range from 400 to 1000 nm are the right choice for radiance measurement in the visible and near infrared wavelength region.

Light Hazard Protection:

The quantity used for determination of blue light hazard and retinal thermal hazard to the human eye is radiance, measured in the radiometric unit of W/m^2*sr.
Three different spectral response functions are typically used for light hazard protection radiance measurements:

- **Blue-light Hazard**
  (400-520 nm)
- **Retinal Thermal Hazard**
  (520-1400 nm)
- **Retinal Thermal Hazard IR-A**
  (780-1400 nm)

Gigahertz-Optik offers three different PD-16 detectors to be combined with the **LDM-9811** viewer module for this application.

- **PD-16BLH:**
  Blue light hazard detector
- **PD-16RTH:** Retinal thermal hazard detector
- **PD-16RTHA:** Retinal thermal hazard IR-A detector

Optional Accessories:

The LDM-98NL narrow lens provides a variable 1:1 to 2:1 near field magnification for measurement of spot diameters down to 0.1 mm.
The LDM-98FC enables coupling a flexible **fibre bundle** instead of a PD-16 detector to the LDM-98 to allow connection and use with spectral radiometers.
The BHO-01 hard carrying case holds the LDM-98/PD16 with P-

9710 optometer for mobile applications.

Calibration in Light Measurement Units:

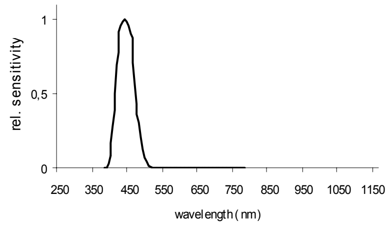
Calibration of the detector is carried out by Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities, traceable to international standards.
Calibration in the units related to the selected PD-16 detector is supplied for each viewing angle with and without optional narrow lens.
For best handling of the multiple calibration factors the P-9710 and P-2000 optometers are recommended for use with the LDM-98/PD16 luminance and radiance detector heads outfitted with (-2) programmable data connectors.

PD-16 Light Detector

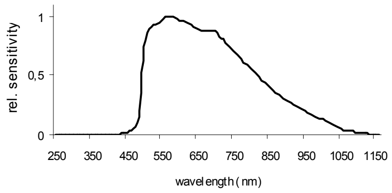
Gigahertz-Optik

Luminance & Radiance

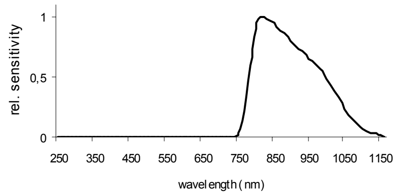
LDM-9810 & LDM-9811: Luminance & Radiance Detectors



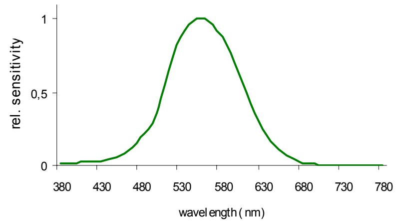
PD-16BLH



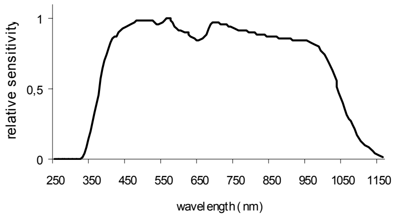
PD-16RTH



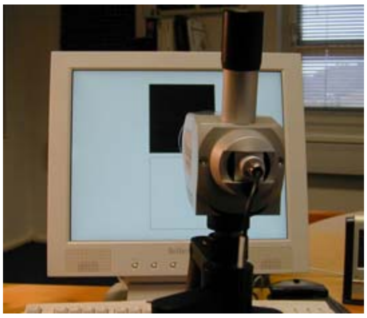
PD-16RTHA



PD-16VL01



PD-16RW05



Measurement Spot Diameters (mm)						
F.O.V. Distance	**LDM-9810**			**LDM-9811**		
	6°	**1°**	**20'**	**100 mrad**	**11 mrad**	**1.7 mrad**
0.3 m	21	3.5	1.2	19.9	2.2	0.4
0.5 m	41.9	7	2.3	39.8	4.4	0.8
1 m	94.3	15.8	5.2	89.6	9.9	1.8
2 m	199	33.2	11	189.2	20.9	3.8
10 m	1037	173	57	986	109	19.8
With LDM-98NL Narrow Lens (Optional)						
100 mm / f=∞	10.5	1.8	0.6	10	1.1	0.2
75 mm / f=0.3m	5.2	0.9	0.3	5	0.6	0.1

Ordering Information & typical Specifications													
Model	λresp	Wavelength Range	f1	Typical Sensitivity			Imax	Sensing Area	cable	Operation Temp.	plug	package
			≤ %	*) nA/cd*m^2 or **) nA/W/m^{2}sr			mA	Lens	m			page
LDM-9810				20'	1°	6°		50 mm Ø		5-40°C		92
PD-16VL01	V(λ)	380-400	3	0.0035 *)	0.033 *)	0.9 *)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
LDM-9811				1.7 mrad	11 mrad	100 mrad		50 mm Ø		5-40°C		92
PD-16BLH	BLH	400-520	-	0.2 **)	5.7 **)	380 **)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
PD-16RTH	RTH	500-1200	-	0.3 **)	11 **)	780 **)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
PD-16RTHA	RTHA	800-1200	-	0.2 **)	5 **)	360 **)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
PD-16RW05	RW05	400-1000	-	0.38 **)	12 **)	840 **)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
PD-16VL01	V(λ)	380-400	3	0.00004 *)	0.00015 *)	1.1 *)	1	5.8 x 5.8	2	5-40°C	1,2,4	92
LDM-98Z-NL	Narrow Lens for use with LDM-9810 and LDM-9811											
LDM-98Z-FC	Fiber Coupler to adapt flexible light guide bundles to the LDM-9810 and LDM-9811											
K-LDM98BLH	Calibration of effective BLH radiance sensitivity with **or** without LDM-98NL in A/W/m^2*sr (at 3 f.o.v. angles). 1)											
K-LDM98RTH	Calibration of effective RTH radiance sensitivity with **or** without LDM-98NL in A/W/m^2*sr (at 3 viewing angles). 1)											
K-LDM98RTHA	Calibration of effective RTHA radiance sensitivity with **or** without LDM-98NL in A/W/m^2*sr (at 3 viewing angles). 1)											
K-LDM98RW05	Calibration of 400-1000 nm radiance sensitivity with **or** without LDM-98NL in A/W/m^2*sr (at 3 viewing angles). 1)											
K-LDM98VL01	Calibration of luminance sensitivity with **or** without LDM-98NL in A/cd/m^2 (at 3 viewing angles). 1)											
K-LDM98NL	Additional calibration of luminance or radiance sensitivity for LDM-98 with LDM-98NL narrow lens											
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components											
1) Includes K-SR with new detector order												

LDM-9901: Luminance Detector

Luminance detectors that are characterized as quality class A or B, in accordance with DIN 5032 Part 7, need to be constructed from carefully selected elements. These include optics with achromatic correction and low stray light, and a photopic detector with a response curve that has been carefully adapted to the ideal V(λ) function. Add an expensive telescopic finder and a focusing optical system for locating the target area and these luminance detector heads become too costly for many applications. The widely used auxiliary lenses that can be attached to illuminance detector heads for luminance measurement are not a good alternative, since they typically do not satisfy the requirements of DIN 5032 Part 7.
An economical alternative which does satisfy the requirements of IEC 61223-2-5 and DIN 5032 Part 7 is the LDM-9901. It is a high quality photometric detector for determining luminance in cd/m². Its properties satisfy the requirements for Quality Class B of DIN 5032 Part 7.

The LDM-9901 detector key components are:

©achromatically corrected low stray light lens to collect light with a 1° field of view

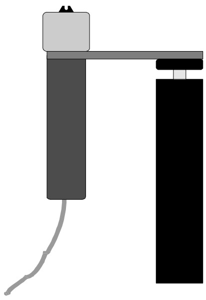
©high-quality photodiode with accurate V(λ) correction filter

©sight for locating the target measuring area

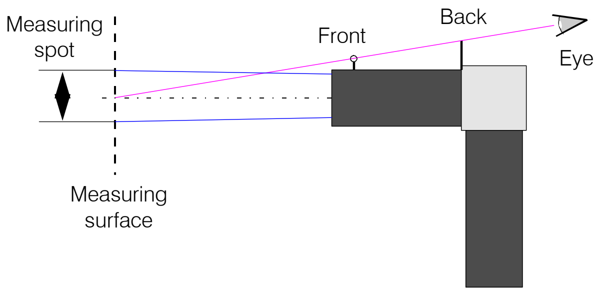
The low-stray-light achromatic corrected objective is designed so that in its useable measurement range of 40 cm to infinity it is not necessary to make focusing adjustments to the lens. The 1° field of view means that the diameter of the measurement spot differs depending on the measuring distance.
The adaptation for photopic vision offers a f_1'of ≤ 5 %. This means that the LDM-9901 detector can be used to measure the output of monitors, LED displays and other sources without suffering from an unacceptable increase in measurement uncertainty due to the quasi-monochromatic type radiation of these sources.

The LDM-9901 detector has an externally mounted targeting These back and front sights are adjusted for measuring distances of 70 cm, 140 cm and ∞ as shown below. In order to locate the object to be measured, the detector head is held in front of the eye at such a distance (about 25 cm) that the back and front sights appear sharp. Depending on the observer's age, other distances may be appropriate. The two sights are then aligned with the desired part of the object being measured.
The sights consists of a black slotted V-notch and a white ball. The following figure shows the different alignments for various measuring distances.
In many applications a luminance detector is used with a tripod. An adapter plate to attach the detector and tripod are offered as options.
The detector is connected to the optometer via a 1 m flexible connecting cable .
Calibration of luminance sensitivity in A/(m²cd^{-1}) is carried out at Gigahertz-Optik's Calibration Laboratory and is confirmed by a factory certificate.

Distance to Spot Comparison	
distance	spot diameter
0.5 m	~ 31 mm
0.7 m	~ 35 mm
1 m	~41 mm
5 m	~ 120 mm
10 m	~ 220 mm
50 m	~ 1000 mm
100 m	~ 2000 mm

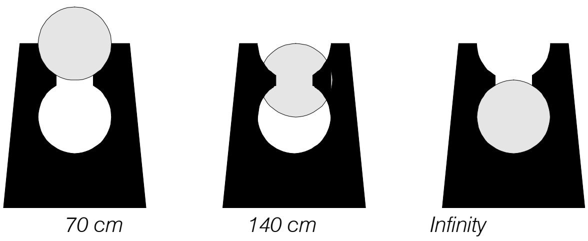


Tripod Adapter (Option)



Notch and Bead Sight

LDM-9901 Comparison to DIN 5032 Class B Limits (%)			
Characteristics	Symbol	LDM-9901	DIN
Calibration Uncertainty	U_{kal}	1.5	4
V(λ) Match Characteristic	f_1	5	6
UV Response Characteristic	u	0.01	2
IR Response Characteristic	r	0.01	2
Linearity Characteristic	f_3	0.2	2
Fatigue Characteristic (at 1 klx)	f_5	0.1	1
Temperature Dependence Characteristic	f_6	1	10



Notch and Bead Sight at difference Distances

Ordering Information & typical Specifications										
Model	λresp	Wavelength Range	f1	Typical Sensitivity	Imax	Sensing Area	cable	Operation Temp.	plug	package
	Photometric		≤ %	pA/cd*m²	mA	Lens	m			page
LDM-9901	V(λ)	380-780 nm	5	25	1	22 mm Ø	2	0-40°C	1, 2, 4	92
LDM-99Z-02	Ambient light shade made by elastic rubber to place the LDM-99 direct on the monitor surface									
K-LDM9901	Calibration of integral luminance sensitivity in A/cd/m². Including K-SR in new detector order.									
KDW-S	Calibration of spectral sensitivity at one or multiples wavelengths									

Luminance & Radiance / Luminous Flux & Radiant Power

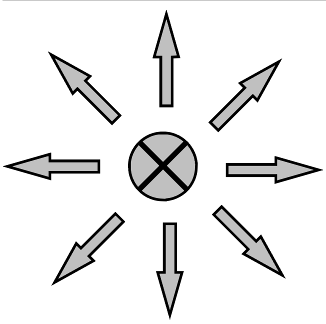
SRT-M37: Front Lenses for 37-Type and 45-Type Illuminance & Irradiance Detectors

In some applications simple front lenses are required to limit the field of view of irradiance and luminance light detectors.
The SRT-M37L series front lenses can be combined with the 37-type and 45-type irradiance, illuminance and luminous color detectors for this purpose.
The detector itself is mounted into the SRT-M45/37 base mount that has a M37x1 front thread where the SRT-M37L front lens can be attached.
The base mount offers a side M6 and camera type (1/4”-20 BSW) threaded hole for standard tripod or bench post or to fixture the device into an application.
Beside the four front lenses offered custom solutions with quartz lenses, other lens diameters are available on special request.
Contact an applications engineer to discuss your requirements.

Ordering Information & typical Specifications

Model	λ_{resp}	Wavelength Range	Typical Sensitivity		Sensing Area Lens	cable m	Operation Temp.	plug	package page
SRT-M37L-1/VL-3701	V(λ)	380-780	1.2	pA/cd*m^2	22.4 mm Ø	2	5-40°C	1, 2 or 4	89
SRT-M37L-2/VL-3701	V(λ)	380-780	2.3	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-5/VL-3701	V(λ)	380-780	12	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-1/CT-4501	V(λ)	380-780	0.05	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-2/CT-4501	V(λ)	380-780	0.4	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-5/CT-4501	V(λ)	380-780	2	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-10/CT-4501	V(λ)	380-780	9	pA/cd*m^2		2	5-40°C	1, 2 or 4	89
SRT-M37L-1/RW-3703	Radiometric	400-800	5	nA/W/m^{2}sr		2	5-40°C	1, 2 or 4	89
SRT-M37L-2/RW-3703	Radiometric	400-800	9	nA/W/m^{2}sr		2	5-40°C	1, 2 or 4	89
SRT-M37L-5/RW-3703	Radiometric	400-800	48	nA/W/m^{2}sr		2	5-40°C	1, 2 or 4	89
Specifications for other Detector/Front Lens Combinations not shown are available on request. Quartz lenses for UV applications are available.									
KDW-P3	Calibration of integral luminance sensitivity of an illuminance detector with front lens in A/cd/m^2								
KDW-R3	Calibration of integral radiance sensitivity of an irradiance detector with front lens in A/W/m^2*sr								
KDW-S3	Calibration of spectral radiance sensitivity of an irradiance detector with front lens in A/W/m^2*sr nm								
SRT-M45/37B	Basic holder to mount 37-type and 45-type detectors to SRT-M37 type components								
SRT-M37L-1	Front lens with 1° field of view. Needs SRT-M45/37B to couple with detector. 1 mm diameter output aperture.								
SRT-M37L-2	Front lens with 2° field of view. Needs SRT-M45/37B to couple with detector. 2 mm diameter output aperture.								
SRT-M37L-5	Front lens with 5° field of view. Needs SRT-M45/37B to couple with detector. 4.8 mm diameter output aperture.								
SRT-M37L-10	Front lens with 10° field of view. Needs SRT-M45/37B to couple with detector. 10 mm diameter output aperture.								
SRT-M37Z01	Ambient light shade made by elastic rubber to be used with the SRT-M37-L lenses or the SRT-M37-5 tube.								

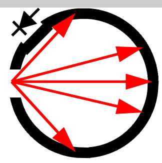
Luminous Flux & Radiant Power



Luminous flux ϕ is the light power of any light source and is measured in lumens (lm). Since light is not typically emitted as a more or less parallel light beam, luminous flux must be measured with a measurement geometry that acquires the luminous flux independent of its spatial distribution. Light collecting integrating spheres or goniophotometers which can sum the angular light output over 360° are often used.
The luminous flux of a 100 W incandescent bulb is about 1380 lm, while that of a 20 W compact fluorescent lamp is about 1200 lm.

Radiant power ϕ is the total power of optical radiation emitted by a source measured in watts (W). The same measurement geometry as in luminous flux measurement applies only the detection system is not photopically corrected.

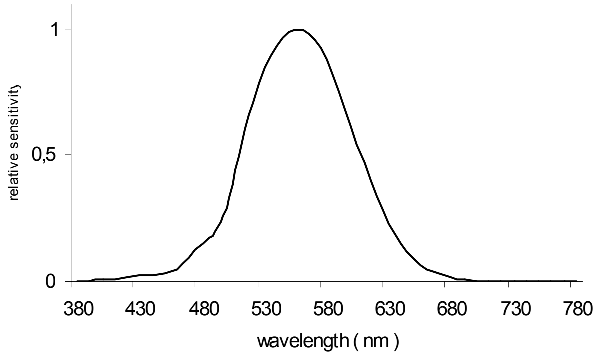
The most common method **to measure luminous flux and radiant power** from all directional emitting divergent beam sources employs an integrating sphere light detection system. Omnidirectional emitting light sources are placed in the center of the sphere, whereas the light from spot lamps enters the sphere through a port in the sphere wall.



Diffuse multiple reflections at the inner sphere wall suppresses disturbance effects created by the angle of incidence, formation of shadows, reflections, modes etc.

In the “Integrating Spheres” chapter several spheres from 8 mm up to 500 mm diameter are described which can be combined with Gigahertz-Optik light detectors and optometers to form complete luminous flux and radiant power light measurement systems.

LSM-9901: Luminous Flux Detector



The LSM-9901 detector is used to measure the luminous flux, in lumens, of directional light beams with varying divergences. The measurement aperture size of its 50 mm diameter integrating sphere is 12.7 mm in diameter, which is sufficient for applications with endoscopes, light emitting diodes, optical fiber bundles and other beam emitters. The photometric light detector is positioned close to the entrance port in accordance with DIN guidelines and allows for an acceptance angle of up to 90°. The detector is shielded from exposure to direct radiation by a baffle

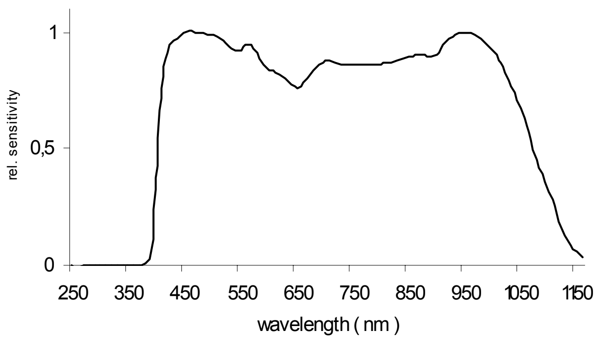
The specifications of the photodiode correspond to DIN quality class B, permitting use with cold light sources, lamps with a high color temperature, or quasi-monochromatic radiation such as that from light emitting diodes.

The 50 mm diameter integrating sphere is coated with $BaSO_4$, guaranteeing diffuse reflectivity and a spectrally neutral reflection characteristic. Optometer connections are made by means of a 2 m coaxial cable with appropriate plug type. Calibration of luminous flux in lumens (lm) is carried out at Gigahertz-Optik's Calibration Laboratory for Optical Radiation Measurement, and is confirmed by a factory certificate.

Ordering Information & typical Specifications

Model	λresp	Wavelength Range	f1	Typical Sensitivity	Imax	Sphere		cable	Operation Temp.	plug	package
	Photometric		≤ %	nA/lm	mA	Port	Diameter	m			page
LSM-9901	V(λ)	380-780 nm	5	40	1	12.5 mm Ø	50 mm	2	5-40°C	1, 2, 4	91
K-LSM9901	Calibration of integral luminous flux sensitivity in A/lm. Includes K-SR in with new detector order.										
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or in combination with accessory components.										

PRW-0505: Polychromatic Radiant Power Detector



Integrating spheres are commonly used in radiant power measurement systems. Functioning as an optical integrator, the integrating sphere is able to measure radiation entering it's port independent of angle.

The PRW-0505 radiometric detector for radiant power measurement in the visible and near infrared (NIR) is fitted with an integrating sphere. The sphere, with an internal diameter of 50 mm, is coated with Barium Sulfate offering a diffuse and spectrally flat reflectance characteristic within a specified wavelength range. BaSO4 offers a high reflectance of ~ 97 % ensuring good sensitivity and also good long term stability.

The detector is positioned close to the sphere's entrance port to allow highly divergent radiation beams of up to 90 degrees to be accurately measured. The input port has a diameter of 12.7 mm.

The radiometric detector is shielded from exposure to direct radiation from the measurement port by a baffle.

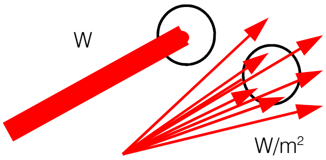
Its radiometric sensitivity covers wavelengths between 400-1000 nm allowing the radiant power of broadband and of quasi-monochromatic lamps (such as light emitting diodes) to be measured irregardless of their emission spectra. Gigahertz-Optik optometers are connected with a 2 m coaxial cable with an appropriate plug type. Calibration of sensitivity to radiant power in W $_{400\text{-}1000\ nm}$ is carried out at Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities, and is supported by a factory certificate.

Ordering Information & typical Specifications

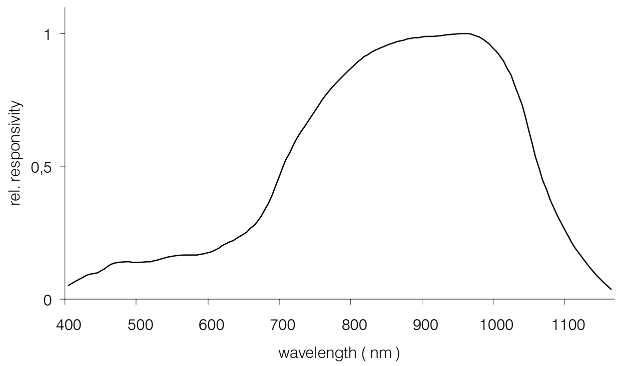
Model	λresp	Wavelength Range	Typical Sensitivity	φmax	Sphere		cable	Operation Temp.	plug	package
	Radiometric		µA/W	mW	Port	Diameter	m			page
PRW-0505	Polychromatic	400-1000 nm	90	500	12.5 mm Ø	50 mm	2	5-40°C	1, 2, 4	91
K-LSM9901	Calibration of integral radiant power sensitivity in A/W. Includes K-SR in new detector order.									
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths without or in combination with accessory components.									

Laser Stray Light / Laser Power

LP-9901: Laser Power and Laser Stray Light Detector



The LP-9901 Detector is designed to measure both laser power in W (the laser beam under fills the detector active area) and laser irradiance in mW/m² (the laser beam overfills the detector active area).
The measurement aperture has a diameter of 7 mm which correlates to the maximum size of the eye's pupil.
The LP-9901 offers a dynamic range from 0.1 μW to 100 mW (at 662.8 nm) for power measurement, and 0.0026 μW/cm² to



260 mW/cm², for the determination of maximum permissible exposure. The low profile detector can be securely held in the laser beam with a rigid 100 mm long detector handle built around the cable and connects to the optometer by a 2 m long cable with appropriate plug type.
Calibration of spectral sensitivity from 400 to 1100 nm is performed in 10 nm increments. Calibration is carried out at Gigahertz-Optik's Calibration Lab and is confirmed by a works certificate.

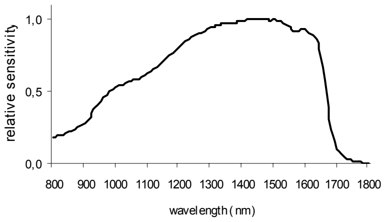
Ordering Information & typical Specifications											
Model	λresp	Wavelength Range	Typical Sensitivity		φmax		cable	Imax.	Operation Temp.	plug	package
	Photodiode		633 nm	900 nm	633 nm	900 nm	m	mA			page
LP-9901	Si & ND Filter	400-1100 nm	1.3 mA/W	20 mA/W	100 mW	50 mW	2	1	0-40°C	1,2,4	91
K-LP9901	Calibration of spectral radiant power sensitivity in A/W nm and calculated spectral irradiance sensitivity A/W/m²										
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths in combination with accessory components										

LP-01 & LP-02: Radiant Power Detectors with OP.DI.MA. Integrating Sphere

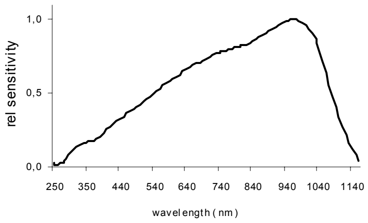
LP-0101 & LP-0103 with FC adapter

LP-0201

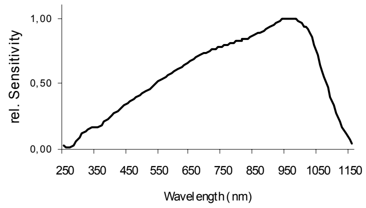
LP-01 detectors are designed for laser power and general optical power measurements in telecommunication testing systems. **Using an integrating sphere** as a light collector enables small size, high shunt resistance photodiodes providing high sensitivity and fast rise time to be used. As a result of multiple diffuse reflectance, integrating spheres can reduce polarization effects, beam misalignment risk, signal bounce-back and PTD saturation. The machined OP.DI.MA. (optically diffuse material) spheres offer the highest reflectance (low attenuation) and longest term stability currently available. The **LP-0101, LP-0102 and LP-0103** are built around a 30 mm diameter sphere with a 5 mm measurement aperture. A unique Gigahertz-Optik baffle design offers a large light acceptance angle with no risk of direct detector irradiation.
The **LP-0201** employs an 8 mm diameter ODM integrating sphere with a 2 mm measurement port diameter for lowest attenuation. A low profile fast Si photodiode is used enabling a very short rise time.
Common features include:
Diode array spectrometer can be coupled to an additional detector port with SMA-type fiber connector.
Open port configuration is standard for direct measurement of laser diodes, LEDs or lasers.
Fiber connector adapters for FC, SC, ST and SMA connectors are available for the 30 mm sphere measurement port.
Calibration of spectral radiant power sensitivity in A/W nm is offered within the sensitivity range of each detector.



Typical spectral sensitivity LP-0101



Typical spectral sensitivity LP-0103



Typical spectral sensitivity LP-0201

LP-01 Series: Radiant Power Detectors with OP.DI.MA. Integrating Sphere

Ordering Information & typical Specifications

Model	λresp	Wavelength Range	Typical Sensitivity		Sphere		cable	Imax.	φmax	Operation Temp.	plug	package
	Photodiode		633 nm	1300 nm	Port	Diameter	m	mA	mW			page
LP-0101	InGaAs	800-1800 nm	-	0.4 mA/W	5 mm ∅	UPK-30-L	2	1	500	5-40°C	1,2,4	91
LP-0102	Si & InGaAs	350-1800 nm	0.6 A/W	0.4 mA/W	5 mm ∅	UPK-30-L	2	1	500	5-40°C	1,2,4	91
LP-0103	Si	350-1100 nm	0.6 mA/W	-	5 mm ∅	UPK-30-L	2	1	500	5-40°C	1,2,4	91
LP-0201	Si LP	400-1100 nm	30 mA/W	-	2 mm ∅	UPK-8-L	2	1	100	5-40°C	1,2,4	91
LP-01Z-01	Additional detector port for UPK-30-L integrating sphere of LP-01 for PD-11 type detectors or UFC-11/SMA socket											
UFC-11/FC	FC-type fiber socket adapter for the measurement port of LP-01 detectors with UPK-30-L integrating sphere											
UFC-11/SC	SC-type fiber socket adapter for the measurement port of LP-01 detectors with UPK-30-L integrating sphere											
UFC-11/ST	ST-type fiber socket adapter for the measurement port of LP-01 detectors with UPK-30-L integrating sphere											
UFC-11/SMA	SMA-type fiber socket adapter for the measurement port of LP-01 detectors with UPK-30-L integrating sphere											
K-LP01xx	Calibration of spectral radiant power sensitivity in A/W nm. xx = detector model number											
K-LP0201	Calibration of spectral radiant power sensitivity in A/W nm											
KDW-S1	Calibration of spectral radiant power sensitivity at one or a chain of wavelength in combination with accessory											

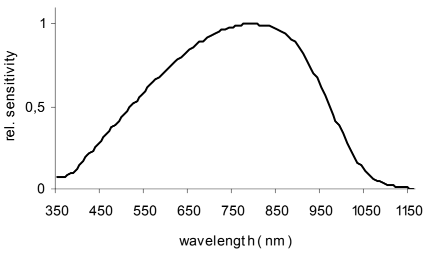
LP-99 Series: Radiant Power Detectors with Barium Sulfate Integrating Sphere

The LP-99 detectors are designed for general radiant power measurements of laser diodes and lasers in the wavelength range from 400 to 1700 nm.
The use of a 50 mm diameter integrating sphere as light collector offers a large 12.7 diameter measurement port and negates the need for using large diameter photodiodes. Small size photodiodes offer lower cost, higher shunt resistance and low capacitance. Also through its multiple reflectance characteristic, integrating spheres can reduce polarization effects, the risk of beam misalignment, signal bounce-back and PTD saturation. Barium sulfate is a cost effective white diffuse coating for larger diameter integrating spheres. It's 97 % reflectance in the visible spectral range exhibits low attenuation making high sensitivity sphere based detectors possible. The LP-99 detectors are built around a 50 mm diameter sphere with a 12.5 mm aperture. A unique Gigahertz-Optik baffle design offers a large light acceptance angle without direct detector irradiation.

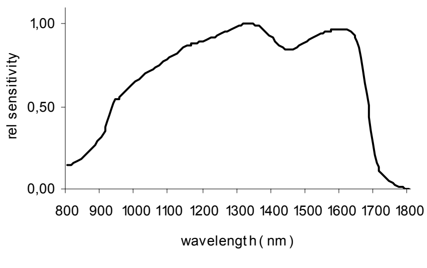
LP-9930 with 2-Channel Optometer P-2000

LP-9910

The LP-9910 is supplied with a Si photodiode covering the 400 to 1100 nm wavelength range.
The LP-9920 is supplied with an InGaAs photodiode for the 800 to 1800 nm range.
The LP-9930 offers both a Si and InGaAs photodiode for broadband use from 400 to 1800 nm with a 2-channel optometer.
The open port configuration is standard for direct measurement of laser diodes, LEDs or lasers.
Calibration of spectral radiant power sensitivity in A/W nm is provided.



LP-9910



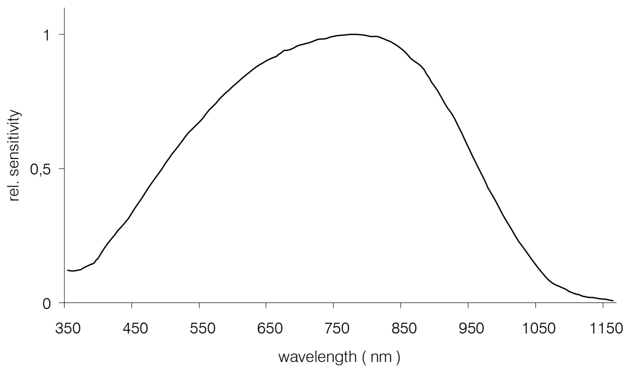
LP-9920

Ordering Information & typical Specifications

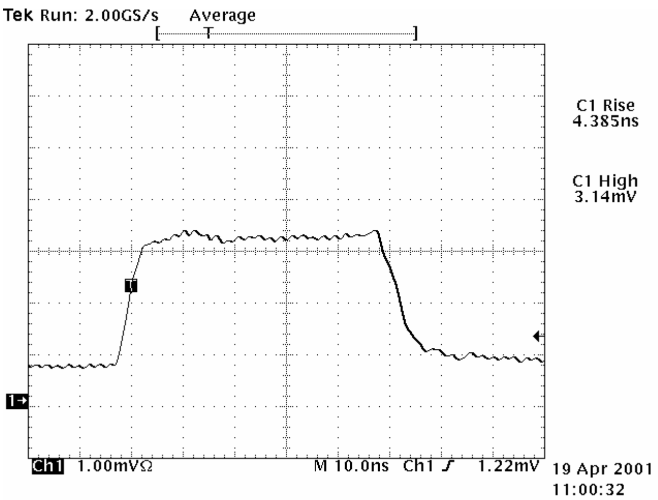
Model	λresp	Wavelength Range	Typical Sensitivity		Sphere		cable	Imax.	φmax	Operation Temp.	plug	package
	Photodiode		633 nm	1300 nm	Port	Diameter	m	mA	mW			page
LP-9910	Si	400-1100 nm	2.5 mA/W	-	12.5 mm ∅	UPB-50-L	2	1	500	5-40°C	1,2,4	91
LP-9920	InGaAs	800-1800 nm	-	0.3 mA/W	12.5 mm ∅	UPB-50-L	2	1	500	5-40°C	1,2,4	91
LP-9930	Si & InGaAs	400-1800 nm	2.5 mA/W	0.3 mA/W	12.5 mm ∅	UPB-50-L	2	1	500	5-40°C	1,2,4	91
LP-99Z-01	Additional detector port for UPB-50-L integrating sphere of LP-99 for PD-11 type detectors or UFC-11/SMA socket											
K-LP99xx	Calibration of spectral radiant power sensitivity in A/W nm. xx = detector model number											
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths in combination with accessory components											

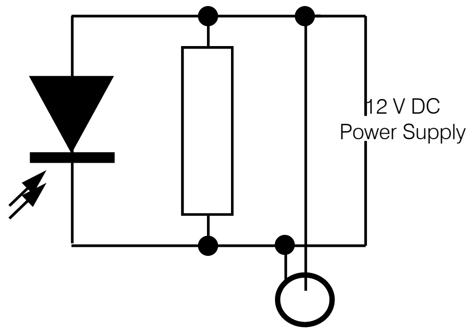
Laser Power & Laser Pulse Shape

LPPA-99: Laser Power and Pulse Shape Detector



Optoelectronic sensing systems such as laser range finders, profile scanners, distance sensors for example, make use of pulsed lasers generating high peak power and pulse lengths in the order of nanoseconds.
For general analysis or for reasons of safety the pulse shape of a single pulse or pulse train needs to be measured, a high speed detector with a rise time shorter than that of the laser pulse is required.
These photodiodes must be very low capacitance as well as offer a deep depletion zone to avoid photon absorption outside the depletion zone.
Photodiodes with small active areas cannot be used to measure radiant power at a risk that the laser beam would be larger than the photodiodes area creating measurement error.
Conventional PIN photodiodes require a large bias voltage for full depletion for long wavelengths above 800 nm.
The LPPA-99 series detectors are designed around a 50 mm diameter integrating sphere. The large 12.7 mm diameter measurement port allows the measurement of large diameter laser beams and laser diodes with divergent beams. A low-profile type Si photodiode provides a fast rise time even at 1060 nm. A baffle protects the photodiode from direct radiation exposure from the entrance port.
These unique features make the LPPA-99 detectors the right choice for pulse analysis of short and high peak power laser pulses in the absolute units of watts (W).
The Low Profile photodiode is operated with 12 V reverse bias, and is placed in series with a load resistor to create a voltage signal that correlates to the radiant power. The detector connects to a fast sensitive oscilloscopes to display the pulse shape.
Digital storage oscilloscopes enable the user to store individual pulse shapes.
Three LPPA-99 models are available with different sensitivities and rise times.
The spectral sensitivity of the detectors in V/W nm is calibrated in 10 nm increments from 400 to 1060 nm.
Calibration is carried out at Gigahertz-Optik's Calibration Laboratory for Optical Radiation Quantities, and is confirmed by a factory certificate.





Output: SMC Socket for 50 Ohm Coaxial Cable

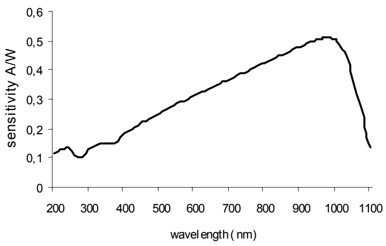
Ordering Information & typical Specifications

Model	λresp	Wavelength Range nm	Typical Sensitivity		ϕmin	ϕmax	Rise Time ns	Sphere Dimension		cable	Load	plug	package
	Photodiode		633 nm	900 nm	@800 nm			Port	Diameter	m	Ohm		page
LPPA-9901	Si LP	400-1060	50 mV/W	50 mV/W	5 mW	100 W 1)	≤ 8	12.5 mm ∅	50 mm	2	50	BNC	91
LPPA-9902	Si LP	400-1060	15 mV/W	15 mV/W	15 mW	333 W 1)	≤ 5	12.5 mm ∅	50 mm	2	50	BNC	91
LPPA-9903	Si LP	400-1060	1 mV/W	1 mV/W	200 mW	5 kW 1)	≤ 2	12.5 mm ∅	50 mm	2	50	BNC	91
K-LPPA99	Calibration of spectral radiant power sensitivity in V/W nm.												

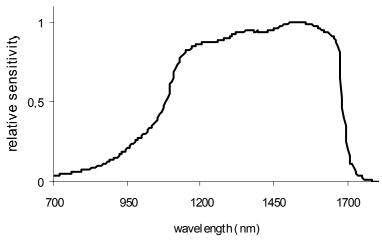
1) Pulse peak power only! Average power should not exceed 500 mW

Modular Light Detectors

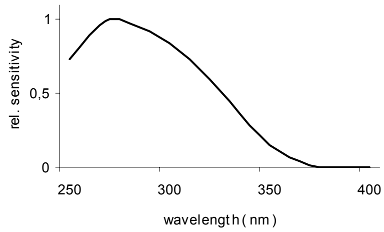
Modular light detectors offer a mechanical interface which allows accessory components such as optical filters, integrating spheres, diffuser windows and other front-end optics to be easily attached and interchanged.
A wide range of base detectors are stocked of different photodiode type and active area. This permits selection of the best fit photodiode spectral sensitivity, light responsivity, rise and fall time for the specific job.
The following spectral plots show the typical spectral sensitivities of the photodiodes available in the PD-11, TD-11 and MD-37 series modular detectors.
Note that spectral sensitivity will change when the detector is combined with an input optic component including integrating spheres. For this reason the actual measured spectral sensitivity of any detector accessory combination is provided in the detector calibration certificate. Calibrations are optional and ordered separately .



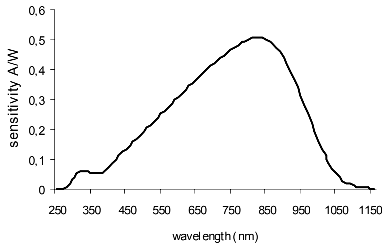
Si Photodiode



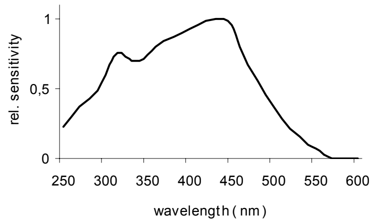
InGaAs Photodiode



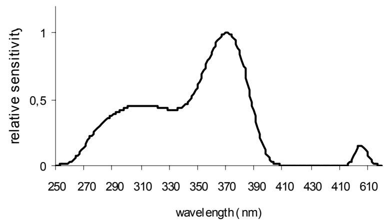
SiC Photodiode



Low Profile Si Photodiode



GaP Photodiode



GaAsP Photodiode

PD-11: Compact Size Modular Detectors

The **PD-11** series modular detectors are primarily designed to be used in combination with Gigahertz-Optik integrating spheres. A typical application example for sphere based detectors is the measurement of radiant power of lasers, laser diodes and other monochromatic light sources.
The PD-11 detectors offer a compact package with flange mount to allow direct mounting to all spheres with 11-type port adapters. Arrangement of discrete linear arrays with a grid size of 11 mm are also possible.
Calibrations are offered with or without accessory.

Ordering Information & typical Specifications													
Model	Photodiode					Typ. Sensitivity A/W			Imax.	Operating Temp °C	plug	cable	package
	λresp	Resp.	λrange nm	mm²	Size mm	@ 350 nm	@ 900 nm	@ 1350 nm	mA			m	page
PD-1101	Si	Page	200-1100	13	3.6 x 3.6	0.15	0,5	-	1	5 to 40	1,2,4	2	90
PD-1102	InGaAs	85	800-1800	0.07	0.3 ∅	-	0.14	0.9	1	5 to 40	1,2,4	2	90
PD-1103	InGaAs	85	800-1800	0.79	1 ∅	-	0.14	0.9	1	5 to 40	1,2,4	2	90
PD-1104	InGaAs	85	800-1800	7.1	3 ∅	-	0.14	0.9	1	5 to 40	1,2,4	2	90
PD-1105	SiC	85	200-400	1	1.1 x 1.1	0.02	-	-	0.05	5 to 40	1,2,4	2	90
PD-1106	Si LP	85	400-1050	0.25	0.5 x 0.5	0.06	0.4	-	1	5 to 40	1,2,4	2	90
PD-1107	Si LP	85	400-1050	3.6	1.9 x 1.9	0.06	0.4	-	1	5 to 40	1,2,4	2	90
PD-1108	Si LP	85	400-1050	11.9	3.4 x 3.4	0.06	0.4	-	1	5 to 40	1,2,4	2	90
PD-1109	GaP	85	250-550	1.0	1.1 x 1.1	0.07	-	-	0.1	5 to 40	1,2,4	2	90
PD-1110	GaAsP	85	200-760	5.2	2.3 x 2.3	0.04	-	-	0.1	5 to 40	1,2,4	2	90
K-PD11xx	Calibration of relative spectral sensitivity. xx = detector model number												
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths in combination with an integrating sphere												
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths in combination with a diffuser												
KDW-S3	Calibration of spectral radiance sensitivity at one or multiple wavelengths in combination with radiance front tube/lens												
KDW-S4	Calibration of spectral radiant intensity sensitivity at one or multiple wavelengths												

Modular

TD-1101, TD-1102 and TD-1103: Temperature Controlled Modular Detectors

The **TD-11 family of** detectors are designed with a unique temperature control feature. The photodiode is precisely heated and maintained at a higher operation temperature than the ambient temperature.
This function ensures measurement accuracy when these detectors are to be used in applications with widely varying ambient temperatures as in laser power measurements involving sphere based detectors for example.
The control electronics are housed in an external box with a plug in power supply.
Both silicon and indium gallium arsenide photodiodes are offered for the wavelength range 200 to 1100 nm and 800 to 1800 nm respectively.
TD-11 detectors can be direct mounted to all spheres with 11-type port adapters.
Calibrations are offered for the detector with or without any accessory components.

Ordering Information & Specifications

Model	Photodiode					Typ. Sensitivity A/W			Imax.	Operating Temp °C	plug	cable	package
	λ_{resp}	page	λ_{range} nm	mm^2	Size mm	@ 350 nm	@ 900 nm	@ 1350 nm	mA			m	page
TD-1101	Si	27	200-1100	13	3.6 x 3.6	0.15	0.5	-	1	55	1,2,4	2	90
TD-1102	InGaAs	27	800-1800	0.07	0.3 ∅	-	0.14	0.9	1	55	1,2,4	2	90
TD-1103	InGaAs	27	800-1800	0.79	1 ∅	-	0.14	0.9	1	55	1,2,4	2	90
K-TD11xx	Calibration of relative spectral sensitivity. xx = detector model number												
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths in combination with an integrating sphere												
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths with a diffuser												
KDW-S3	Calibration of spectral radiance sensitivity at one or multiple wavelengths in combination with radiance front tube/lens												
KDW-S4	Calibration of spectral radiant intensity sensitivity at one or multiple wavelengths wavelengths												

MD-37: Modular Detector

The modular light detectors of the MD-37 series feature a M30x1 threaded front interface for fast and simple screw-on assembly of mating accessory components.
For multi-purpose use modular detectors offer a wide range of base photodiode detector types and different active areas. This provides a great degree of freedom in selecting a spectral sensitivity, light responsivity, rise and fall time for a specific job.
M30x1 is the standard thread size for all 37-type accessories which mate to the MD-37 detectors.
Some typical detector set-ups for the MD-37 series include:

- Broadband irradiance detectors (MD-37 with MD-37Z-DR11 diffuser front cap)
- Narrow band irradiance detectors (MD-37 with narrow band pass filter assembled in MD-37Z-H7 plus diffuser front cap MD-37Z-FR11)

Calibrations are offered with or without accessory components attached.

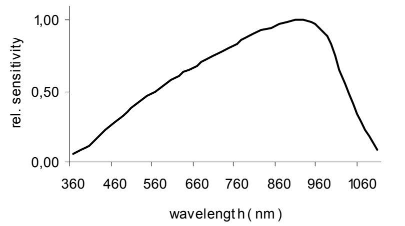
Ordering Information & Specifications

Model	Photodiode					Typ. Sensitivity A/W			Imax.	Operating Temp °C	plug	cable	package
	λ_{resp}	Resp.	λ_{range} nm	mm^2	Size mm	@ 350 nm	@ 900 nm	@ 1350 nm	mA			m	page
MD-37-GP6	GaP	27	250-550	6.25	2.5 x 2.5	0.07	-	-	0.1	5 to 40	1, 2, 4	2	90
MD-37-GAP5	GaAsP	27	200-760	5.29	2.3 x 2.3	0.04	-	-	0.1	5 to 40	1, 2, 4	2	90
MD-37-IGA1	InGaAs	27	800-1800	0.79	1 ∅	-	0.14	0.9	1	5 to 40	1, 2, 4	2	90
MD-37-IGA3	InGaAs	27	800-1800	7.1	3 ∅	-	0.14	0.9	1	5 to 40	1, 2, 4	2	90
MD-37-SC1	SiC	27	800-1800	1	1 sq	0.02	-	-	0.05	5 to 40	1, 2, 4	2	90
MD-37-SU13	Si	27	200-1100	12.96	3.6 x 3.6	0.15	0.5	-	1	5 to 40	1, 2, 4	2	90
MD-37-SU33	Si	27	200-1100	33,64	5.8 x 5.8	0.15	0.5	-	1	5 to 40	1, 2, 4	2	90
MD-37-SU100	Si	27	200-1100	100	10 x 10	0.15	0.5	-	1	5 to 40	1, 2, 4	2	90
MD-37Z-C11	Front cap with 11 mm diameter aperture												
MD-37Z-DR11	Front cap with 11 mm diameter RADIN diffuser												
MD-37Z-H7	Front adapter and/or filter holder for 0.5 to 1 inch diameter filters												
MD-37Z-H7xx	Front adapter with custom specified band-pass or edge filter. xx = filter type												
K-PD37xx	Calibration of relative spectral sensitivity. xx = detector model number												
KDW-S1	Calibration of spectral radiant power sensitivity at one or multiple wavelengths in combination with an integrating sphere												
KDW-S2	Calibration of spectral irradiance sensitivity at one or multiple wavelengths in combination with a diffuser												
KDW-S3	Calibration of spectral radiance sensitivity at one or multiple wavelengths in combination with radiance front tube/lens												
KDW-S4	Calibration of spectral radiant intensity sensitivity at one or multiple wavelengths												

PD-93: 1 cm² Circular Area Modular Light Detectors

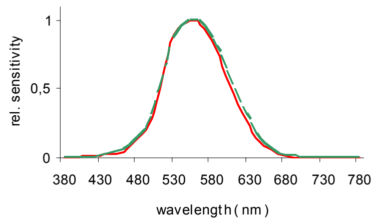
Modular light detectors using photodiodes with a one square centimetre circular active area have been offered by Gigahertz-Optik since 1986. The symmetry of a circular detection area combined with a large 11.28 mm diameter has made these detectors a standard for many applications.
The area around the light sensitive 1 cm² area is metal shielded and thus insensitive to light so that irradiance (W/cm²) can easily be calculated from a known radiant power (W) assuming the active area is to be evenly overfilled.
The photodiodes mounted into a housing that can be fastened into optical test arrangements using the threaded M6 and 1/4-20 side holes. The front of the housing is internally threaded into which accessories can be attached (common 1.3/16-24-UNS thread size). In addition to two different photodiodes, Gigahertz-Optik offers accessories to form a wide variety of detector configurations The simple design of the mechanical parts also means that special custom fabrications can be prepared easily and economically for solutions to particular applications. Our sales engineers are ready to work with you and provide advice on standard and custom configurations.

PD-9304: 1 cm² Si-Photodiode



The **PD-9304** is a large, 1 cm² photodiode for general light measurement purposes and for use in combination with PD-93VL and PD-93RW photometric and radiometric correction filters for illuminance and integral irradiance measurements.

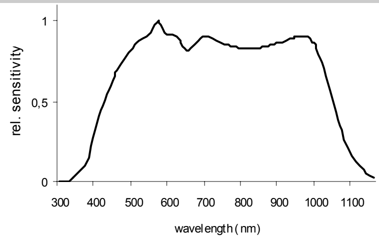
PD-93VL: Photometric Filter



Typical spectral sensitivity with PD-9304

The **PD-93VL** V(λ) correction filter screws directly onto the PD-9304 detector. It's built into the PD-9302 filter holder which is internally and externally threaded (1.3/16-24-UNS) for mating to PD detectors and to accept accessories.

PD-93RW: Radiometric Filter



Typical spectral sensitivity with PD-9304

The **PD-93RW** filter built into the PD-9302 filter holder, gives the PD-9304 a radiometric flat spectral sensitivity within the wavelength range from 400 and 1000 nm.

PD-93COS: Diffuser

The **PD-93COS** diffuser cap generates a field of view approximating a cosine-corrected function, enabling the measurement of illuminance or irradiance. The diffuser screws onto the PD-9302 or PD-9304.

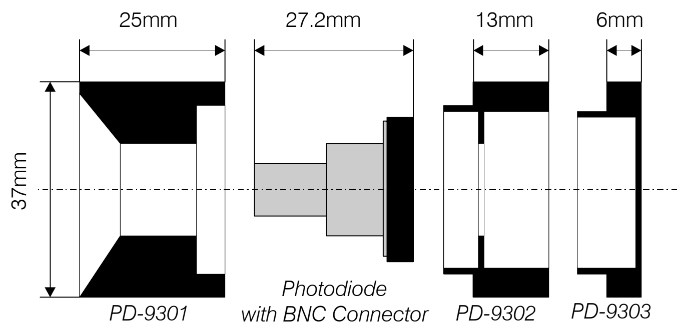
PD-9302: Universal

The **PD-9302** universal holder is 1.3/16-24-UNS internally and externally threaded suitable for attachment to the **PD-9301** detector housing. One inch diameter filters like neutral density, band pass and correction filters can be mounted into it.

PD-9303: Front Cap

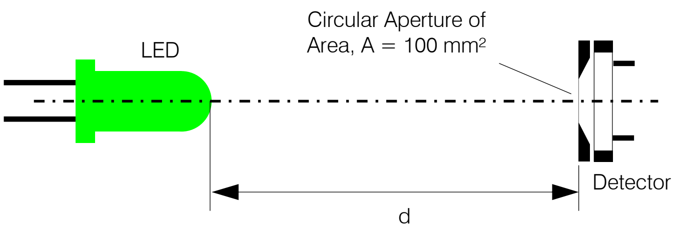
The PD-9303 cap can be used as an end piece on the PD-9301 detector housing, or the PD-9302 universal holder.

PD-9302: Modular Schematic



PD-9311 & PD-9312: Averaged LED Intensity Front Tubes

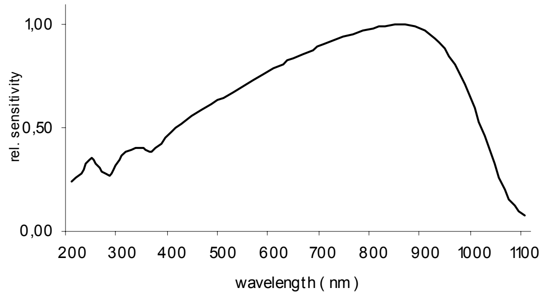
One of the parameters most commonly used to specify LEDs is the directional output intensity. This radiometric or photometric intensity is derived from the flux incident on a detector by the LED at specified distance.
A detector with a circular entrance aperture having 100 mm² (11.3 mm diameter) is specified for the CIE standard A and B measurement conditions for average LED intensity. The distance between the front tip of the LED and the plane of the entrance aperture of the detector is stated at d = 316 mm for CIE standard condition A and d = 100 mm for standard condition B. This corresponds to solid angles of view of 0.001 sr for Condition A and 0.01 sr for Condition B. The PD-9311 and PD-9312 front tubes attach to the PD-9304 detector with either PD-93VL photometric or PD-93RW radiometric filter for CIE Condition A and B conformal measurements. Calibration of the average LED Intensity sensitivity in cd and W/sr is offered by Gigahertz-Optics calibration laboratory.



Modular, Weather Proof

PD-9306: 1 cm² Circular Area Light Detector

The **PD-9306 is a** large area 1 cm² UV-enhanced silicon photodiode for spectral radiant power and/or spectral irradiance measurements. It's large diameter active area offers higher signals for applications with low intensity monochromatic radiation.
The detector is supplied in the PD-9301 housing with internal 1.3/16-24-UNS front thread to accept other accessory components. A 2 m long coaxial cable with BNC plugs can be coupled to the BNC connector at the end of the photodiode.
Calibration of spectral radiant power sensitivity is supplied by the Gigahertz-Optik's calibration laboratory as required.



Ordering Information & Specifications										
Model	λresp	Wavelength Range	Typical Sensitivity		Sensing Area	Imax	cable	Operating Temp °C	plug	package
					Photodiode	mA	m			page
PD-9304	Si Photodiode	380-1100 nm	0.4	A/W @ 633 nm	1 cm²	1	2	5 to 40	1,2,4	91
PD-93VL&PD-9304	V(λ)	380-780 nm	28	nA/lx	1 cm²	1	2	5 to 40	1,2,4	91
PD-93COS&PD-93VL&PD9304	V(λ)	380-780 nm	2.8	nA/lx	1 cm²	1	2	5 to 40	1,2,4	91
PD-9311&PD93-VL&PD-9304	V(λ)	380-780 nm	2.6	µA/cd	1 cm²	1	2	5 to 40	1,2,4	91
PD-93RW&PD-9304	Radiometric	400-1100 nm	0.2	A/W @ 800 nm	1 cm²	1	2	5 to 40	1,2,4	91
PD-93COS&PD-93RW&PD-9304	Radiometric	400-1100 nm	16	mA/W/cm²	1 cm²	1	2	5 to 40	1,2,4	91
PD-9311&PD-93RW&PD-9304	Radiometric	400-1100 nm	1.8	mA/W/sr	1 cm²	1	2	5 to 40	1,2,4	91
PD-9306	UV Si	250-1100 nm	0.16	A/W @ 350 nm	1 cm²	0.2	2	5 to 40	1,2,4	91
K-PD9304	Calibration of spectral radiant power sensitivity in A/W/nm from 350 to 1100 nm in 10 nm steps									
K-PD9306	Calibration of spectral radiant power sensitivity in A/W/nm from 250 to 1100 nm in 10 nm steps									
KDW-P2	Calibration of illuminance sensitivity in lx of PD-9304/PD-93VL with or without PD-93COS									
KDW-P4	Calibration of average LED Intensity sensitivity in cd of PD-9304&PD-93VL&PD-9311 or PD-9312									
KDW-R2	Calibration of irradiance sensitivity in W/m² of PD-9304/PD-93RW with or without PD-93COS									
KDW-R4	Calibration of average LED Intensity sensitivity in W/sr of PD-9304&PD-93RW&PD-9311 or PD-9312									
KDW-S	Calibration of spectral sensitivity at one or multiple wavelengths without or with accessory components									

WPD: Weather Proof Detector

The **WPD** series weather proof detectors are designed for year round outdoor light measurements. To withstand all environmental conditions the light sensor is shielded in a rugged metal housing. The detector aperture is enclosed and sealed under a precision made quartz dome. Photodiode, filter and diffuser are temperature stabilized to +25 deg C by a peltier cooler. Temperature is stabilized to +/- 1 deg C for operation independent of the ambient conditions. The specified operating temperature range is –20 to + 50 deg. C. The electronics of the **PTC-0101** peltier temperature controller are supplied in a separate compact housing for bench-top or rack-mount use with cable connections.
In principle the sensor elements of all Gigahertz-Optik light detectors can be integrated into the WPD housing. The most common applications to date are in the ultraviolet spectral range. For example WPD detectors can serve as reference detectors for high resolution spectral radiometers monitoring global solar UV radiation.

The WPD water proof light detectors are normally connected with a Gigahertz-Optik signal amplifier or optometer for direct measurement of current or irradiance as well as data logging.

Due of the custom nature of this detector and supporting electronics interested customers should contact the factory to discuss his specific requirements .

SRT-M37: Front Tubes and Front Lenses

SRT-M45/37B: Base holder for coupling 45-type and 37-type standard light detector and 37-type solid angle tubes and SRT-37L front lenses.
M30x1 front thread. M6 and camera tripod (1/2"-20BSW) side mounting holes.

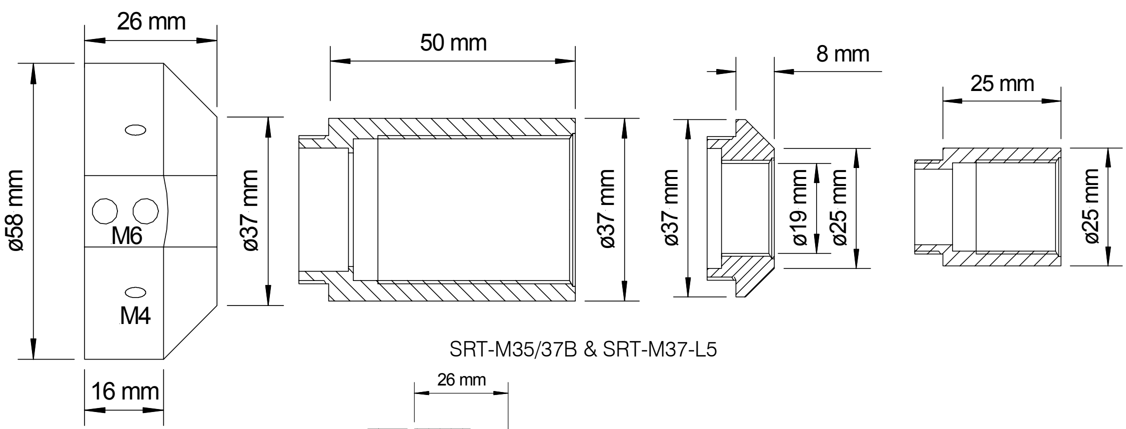
Front Tubes:

SRT-M37-50: 37 mm outside diameter tube, 50 mm length internally threaded over its complete length and externally threaded front end (both M30 x 1). Can be machined to any length down to 12.5 mm.
SRT-37-AB Apertures can be glued into the tube at either end.
SRT-37/25: Reducer to couple SRT-M37-50 to SRT-M25-25 to decrease the outside diameter of solid angle tubes.
SRT-25-25: 25 mm outside diameter tube, 25 mm length internally threaded over its complete length and externally threaded front end (both M20 x1). Can be machined to any length down to 12.5 mm.
SRT-37-AB: Aperture plate insert for SRT-M37 tubes. 2 mm diameter centering hole for drilling the aperture opening to the desired diameter.

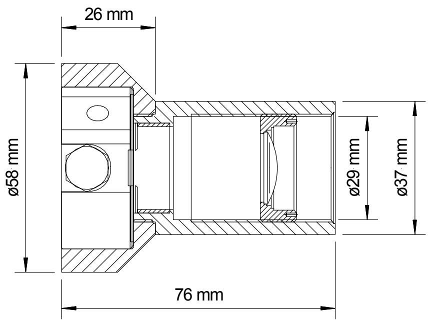
Front Lenses:
The SRT-M37L Front Lenses are used with the 37-type (eg. VL-3701, RW-3701) or 45-type (eg. HCT-99) Gigahertz-Optik detectors to form economical luminance and radiance measurement set-ups. The detector plus front lens can be used for relative measurement or can be calibrated for direct readout in cd/m² or W/m²/sr with a Gigahertz-Optik optometer.
The SRT-M37L set-up consists of the SRT-M45/37B base holder which mounts onto the detector by means of its M30x1 threaded front and one of the SRT-M37L lenses mounted into it. Lenses are available with different field-of-views. The 25 mm diameter BK7 lens provides a „flat“ wavelength range from 380 nm to 1500 nm. Quartz lenses are available on request

Dimensions

SRT-M45/37B SRT-M37-50 SRT-M37/M20 SRT-M20-25



SRT-M35/37B & SRT-M37-L5



Ordering Information & Specifications			
Model	**Description**	**Min. Required Detector Aperture**	**Specifications with Detectors on Page**
SRT-M45/37B	Base holder to couple 45 and 37 type light detectors to SRT-M37 accessory	-	-
SRT-M37-50	37 mm diameter front tube, 50 mm length and M30x1 thread	-	-
SRT-M37/M20	Adapter to mount 37 and 25 tubes together	-	-
SRT-M20-25	25 mm diameter front tube, 25 mm length and M20x1 thread	-	-
SRT-M37-AP	Aperture plate to glue into SRT-M37-50 front tube. 2 mm center hole	-	-
SRT-M37L-1	Luminance & radiance front lens for SRT-M45/37B with 1° field-of-view	0.7 mm ∅	80
SRT-M37L-2	Luminance & radiance front lens for SRT-M45/37B with 2° field-of-view	1.4 mm ∅	80
SRT-M37L-5	Luminance & radiance front lens for SRT-M45/37B with 4.8° field-of-view	3.4 mm ∅	80
SRT-M37L10	Luminance & radiance front lens for SRT-M45/37B with 10° field-of-view	7 mm ∅	80

Gigahertz-Optik

Light Detector Accessories / Dimensions

/WQ: Waterproof Detector Option

The /WQ Waterproof Option effectively seals any type-37 series detector housing. This modification enables full submersion of the detector in water and other liquids. UV/Vis/NIR underwater detectors can be custom tailored for many fields of study including:

- © Oceanography
- © Limnology
- © Aquaculture
- © Solar Bioeffects Research

Custom detector cable lengths and other user specific requirements are available through Gigahertz-Optik's custom design services.

A transparent dome, made from glass or UV transmitting quartz covers the cosine diffuser. The detector housing is sealed and filled with a drying agent (desiccant). This option cannot be retrofit as an after sales modification!

Please contact our application engineering department to discuss your underwater light measurement project.

Ordering Information & Specifications	
Model	**Description**
/WG	Waterproof modification of 37 type detectors. Glass dome cap for VISIBLE to NIR , and internal modifications. Ordering P/N example: PS-3703-2/WG.
/WQ	Waterproof modification of 37 type detectors. Quartz dome cap for UV to NIR, and internal modifications. Ordering P/N example: PS-3702-2/WQ.

/LC: Cable Extension

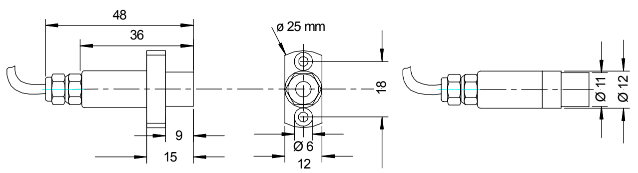
For long distance applications requiring the standard 2 m cable between optometer and light detector be extended. This option is offered for single channel detectors with BNC type (-1) and calibration type (-2) detectors only. For a VL-3701 detector requiring a total cable length of 5 m three 3 m /LC should be ordered since 2 m is already included in the detector price.

Ordering Information & Specifications	
Model	**Description**
/LC	Cable extension in 1 m steps for light detectors with BNC type (-1) or calibration data type (-2) connectors

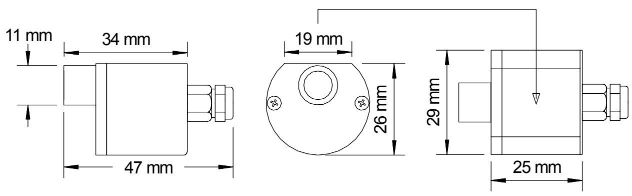
BHO: Carrying Cases

Carrying cases are offered for storage and transporting light detectors and optometers. Please see Optometer chapter for information on available models.

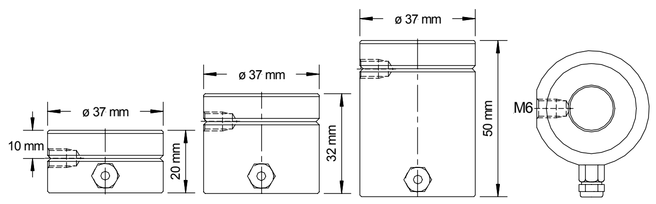
11 Type Housing Dimensions



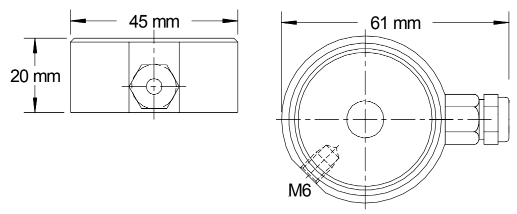
TD-11 Type Housing Dimensions



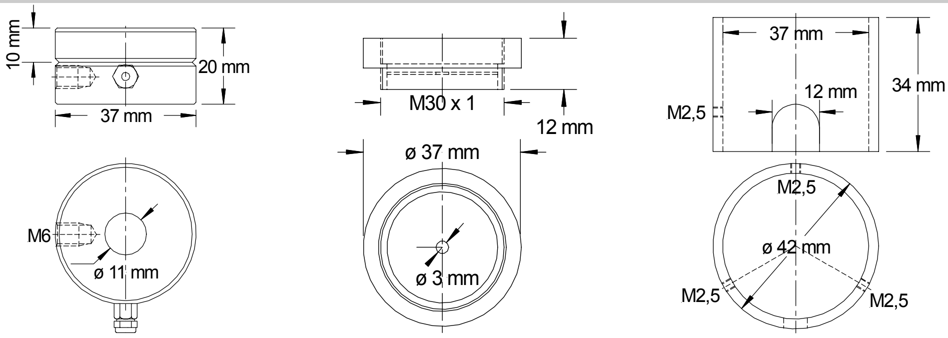
37 Type Housing Dimensions



45 Type Housing Dimensions

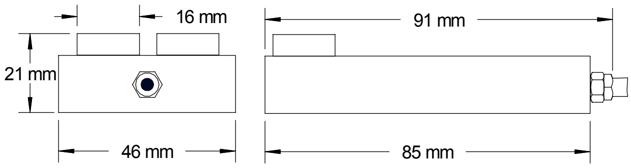


MD-37 Type Housing Dimensions

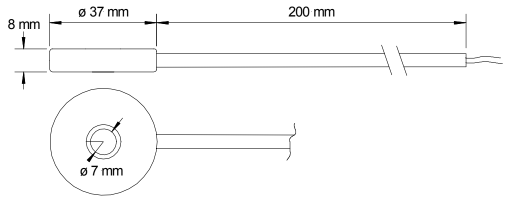


Light Detector Dimensions

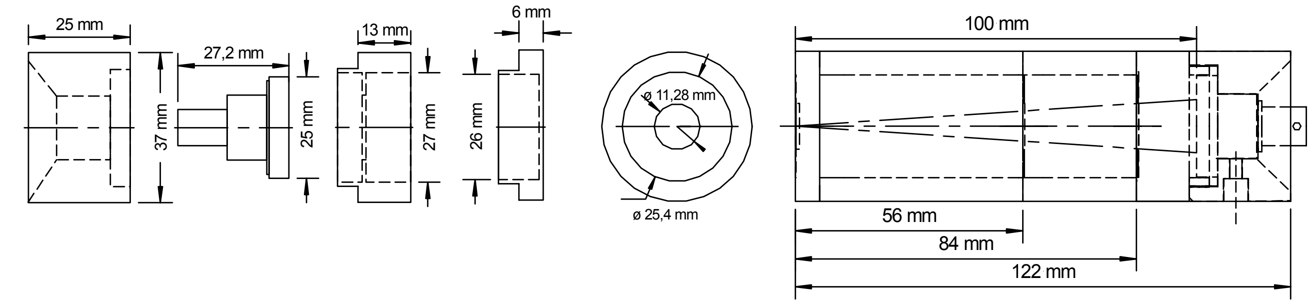
XD-95 Series Housing Dimensions



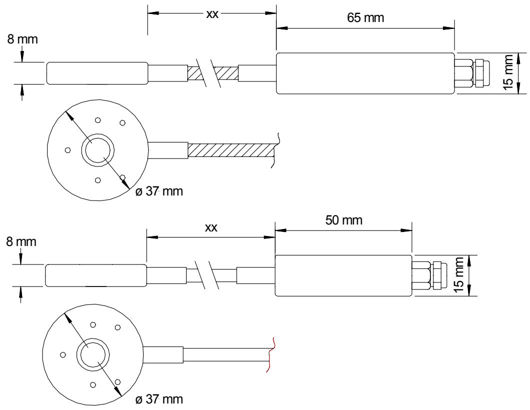
LP-99 Housing Dimensions

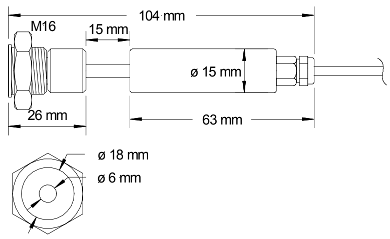


PD-93 Series Housing Dimensions

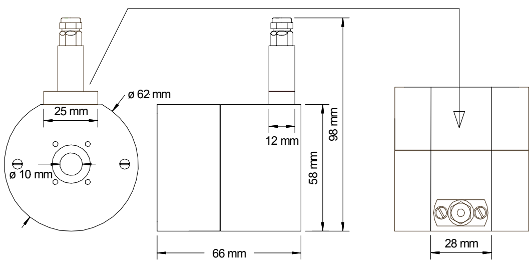


RCH-0, RCH-1 and RCH-5 Housing Dimensions

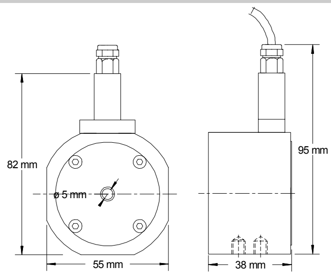




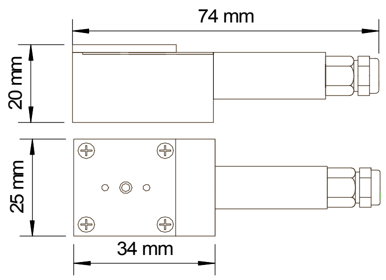
LP-99, LSM-99 and PRW-05 Housing Dimensions



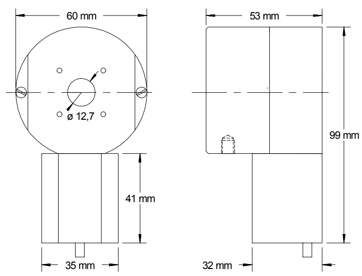
LP-01 Series Housing Dimensions



LP-02 Housing Dimensions

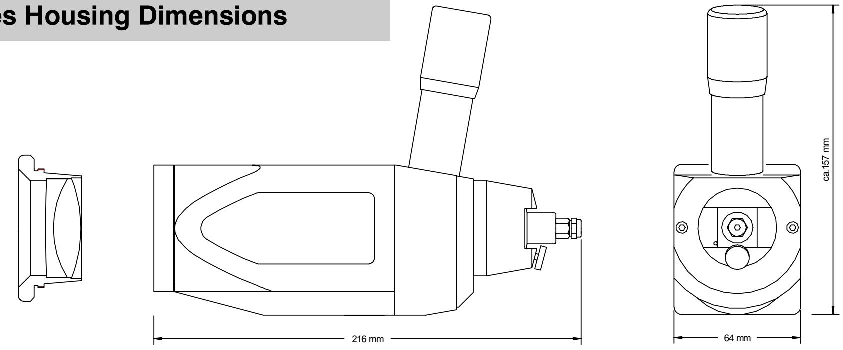


LPPA-9901 Housing Dimensions

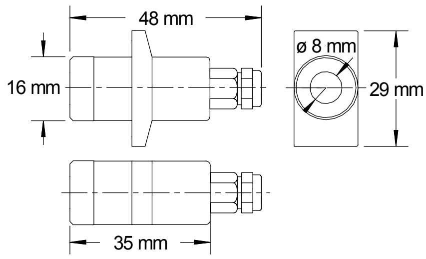


Light Detector Dimensions

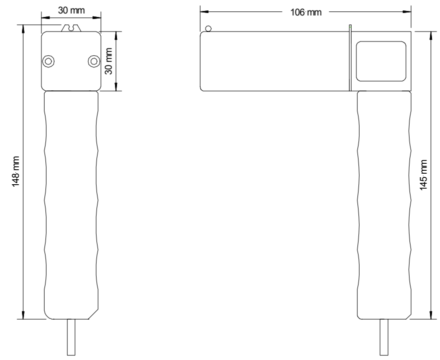
LDM-98 Series Housing Dimensions



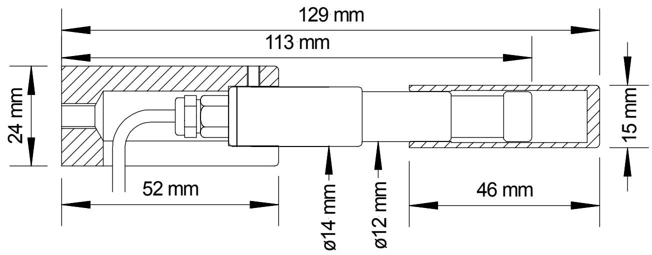
PD-16 Series Housing Dimensions



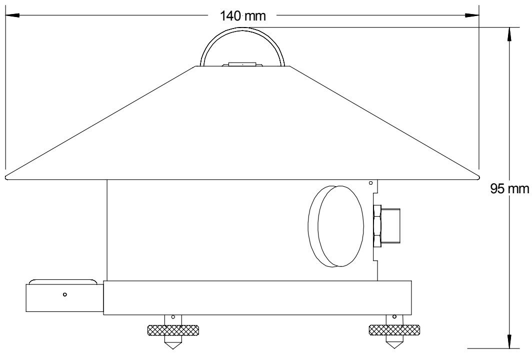
LDM-9901 Housing Dimensions



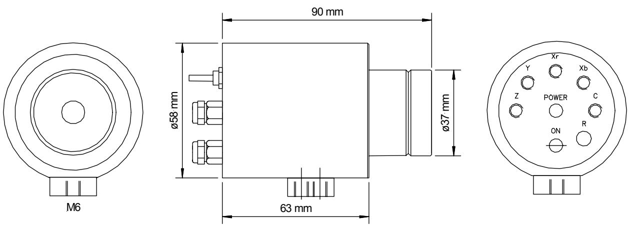
ROD-360 Housing Dimensions



WPD Series Housing Dimensions

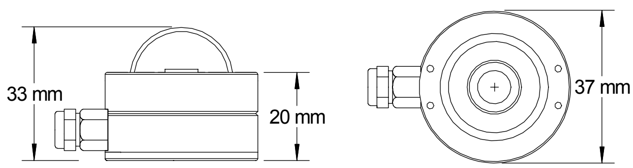


CT-3701 Housing Dimensions



/WG and /WQ Option Dimensions

Example



Integrating Spheres

Integrating spheres are unique tools used in many laser & photonics applications. Gigahertz-Optik offers a wide range of integrating spheres for both detection purposes and for uniform light sources . To meet the many varied application demands, spheres with different diameters are offered as well as different coatings and measurement geometries. Besides the modular UM series for light measurements and uniform light source set-ups Gigahertz-Optik offers the UP series with precisely aligned port geometries for reflectance and transmittance measurements. Complete systems can be assembled using accessory components and an instrument from Gigahertz-Optik's photometer, radiometer and colorimeter program. To satisfy specific application demands, custom design and private labeling solutions are offered.

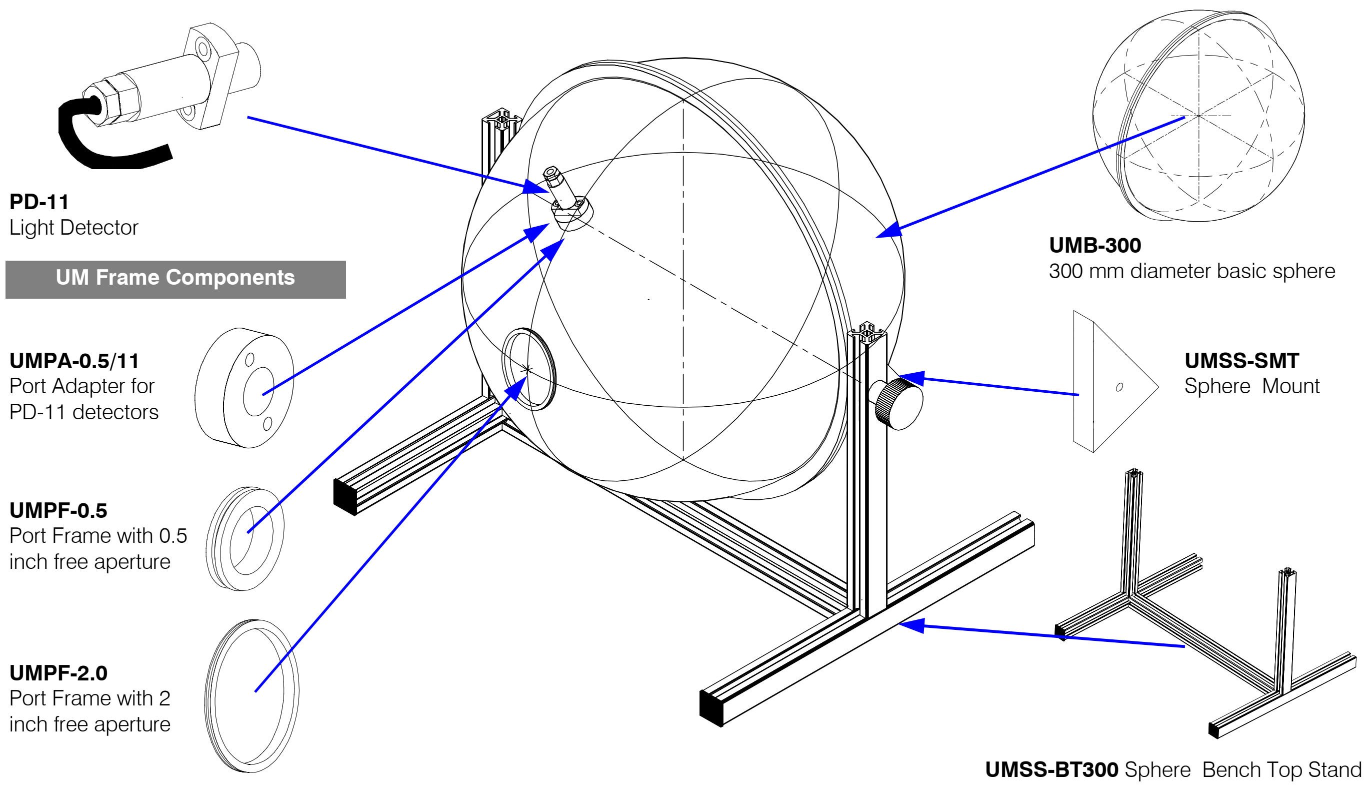
Gigahertz-Optik

Table of Contents

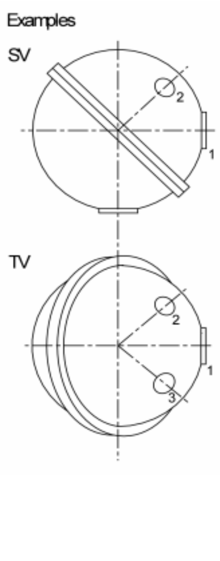
Individual Sphere Design

Years of experience in manufacturing integrating spheres has taught us that a line of standard spheres will not fulfill all possible customer needs. Most often either the end-user accepts a standard sphere as a compromise solution or must have the stock item custom modified adding extra cost and lead time. The new **UM** integrating sphere series allows individual integrating sphere set-up in the specific configuration required with only those components needed. An added benefit to this design freedom is that you don't pay for something you don't need.
With standardized stock components and an innovative assembly process the UM series offers economical prices and short delivery times for integrating spheres that others can only claim as custom products.
Port frames with free apertures in different diameters as well as detector and light source ports can be added and positioned on the basic spheres according to end-user design. **UMB Basic Spheres** are available in different diameters and with different coatings.
Sphere Accessory Components such as port plugs, reducers, adapters, baffles, sphere mounts and stands are available.
Application Accessory Components & Instruments like fiber optic adapters, light sources & detectors, photometers, radiometers, colorimeters & calibration standards allow complete systems to be assembled.
The following pages describe typical application set-ups as well as individual component specifications. Light measurement instrumentation and calibration equipment technical specifications and descriptions are shown in other chapters of this catalog.

Light Detector | **UM Sphere Configuration** | **Sphere Components**



Assembly Orientation

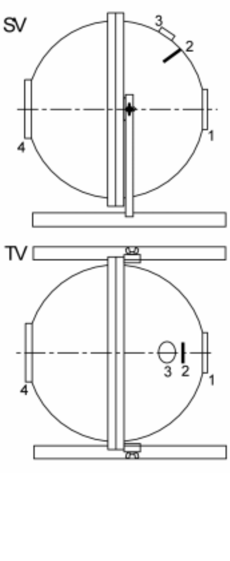


Side View
Flange 135°
Port Ø 1 0°
Port Ø 2/3 45°
Stand 270°

Top View
Port Ø 1 0°
Port Ø 2 45°
Port Ø 3 315°

Side View
Flange 90°
Port Ø 1 0°
Port Ø 2 60°
Port Ø 4 180°
UMPB /2 45°
Stand 90°

Top View
Port Ø 1 0°
Port Ø 3 0°
Port Ø 4 180°
UMPB /2 0°



UMB Basic Spheres are assembled using two hollow hemispheres made from aluminum sheet stock.
The **Orbit Flange** located on open side of each hemisphere is used to mechanically mate the sphere halves. The standard position for the orbit flange is vertical as shown in the above drawing. But its actual position can be specified at any angle from vertical. Note that port frames, sphere stands or other accessory may limit the choice of angle. 5 deg. angle steps with a tolerance of +/- 5 deg. are recommended.

To specify position coordinates for **Accessory Components,** the same 5 deg. +/-5 deg. resolution is recommended. Position can be mapped using the side-view 'SV' and top-view "TV' angle charts as shown above.
The sphere Al sheet forming process only allows a typical position tolerance of +/- 5 degrees.
For more precise alignment **UP series spheres** are recommended.

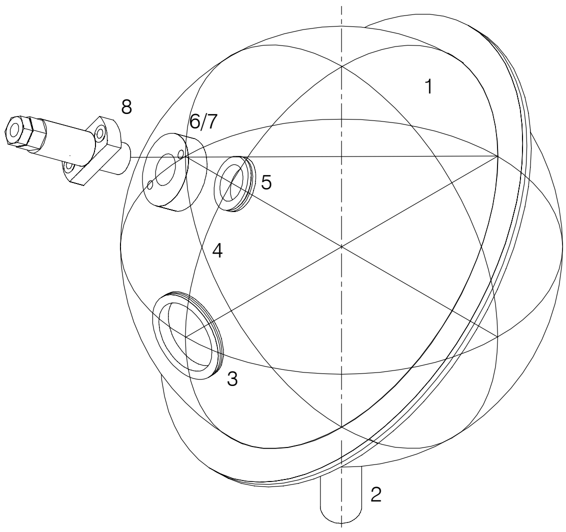
Gigahertz-Optik

UM Series “Set-up Examples”

Luminous Flux & Radiant Power Measurement of Spot Sources

The integrating sphere is the preferred tool for the measurement of radiant power or luminous flux of spot sources with a diverging light beam. Typical examples of spot sources are LEDs, LED panels, laser diodes, fiber bundle light sources, reflector spot lamps, flat panel displays, endoscopes and others.
The reason why the integrating sphere is preferable to a planar detector is that typical photodiode detectors are limited in active area, size and acceptance angle. Integrating spheres offer large area measurement apertures and large acceptance angles in observance to the rule that the ‘measurement aperture area should not exceed 5% of the total sphere area’. Temperature is another reason for using integrating spheres in applications involving high power tungsten or xenon spot lamps. Large diameter spheres are required to maintain temperature within operating limits, prohibit heat damage and for stability/accuracy of the measurement.
In this set-up a measurement port and a detector port is needed. Photometric, radiometric or colorimetric detectors can be mounted onto the integrating sphere with an accompanying read-out instrument. In applications where wide variations in sphere housing temperature may occur, detectors with temperature stabilization are recommended to avoid drift of the measured signal. A spectrometer can also be used with or as an alternative to the integral light detector. Baffles are placed between the lamp and detector to prohibit direct illumination of the detector by the incoming signal.
The complete sphere system can be calibrated in absolute quantities such as luminous flux (lm), radiant power (W) or spectral radiant power (W/nm). Lamp standards are normally used for calibrations in illuminance (lx) or spectral irradiance (W/(m² nm)) . See *Calibration Standards* sec-

Directional LED Measurement



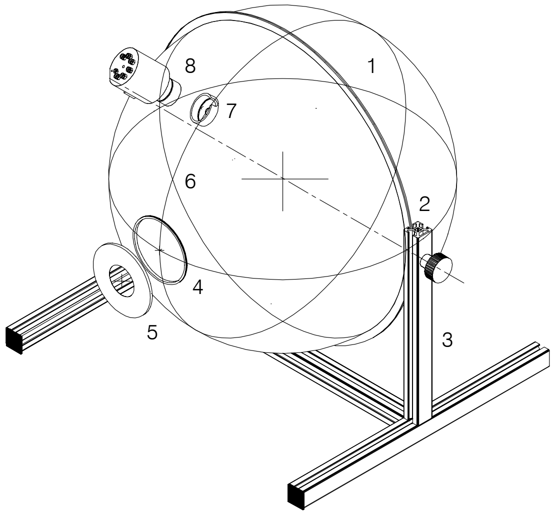
150 mm (6 in) dia sphere with photometric detector for luminous flux measurements.

1. *UMBB-150: 150 mm (6”) dia integrating sphere*
2. *UMSS-SM14: sphere socket*
3. *UMPF-1.0: 1.0” dia port frame*
4. *UMPB-SM: port baffle*
5. *UMPF-0.5: 0.5” dia port frame*
6. *UMPA-0.5/11: port adapter for 11-type light detector*
7. *UMPA-0.5/RADIN: diffuser for UMPA-0.5/11 port adapter*
8. *VL-1101-2: photometric detector with calibration data connector for P-9710-1*
9. *P-9710-1: single channel optometer with RS232 Interface*
10. *KDW: Calibration of luminous flux sensitivity*

Options:

- *TD-11VL01-2: temp. stabilized photometric detector*
- *P-2000: two channel optometer with RS232 and IEEE488 interface.*
- *UMPF-2.0: 2.0” dia port frame*
- *UMPR-2.0/xx: port reducer plug, xx = aperture dia*
- *PM-B + PM-P: post stand*
- *UMSS-BT150: bench-top stand alternative to UMSS-*

Spot Lamp Measurement



500 mm (20 in) dia sphere with colorimetric detector for luminous flux and color temperature measurements.

1. *UMBB-500: 500 mm (20”) dia integrating sphere*
2. *UMSS-SMT*
3. *UMSS-BT500: bench-top stand*
4. *UMPF-4.0: 4.0” dia port frame*
5. *UMPR-4.0/xx: 1 or more port reducer, xx = aperture dia*
6. *UMPB-SM: port baffle*
7. *UMDP-37: detector port for 37type detectors*
8. *CT-3701: luminous flux, color temperature and xy chromaticity value detector. Temperature stabilized*
9. *P-9801: 8-channel optometer with RS232 and IEEE488 interface*
10. *OS-P9801: remote control software*
11. *KDW: calibration of luminous flux sensitivity and color temperature*

Options:

- *UMSS-HF500: hinge Frame bench top stand for full opening of the front hemisphere*
- *Additional radiometric detectors*

Luminous Flux & Radiant Power Lamp Measurement

Measuring total radiant power or luminous flux emitted by lamps is one of the most common applications for integrating spheres. Other than spot sources, lamps emit light in all directions. The integrating sphere collects all of the emitted light entering it and supplies an integrated signal to its mounted light detector .

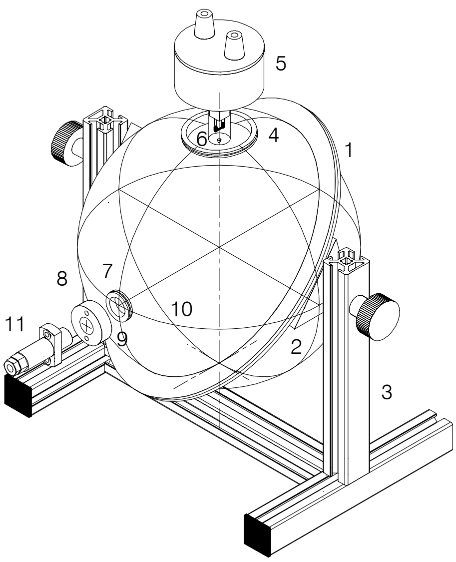
Lamps come in many different form, size and output power today. Examples include tungsten filament lamps, fluorescent tube & bulb shape lamps, high power xenon sources and many more. Selecting the size of the integrating sphere is typically based on the maximum dimension of the lamp to be measured. The sphere diameter should be at least ten times the maximum dimension of the lamp. For tube lamps it should be twice the largest dimension of the source.

For flux measurements a multi-directional lamp is placed in the center of the sphere. Different forms and sizes of sockets and individual lamp holders are required for each different lamp type. For smaller size lamps a top-load port can be used for insertion and removal. For large size lamps integrating spheres with a hinged frame allowing one half of the sphere to fully open are recommended .

Photometric, radiometric or colorimetric detectors can be mounted onto the integrating sphere with an accompanying read-out instrument. In applications where wide variations in sphere housing temperature may occur, detectors with temperature stabilization are recommended to avoid drift of the measured signal. A spectrometer can also be used with or as an alternative to the integral light detector. Baffles are placed between the lamp and detector to prohibit direct illumination of the detector by the incoming signal.

The complete integrating sphere light detection system can be calibrated in absolute optical measurement quantities such us luminous flux (lm), radiant power (W) or spectral radiant power (W/nm). Please refer to the *Calibration Standards* section for further

Miniature Lamp Measurement



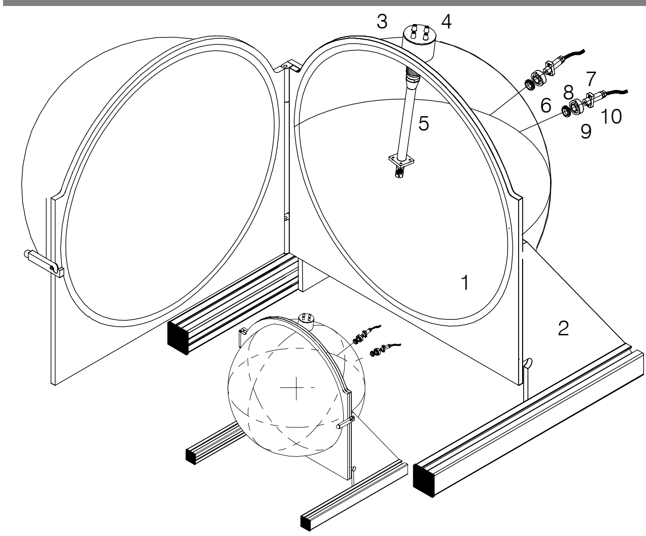
150 mm (6") dia top-load sphere with photometric detector for luminous flux measurement:

1. *UMBB-150: 150 mm (6") dia Sphere*
2. *UMSS-SMT: sphere mount*
3. *UMSS-BT150: bench-top stand*
4. *UMPF-1.5: 1.5" dia port frame*
5. *UMLA-1.5/B: lamp adapter base*
6. *UMLA-150: lamp holder. Without socket*
7. *UMPF-0.5: 0.5" dia port frame*
8. *UMPA-0.5/11: port adapter for 11 type detector head*
9. *UMPA-0.5/RADIN: RADIN Diffuser for UMPA-0.5/11 port adapter*
10. *UMPB-PM: port baffle*
11. *TD-11VL01-2: temp. stabilized photometric detector*
12. *P-9710: single channel optometer with RS232 Interface*
13. *BN-0104: luminous flux transfer standard with UMLA-150 lamp holder*
14. *LPS-250: lamp power supply*

Option:

- *P-2000: two channel bench-top optometer with RS232 and IEEE488 interface.*

Large-size Lamp Measurement



500 mm (20") dia sphere with photometric and UV-A detector for luminous flux and UV-A radiant power measurements.

1. *UMBB-500: 500 mm (20") dia sphere*
2. *UMSS-HF500: hinge frame bench-top stand*
3. *UMPF-1.5: 1.5" dia port frame*
4. *UMLA-1.5/B: lamp adapter base*
5. *UMLA-500: lamp holder. Without socket*
6. *2 x UMPF-0.5/11: 0.5" port frame*
7. *2 x UMPA-0.5/11: port adapter for MD-11 detector head*
8. *2 x UMPA-0.5/RADIN: diffuser for UMPA-0.5/11 port adapter*
9. *UMPB-PM: port baffle*
10. *TD-11VL01-2: temp. stabilized photometric detector*
11. *TD-11UV01-2: temp. stabilized UV-A detector*
12. *P-2000: two channel bench-top optometer with RS232 and IEEE488 interface.*
13. *BN-0104: spectral radiant power transfer standard lamp*
14. *LPS-250: lamp power supply*

Options:

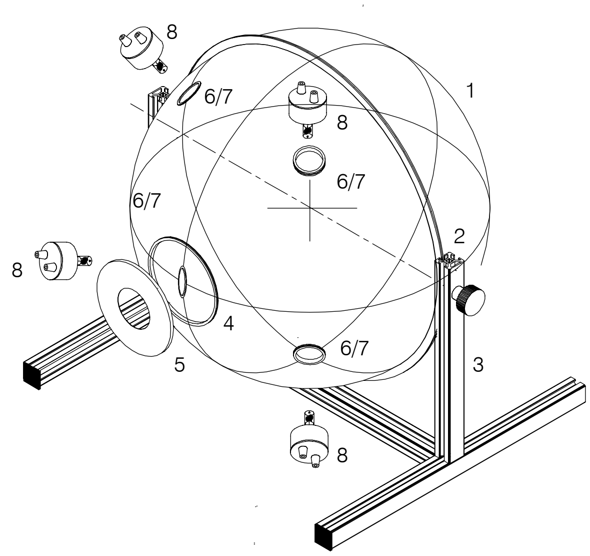
- *UMLA-500: Additional lamp holder*
- *UMPA-2.0/AXL: Auxiliary lamp adapter*

UM Series "Set-up Examples"

Uniform Light Source, Luminance and Spectral Radiance Standard

Uniform light sources are required to perform uniformity calibration of imaging systems and to calibrate luminance and spectral radiance measurement instruments.
Because of the integrating sphere's ability to produce multiple diffuse internal reflections and a uniform illumination of the inner sphere wall, it is the right tool to form the basis for uniform light sources.
Integrating spheres are available in different diameters offering the possibility for larger diameter emitting windows.
A number of optional accessory components can be added to the integrating sphere to expand its basic capabilities.
- Multiple lamps can be mounted onto one sphere offering high flexibility in intensity level.
If each lamps is operated with its own power supply, intensity can be varied in steps by simply switching light sources on and off.
- External spot lamps can be combined with variable attenuators to control the light output intensity in small steps. Attenuators with different resolutions are available.
- External spot lamps can also be combined with manually exchangeable filters used for both neutral density attenuation and for forming the emission spectrum purposes.
- Remote control filter wheels and attenuators are another option to build a completely automated system.
- A large dynamic intensity range can be realized by combining neutral density filters with a variable attenuator.
- Extra band pass filtering allows uniformity calibration across different wavelength ranges.
- High speed shutters as fast as 40 ms enable calibration of the lamp's on/off characteristic.
- Luminance and spectral radiance calibration is available through GO's calibration lab (ISO EN 17025 accredited for spectral irradiance & sensitivity).

Large Aperture Uniform Light Source

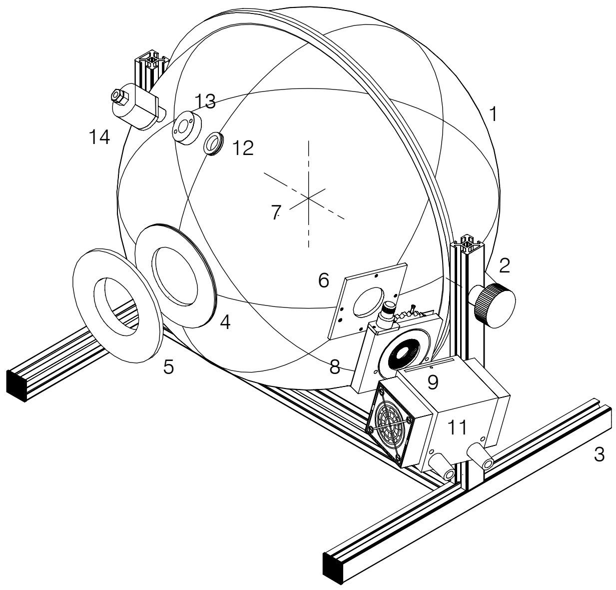


Uniform light source 500 mm (20 in) dia sphere and (4) light sources for high uniformity and high luminance intensity. Color temperature controlled light sources.

1. *UMBB-500: 500 mm (20") dia. integrating sphere*
2. *UMSS-SMT: sphere mount*
3. *UMSS-BT500: Bench top sphere stand*
4. *UMPF-5.0: 5" dia port frame*
5. *UMPR-5.0/xx: port reducer. xx = 100 mm dia*
6. *4 x UMPB-SM: port baffle*
7. *4 x UMPF-1.5: 1.5" dia port frame*
8. *4 x LS-IS1.5: light source with 50 W QH lamp*
9. *4 x LPS-250: lamp power supply*
10. *4 x BTH-19/2: 1/2 19" bench to housing for LPS-250*
11. *UMDP-37: detector port*
12. *UMPB-SM: port baffle*
13. *CT-3701: temperature stabilized color detector*
14. *P-9801: 8-channel meter*
15. *KLW: calibration of color temperature und luminance*

Options:
Software for remote control of intensity and color temperature control of each lamp

Adjustable Uniform Light Source



Adjustable uniform light source 300 mm (12 in) dia sphere and light source with manually controlled attenuator. Calibrated luminance detector for luminance intensity control.

1. *UMBB-300: 300 mm (12") dia integrating sphere*
2. *UMSS-SMT: sphere mount*
3. *UMSS-300: bench top sphere stand*
4. *UMPF-2.0/3.5: port frame*
5. *UMPR-2.0/3.5/xx: port reducer, xx = 50 mm dia*
6. *UMPF-LSOK30: port frame*
7. *UMPB-PM: port baffle*
8. *LS-OK30-MIR: micrometer drive variable attenuator*
9. *LS-OK30-H100: spot lamp with 100 W QH lamp*
10. *LPS-250: lamp power supply*
11. *BTH-19/2: 1/2 19" bench top housing for LPS-250*
12. *UMPF-0.5: port frame*
13. *UMPA-0,5/11: port adapter*
14. *TD-11VL01-2: temperature stabilized photometric detector head*
15. *P-9710-1: optometer*
16. *KLW: calibration of luminance intensity*

Multi-port Configurations for Reflectance, Transmittance, Absorbance

Integrating spheres offer unique functions which makes them very useful in reflectance, transmittance and absorbance applications.

The **Lambertian emittance characteristic** of uniform light sources incorporating integrating spheres provides a hemispherical diffuse and uniform illumination of test samples e.g. such as light panels used for backlighting of displays.

In this case the luminance contrast of the light panels can be measured using an additional luminance meter viewing through an additional port.

The large acceptance angle of integrating sphere based light detection systems is the main reason for using spheres in reflectance and transmittance applications.

Any light that is reflected by a diffuse material or passing through a diffuse material must be completely detected. This should be independent of the angle of reflected or transmitted light and also from any increase in spot size. Flat field detectors do not meet this requirement.

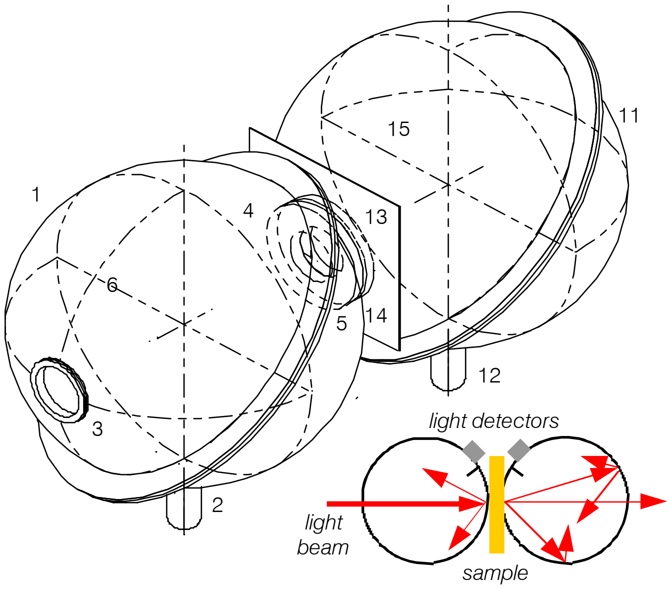
The port frame will not interfere with the acceptance angle if it is designed with a **knife-edge**.

Besides acceptance angle, larger measurement apertures can be made, an other argument for the integrating sphere.

A precisely collimated light beam is a prerequisite for accurate reflectance and transmittance measurements. The collimated beam must not only precisely target the sample area but also not contain any diffraction rings which can produce an offset light level inside the sphere limiting measurement resolution.

Consider the UP series integrating spheres for reflection, transmission, absorbance and other applications where more precise port positioning is critical.

Reflectance & Transmittance



Combined reflectance transmittance system built with two 150 mm (6 in) dia. spheres and two detectors.

Reflectance sphere:

1. *UMBB-150: 150 mm (6”) dia integrating sphere*
2. *UMSS-14/M6: post stand*
3. *UMPF-1.0: 1.0” dia port frame*
4. *UMPF-1.5: 1.5” dia port frame*
5. *UMPR-1.5/xx: 1.5” port reducer with xx = 25 mm dia and knife edge*
6. *UMPB-SM: port baffle*
7. *UMPF-0.5: 0.5” dia port frame*
8. *UMPA-0.5/11: port adapter*
9. *UMPA-0.5/RADIN: diffuser*
10. *PD-1101-2: detector head*

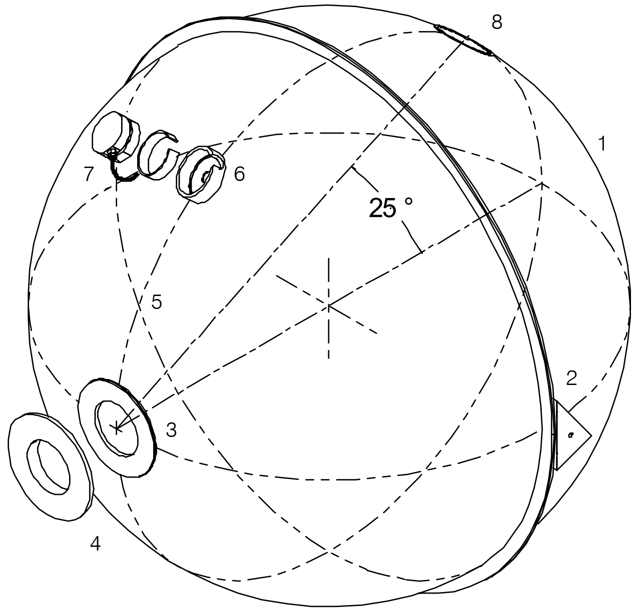
Transmittance sphere:

11. *UMBB-150: 150 mm (6”) dia integrating sphere*
12. *UMSS-14/M6: post stand*
13. *UMPF-1.5: 1.5” dia port frame*
14. *UMPR-1.5/xx: 1.5” port reducer with xx = 50 mm dia and knife edge*
15. *UMPB-SM: port baffle*
16. *UMPF-0.5: 0.5” port frame*
17. *UMPA-0.5/11: port adapter*
18. *UMPA-0.5/RADIN: diffuser*
19. *PD-1102-2: detector head*

Option:

20. *P-2000: 2-channel optometer*

Transmittance of Diffuse Transmitting Samples



Reflectance sphere 500 mm (20”) dia, 25 deg illumination port and photometric detector. Without bench top stand.

1. *UMBB-500: 500 mm (20”) dia integrating sphere*
2. *UMSS-SMT: sphere mount*
3. *UMPF-2.5/3.5: 2.5/3.5” port frame*
4. *UMPR-2.5/3.5/xx: 2.5/3.5” port reducer with xx = 50 mm dia and knife edge*
5. *UMPB-SM: baffle*
6. *UMDP-37: 37mm dia detector port*
7. *VL-3701-2: photometric illuminance detector with 37type package*
8. *UMPF-2.0: 2.0” dia port frame*

Option:

9. *P-9710: Optometer*
10. *LS-CB50: collimated light source set-up for 25 mm beam diameter*
11. *LPS-250: lamp power supply*
12. *BTH-19/2: 1/2 19” bench top housing*

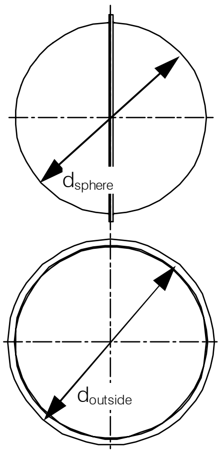
UM Series Components

UM Basic Spheres

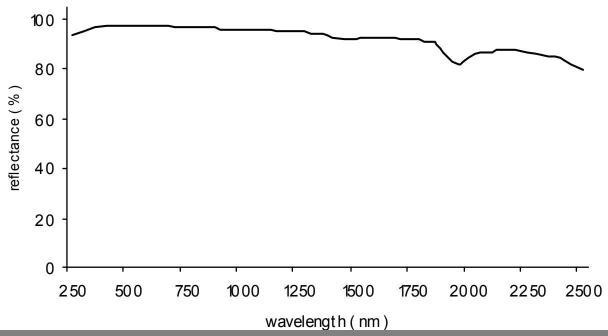
Hollow spheres with diameters from 100 mm (4 in.) to 1700 mm (68 in.) and three different coatings are offered to build integrating spheres to your need. Port frames, sphere stand and application accessory is assembled by your selection.
Please contact your local representation or the Gigahertz-Optik head office for personal assistance to discuss the set-up of the sphere and get your offer for the complete sphere set-up.

O.E.M. inquiries with different diameters, custom color painting of the sphere housing etc. are welcome.

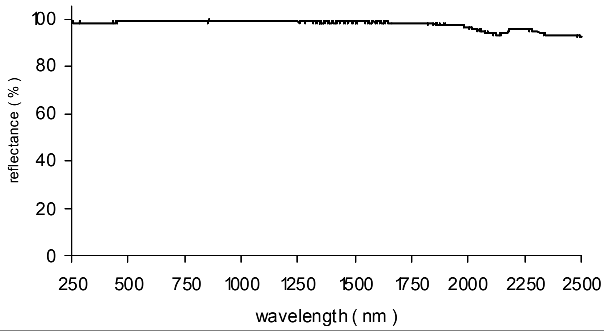
UMB: Basic Spheres



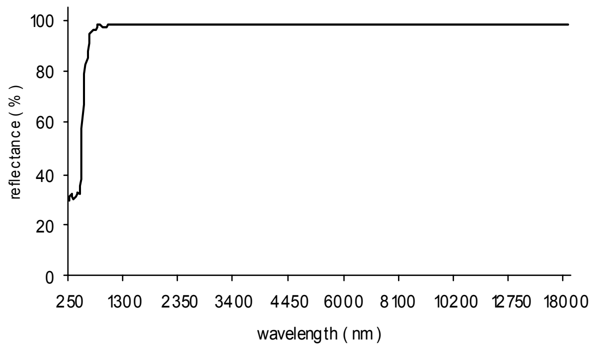
UMBB - Barium-Sulfate Coating



UMBK - OP.DI.MA. Coating



UMBG - Gold Coating



Barium sulfate is an economical coating offering a ~ 97 % (555nm) diffuse reflectance characteristic within the wavelength range from 300 nm to 2400 nm. For photometric applications the reflectance can be reduce to ~ 80 % to reduce substitution effects errors produced by high reflectance.
Besides the standard ODP97 coating with best reflectance characteristic a more durable coating is available with slightly less reflectance capability.

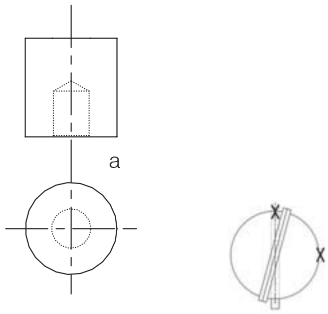
OP.DI.MA. is Gigahertz-Optik's own white plastic with an excellent diffuse reflectance characteristic and high durability.
Its diffuse reflectance is close to that of a perfect lambertian reflector ensuring a highly uniform light distribution across the inner walls of the integrating sphere.
The spectral reflectance covers a wide spectral range from ultraviolet to IR, 250 nm to 2500 nm with > 95 % reflectance and a peak reflectance of > 98 % in the VIS/NIR spectral range.

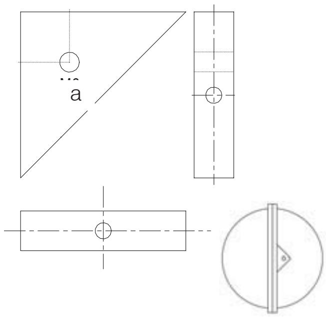
Uncoated gold outperforms all other uncoated metallic reflectors at infrared wavelengths. Gold's high reflectivity in the red portion of the visible spectrum is apparent by it's yellow hue. With a reflectance of ~ 95 % in the wavelength range from 800 nm to 20 μm, gold is the best choice for surface coating of integrating spheres used in IR applications. A proprietary interior surface preparation creates the diffuse reflectivity required for uniform light distribution inside the sphere .

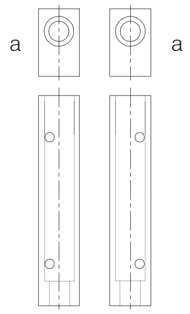
Ordering Information & typical Specifications

Model	Coating / Reflectance %	Hollow Sphere Diameter mm / in.	Sphere Frame Diameter mm / in.	Hollow Sphere Surface cm²	5% Area Port Size mm / in.
UMBB-100	ODP97 / 97%	100 / 4	124 / 4.9	314	43 / 1.7
UMBB-150	ODP97 / 97%	150 / 6	174 / 6.8	707	66 / 2.5
UMBB-210	ODP97 / 97%	210 / 8.3	234 / 9.2	1385	93 / 3.6
UMBB-300	ODP97 / 97%	300 /12	324 / 12.7	2827	130 / 5.1
UMBB-500	ODP97 / 97%	500 /20	524 / 20.6	7584	220 / 8.6
UMBB-1000	ODP97 / 97%	1000 / 39	tbc	31416	450 / 17.7
UMBB-1700	ODP97 / 97%	1700 / 68	tbc	90792	760 / 29.9
UMBK-190	ODM98 / 98%	190 / ~7.5	234 / 9.2	1134	84 / 3.3
UMBK-250	ODM98 / 98%	250 / 10	324 / 12.7	1964	112 / 4.4
UMBK-460	ODM98 / 98%	460 / 18	524 / 20.6	6648	205 / 8.0
UMBG-100	ODG95 / 95%	100 / 4	124 / 4.9	314	43 / 1.7
UMBG-150	ODG95 / 95%	150 / 6	174 / 6.8	707	66 / 2.5
UMBG-300	ODG95 / 95%	300 / 12	324 / 12.7	2827	130 / 5.1

UMSS-SM14, UMSS-SMT & UMSS-SMV Sphere Mount Adapters







UMSS-SM14

The UMSS-SM14 sphere mount is the right choice for small diameter spheres up to 150 mm (6 in). The 14 mm diameter socket with M6 tapped hole allows the spheres to be mounted to commercial optical bench posts. The UMSS-SM14 is specified for upright use or for hanging .

The UMSS-SMT sphere mount is required to assemble UMB series spheres to the UMSS-BT bench-top stands using the M6 horizontal side holes provided. The SMT is fixed to the orbit flange. Additional M6 holes offer additional sphere mounting options into end-user applications.

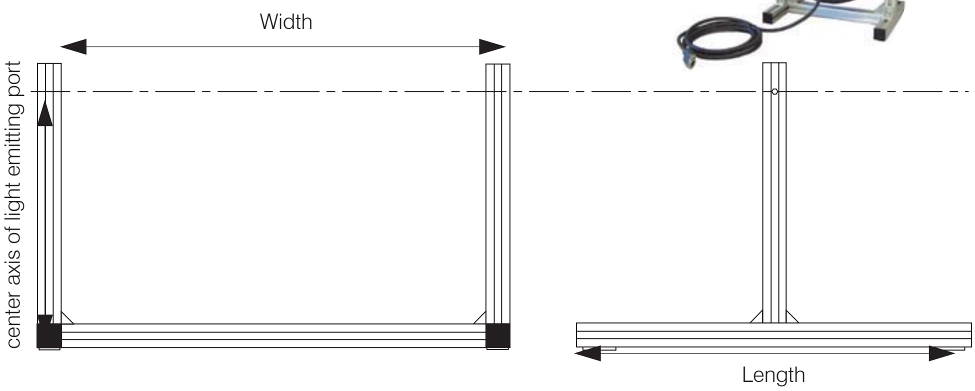
The UMSS-SMV sphere mount enables spheres with a vertical orbit orientation to be assembled onto post mounts. The SMV is fixed to the orbit flange. Vertical M6 holes are provided for this purpose.

UMSS-SMT

Ordering Information & typical Specifications		
Model	**Description**	**Mounting Holes a**
UMSS-SM14	Post mount socket fix mounted to sphere	M6
UMSS-SMT	Pair of flange mounted triangular sockets fix mounted to sphere	M6
UMSS-SMV	Pair of flange mounted sockets for fix mounted to sphere	for M6 screws
Only available with UMB basic sphere order		

UMSS-BT Bench-top Sphere Stands

UMBB-150 in UMSS-BT150 in the set-up for luminous flux measurement with top load port

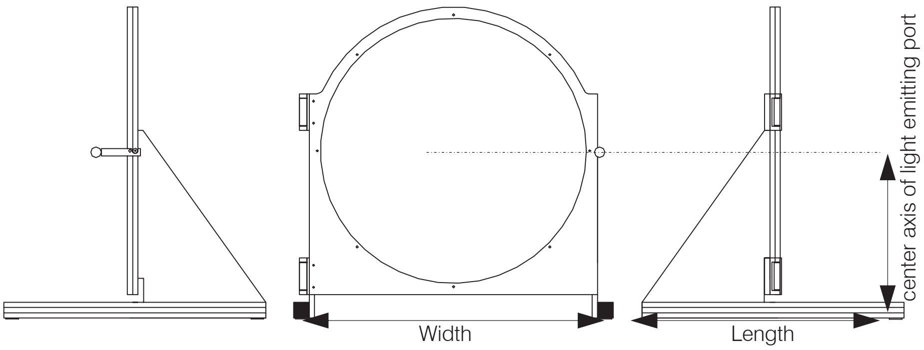


The UMSS-BT stands are available for UMB series spheres from 150 mm (6") to 1700 mm (68") diameters.
The stands are made out of aluminum for lightweight stability. A modular design allows freedom for custom design modification or complete application set-ups.

Ordering Information & typical Specifications					
Stand Model	**Sphere Model**	**Optical Axis (mm)**	**Width (mm)**	**Length**	**Al profile**
UMSS-BT150	UMBB&UMBK-150	118	220	150	20 x 20
UMSS-BT210	UMBB-210, UMBK-190	tbc	tbc	tbc	20 x 20
UMSS-BT300	UMBB-300, UMBK-250, UMBG-300	203	370	300	20 x 20
UMSS-BT500	UMBB-500, UMBK-460	315	593	500	30 x 30
UMSS-BT1000	UMBB-1000	tbc	tbc	tbc	tbc
UMSS-BT1700	UMBB-1700	tbc	tbc	tbc	tbc
Only available with UMB basic sphere order					

UM Series Components

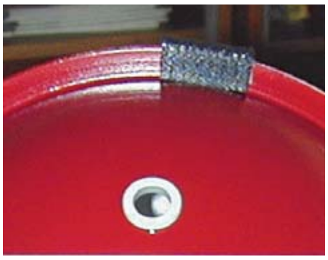
UMSS-HF Bench-top Hinged Frame Sphere Stands

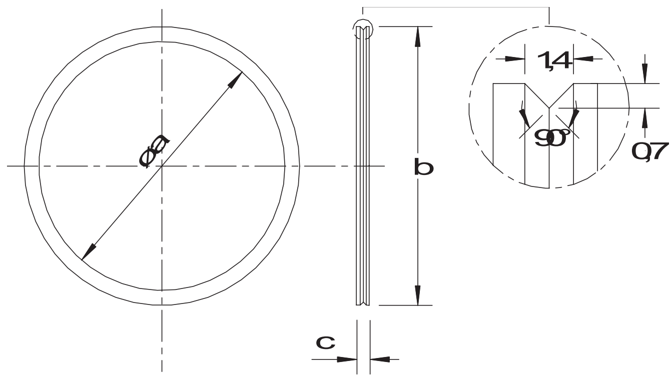


The UMSS-HF bench-top sphere stand is designed for those applications requiring open access to the center of the integrating sphere for insertion and removal of the test lamp or sample. This is a common requirement in luminous flux or radiant power measurements of large multi-directional lamps, absorbance and transmission measurements. The UMSS-HF stands are designed for rugged long-term use. Port frames and other components like detector ports, light guide adapters, auxiliary lamps & lamps holders can be assembled to both sphere halves.

Ordering Information & Specifications					
Model	**Sphere Model**	**Height of optical axis**	**Width**	**Length**	**Al profile**
UMSS-HF300	UMBB-300	tbc	tbc	tbc	tbc
UMSS-HF500	UMBB-500	345	610	500	20 x 40
UMSS-HF1000	UMBB-1000	tbc	tbc	tbc	tbc
UMSS-HF1700	UMBB-1700	tbc	tbc	tbc	tbc
Only available with UMB basic sphere order					

UMPF Port Frames

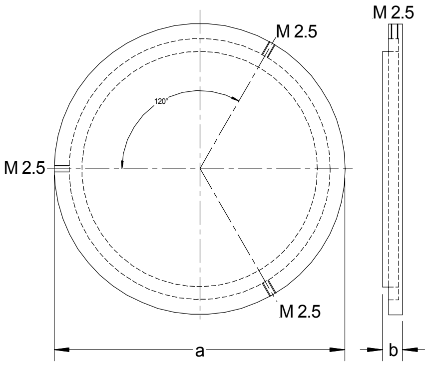




Port frames are permanently mounted to the sphere at specified positions. Frames are available with free apertures from 0.5 to 5 inch diameter. A machined V-groove around the frame's outer edge allows assembly of port plugs, reducers, adapters and other accessory components onto the port. Gold coated port frames are offered for use with UMBG series spheres.

Ordering Information & Specifications				
Model BaSO4	**Model Gold**	**Free aperture diameter (a)**	**Outer diameter (b)**	**Frame Height (c)**
UMPF-0.5	**UMPF-0.5-G**	0.5 in. / 12.7 mm	0.75 in. / 18.8 mm	0.1 in. / 2.7 mm
UMPF-1.0	**UMPF-1.0-G**	1.0 in. / 25.4 mm	1.25 in. / 31.5 mm	0.1 in. / 2.7 mm
UMPF-1.5	**UMPF-1.5-G**	1.5 in. / 38.1 mm	1.75 in. / 44.2 mm	0.1 in. / 2.7 mm
UMPF-2.0	**UMPF-2.0-G**	2.0 in. / 50.8 mm	2.25 in. / 56.9 mm	0.1 in. / 2.7 mm
UMPF-2.0/3.5	**UMPF-2.0/3.5-G**	2.0 in. / 50.8 mm	3.5 in. / 88.9 mm	0.1 in. / 2.7 mm
UMPF-2.5	**UMPF-2.5-G**	2.5 in. / 63.5 mm	2.75 in. / 69.6 mm	0.1 in. / 2.7 mm
UMPF-3.0	**UMPF-3.0-G**	3.0 in. / 76.2 mm	tbc	0.1 in. / 2.7 mm
UMPF-4.0	**UMPF-4.0-G**	4.0 in. / 101.6 mm	4.25 in. / 107.7 mm	0.1 in. / 2.7 mm
UMPF-5.0	**UMPF-5.0-G**	5.0 in. / 127 mm	5.25 in. / 133.1 mm	0.1 in. / 2.7 mm
Only available with UMB basic sphere order				

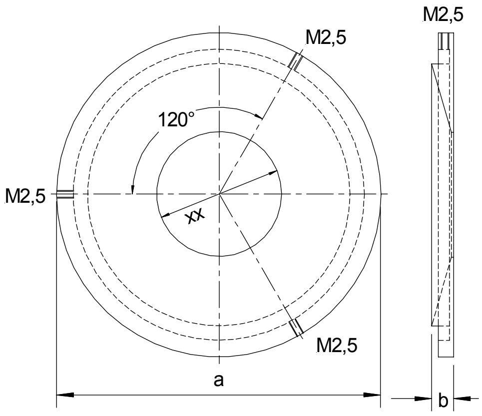
UMPP Port Plugs



Port plugs are used with UMPF port frames to close sphere port openings while maintaining it's uniformly coated interior surface. Plugs are fixed onto the side V-groove of the port frame with three M2.5 screws. The surface facing the sphere interior is coated with barium sulfate or gold as applicable. Port plugs for UMBK spheres are available by special request.

Ordering Information & Specifications				
Model BaSO4	**Model Gold** 1)	**Port Frame**	**Outer diameter a (mm / inch)**	**Height b (mm / inch)**
UMPP-0.5	**UMPP-0.5-G**	UMPF-0.5	27 / 1.06	5.3 / 0.2
UMPP-1.0	**UMPP-1.0-G**	UMPF-1.0	39.9 / 1.57	5.3 / 0.2
UMPP-1.5	**UMPP-1.5-G**	UMPF-1.5	52.6 / 2.07	5.3 / 0.2
UMPP-2.0	**UMPP-2.0-G**	UMPF-2.0	65.3 / 2.57	5.3 / 0.2
UMPP-2.0/3.5	**UMPP-2.0/3.5-G**	UMPF-2.0	97 / 3.81	5.3 / 0.2
UMPP-2.5	**UMPP-2.5-G**	UMPF-2.5	78 / 3.07	5.3 / 0.2
UMPP-3.0	**UMPP-3.0-G**	UMPF-3.0	tbc	5.85 / 0.23
UMPP-4.0	**UMPP-4.0-G**	UMPF-4.0	116.1 / 4.57	5.85 / 0.23
UMPP-5.0	**UMPP-5.0-G**	UMPF-5.0	141.5 / 5.57	5.85 / 0.23
1) Only available with sphere system order				

UMPR Port Reducer



Port reducers for the UMPF series spheres enable the free aperture diameter of port frames to be variably decreased according to the application. The aperture diameter can be end-user specified up to the maximum aperture on order. The edge of the aperture is machined in a knife-edge design. Port reducers are fixed onto the V-groove of the port frame with three M2.5 screws. The surface facing the sphere interior is coated with barium sulfate or gold as applicable. Port plugs for UMBK spheres are available by special request. Other optional forms of non-circular reducer such as slits can be custom ordered.

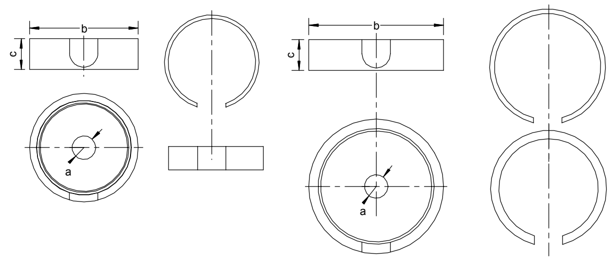
Ordering Information & Specifications					
Model BaSO4	**Model Gold**	**Port Frame**	**Outer diameter a (mm / inch)**	**Height b (mm / inch)**	**xx = 0 to max free aperture *)**
UMPR-0.5/xx	**UMPR-0.5/xx-G**	UMPF-0.5	27 / 1.06	5.3 / 0.2	12.5 / 0.5
UMPR-1.0/xx	**UMPR-1.0/xx-G**	UMPF-1.0	39.9 / 1.57	5.3 / 0.2	25.4 / 1.0
UMPR-1.5/xx	**UMPR-1.5/xx-G**	UMPF-1.5	52.6 / 2.07	5.3 / 0.2	38.1 / 1.5
UMPR-2.0/xx	**UMPR-2.0/xx-G**	UMPF-2.0	65.3 / 2.57	5.3 / 0.2	50.8 / 2.0
UMPR-2.0/3.5/xx	**UMPR-2.0/3.5/xx-G**	UMPF-2.0	97 / 3.81	5.3 / 0.2	50.8 / 2.0
UMPR-2.5/xx	**UMPR-2.5/xx-G**	UMPF-2.5	78 / 3.07	5.3 / 0.2	63.5 / 2.5
UMPR-3.0/xx	**UMPR-3.0/xx-G**	UMPF-3.0	tbc	5.85 / 0.23	76.2 / 3.0
UMPR-4.0/xx	**UMPR-4.0/xx-G**	UMPF-4.0	116.1 / 4.57	5.85 / 0.23	101.6 / 4.0
UMPR-5.0/xx	**UMPR-5.0/xx-G**	UMPF-5.0	141.5 / 5.57	5.85 / 0.23	127 / 5.0
*) free aperture diameter xx in mm / inch with or without knife wedge needs to be specified on order					

Gigahertz-Optik

UM Series Components

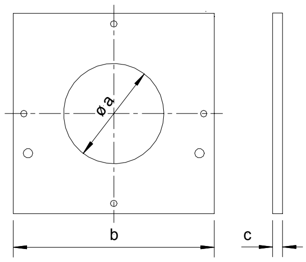
UMDP Detector Ports

Detector ports are required to mount 37 and 45 mm diameter photometric, radiometric and color detectors to UM series integrating spheres.
The plastic ring that holds the detector electrically and thermally isolates the detector from the sphere.
It's free aperture can be increased according to the detector diffuser size. The sphere surface side of the detector adapters are coated with barium sulfate.
Simple adapters that fit into the detector port allow detector heads with different outside diameters to be mounted.



Ordering Information & Specifications				
Model	**Detector dia.**	**Free aperture diameter *) a**	**Outside diameter b**	**Height c**
UMDP-37	37 mm	10 to 38 mm	46 mm	13 mm
UMDP-45	42 & 45 mm	10 to 47 mm	56.9 mm	13 mm
*) machined on order. Only available in order with UMB basic sphere				

UMPF-LSOK Port Frames for Light Source LS-OK30 & LS-OK45



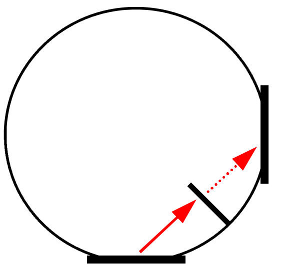
These port frames are needed to mount LS-OK30 and LS-OK34 external light sources to the integrating sphere. Typically these light sources are used together with the LS-OK30-VA variable attenuator.

Ordering Information & Specifications		
Model	**Aperture Dia. a**	**Dimension (mm)**
UMPF-LSOK30	30 mm	60 x 60
UMPF-LSOK45	45 mm	tbc
Only available with UMB basic sphere order		

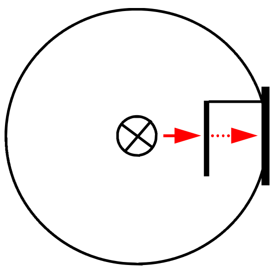
UMPB Port Baffles

Baffles are employed to shield ports from direct irradiation from an other port, a lamp, probe or from first reflection off the sphere surface.
UMDB-SM baffles are direct mounted to the sphere housing. They are typically used between two ports or between inside assembled lamps and ports.
UMDB-PM baffles are used in front of detector ports to prohibit direct irradiation of the detector from centrally mounted lamps. This baffles are typically post mounted.

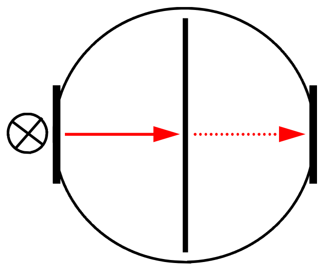
UMDB-IL baffles are uses between to ports in-line assembled to the sphere. This arrangement is typically used for uniform light source set-ups with an external lamp at one port and the light output at the other port.



UMPB-SM



UMPB-PM



UMPB-IL

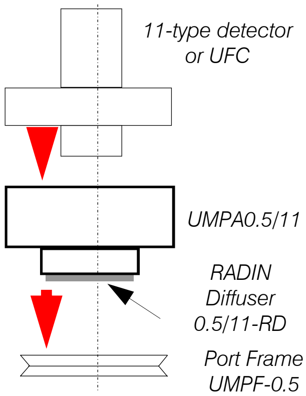
Ordering Information		
Model BaSO4	**Model Gold**	**Description**
UMPB-SM	**UMPB-SM-G**	Sphere mount baffle
UMPB-PM	**UMPB-PM-G**	Post mount baffle
UMPB-IL	**UMPB-IL-G**	In-Line spider mount baffle
Only available with UMB basic sphere order		

UMPA Port Adapter

Port adapters are universal tools used to assemble detectors, light guides, accessories and samples to UMPF sphere series port frames. The port adapter can be fixed in place by three M2.5 screws to the port frame's standard V-groove. The port adapters can be replaced by port plugs to close the port as required by the application. The following list of port adapters represents only a small sample of available parts in Gigahertz-Optik's continuously expanding program. Please contact your local representative or the factory for detailed drawings and also to keep abreast of new product developments.

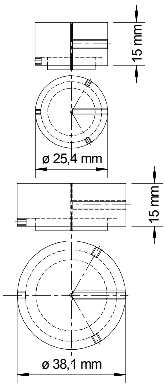
UMPA –0.5/11

Port adapter specially designed to mount standard Gigahertz-Optik 11-type housing detectors or UFC fiber connectors with 11-type adapter flanges to the UMPF-05 port frame.



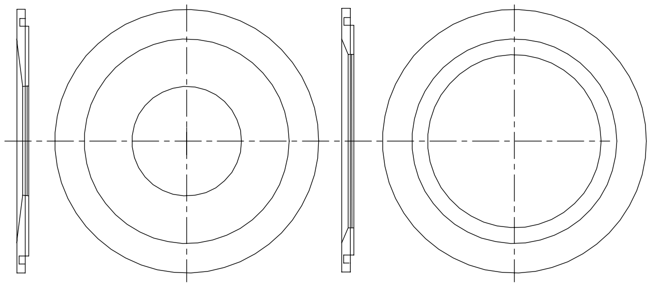
UMPA –0.5/F & -1.0/F

Port adapter for use on UMPF-0.5 and UMPF-1.0 port frames respectively. The standard 1 mm dia. hole can be easily modified to larger diameters up to 0.5 / 1 in. (12.5 / 25.4 mm) to mount light guides and other accessories.



UMPA-4.0/QD1.9 & UMPA-4.0/QD3.0

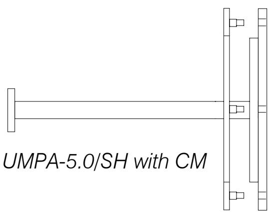
Port adapter designed for uniform light source set-ups requiring a diffuser window. The 48 mm / 1.9 in dia. (model 1.9/QD) or 76.2 mm / 3.0 in dia. (model 3.0/QD) diffuse quartz windows offer a useful wavelength range from 250-2500 nm.

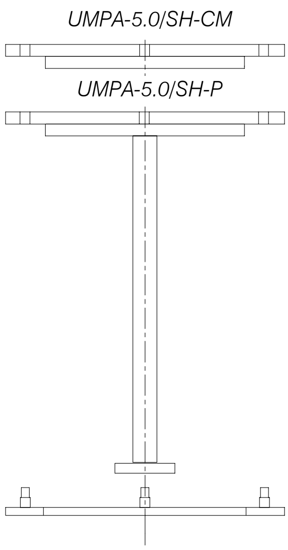


UMPA-4.0/QD1.9 UMPA-4.0/QD3.0

UMPA-5.0/SH, SH-P & SH-CM

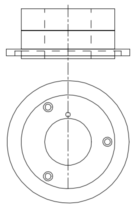
Model UMPA-5.0/SH is a universal sample holder system which fits onto the UMPF-5.0 port frame. A 101.6 mm (4 in.) diameter free aperture allows samples to be placed in front or inside the sphere. The **UMPA-5.0/SH-P** port plug can also be used for custom modifications. The **UMPA-5.0/SH-CM** adapter is used when samples should be placed in the sphere center.

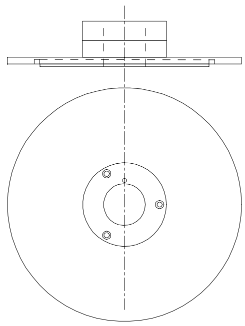




UMPA-2.0/LED5 & UMPA-5.0/LED5

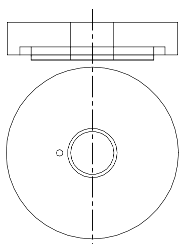
Port adapter which allows the precise positioning of LEDs mounted in the LED-5xx mount series of Instrument Systems / Munich to the entrance port of Gigahertz-Optik's integrating spheres.





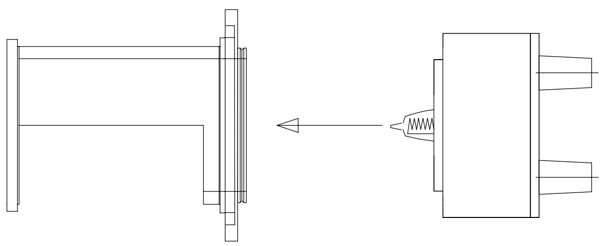
UMPA-1.5/LGA13

Port adapter to mount light guides with 13.2 mm dia. type adapter to the UM series integrating spheres.



UMPA-2.0/AXL

Port adapter to set-up an auxiliary lamp by using a LS-IS1.5-H10 external light source. The adapter includes a hemisphere baffle to protect ports and other components for direct illumination. The LS source can be direct mounted.

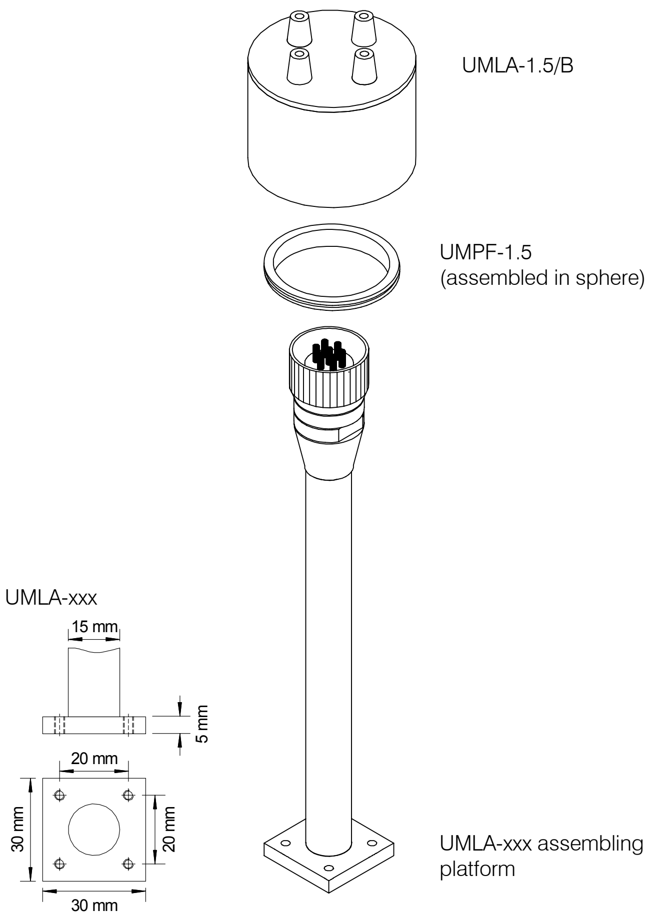


UMPA-2.0/AXL LS-IS1.5 optional

UM Series Components

Ordering Information & Specifications				
Model	**Port Frame**	**Mechanical Interface**	**Outside Diameter**	**Height**
UMPA-0.5/11	UMPF-0.5	11-type detectors & UFC fiber couplers	25.4 mm / 1.0 in.	8.5 mm / 0.34 in.
UMPA-0.5/11-RD	-	RADIN diffuser to be glued into UMPA-0.5/11	12 mm / 0.47 in.	1 mm / 0.04 in.
UMPA-0.5/F	UMPF-0.5	1 mm dia., machineable up to 12.5 mm	25.4 mm / 1.0 in.	15 mm / 0.59 in.
UMPA-1.0/F	UMPF-1.0	1 mm dia., machineable up to 25.4 mm	38.1 mm / 1.5 in.	15 mm / 0.59 in.
UMPA-1.5/LGA13	UMPF-1.5	Socket for 13.2 mm dia light guide adapter	52.6 mm / 2.1 in	10.4 mm / 0.41 in
UMPA-2.0/AXL	UMPF-2.0	Auxiliary lamp adapter with baffle for LS-IS1.5-10	65.3 mm / 2.6 in	6.4 mm / 0.25 in
UMPA-2.0/LED5	UMPF-2.0	Socket for Instrument Systems LED-5xx LED adapter	65.3 mm / 2.57 in	25.85 mm / 1.01 in
UMPA-4.0/QD1.9	UMPF-4.0	48 mm / 1.9 in dia quartz diffuser	116.1 mm/ 4.57 in	3.7 mm / 0.15 in.
UMPA-4.0/QQ3.0	UMPF-4.0	76.2 mm / 3.0 in. diameter quart diffuser	116.1 mm / 4.57 in	3.7 mm / 0.15 in
UMPA-5.0/LED5	UMPF-5.0	Socket for Instrument Systems LED-5xx LED adapter	141.5 mm / 5.57 in	25,85 mm / 1.01 in
UMPA-5.0/SH	UMPF-5.0	101.6 mm / 4.0 in free aperture sample holder base	141.5 mm / 5.57 in	4.25 mm / 0.17 in.
UMPA-5.0/SH-P	UMPF-5.0	Universal sample holder plate	141.5 mm / 5.57 in	6 mm / 0.24 in.
UMPA-5.0/SH-CM	UMPF-5.0	Universal center mount sample holder	141.5 mm / 5.57 in	6 mm / 0.24 in.

UMLA Lamp Adapter for Center Mount



UMLA lamp adapters are designed to mount lamps in the center of the integrating sphere for luminous flux or radiant power measurements.
The **UMLA-1.5/B** base offers four banana sockets for current and voltage connections to the lamp sample. It's rugged connector socket permits mounting and connection of the UMLA-xx lamp adapters. A UMPF-1.5 port frame is needed to mount the UMLA.1.5/B adapter onto the sphere.
The **UMLA-xx** lamp holders are available in different lengths for compatibility with different size spheres. It's connector positioned at the top end of the UMLA-xx allows simple connection and mounting to the UMLA-1.5/B base socket. Lamp socket is supplied and assembled by the end-user.
The **UMLA-xx** includes a lamp socket specified by the end-user as a special order. Consult factory for assistance.

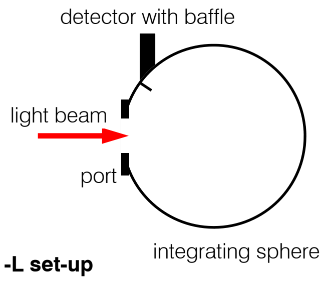
Ordering Information & Specifications		
Model	**Accessory**	**Description**
UMLA-1.5/B	UMPF-1.5	Base adapter for UMLA-xx lamp holder
UMLA-300	UMLA-1.5/B	Lamp holder for 300 mm / 12" diameter spheres
UMLA-500	UMLA-1.5/B	Lamp holder for 500 mm / 20" diameter spheres
UMLA-xx	UMLA-1.5/B	Lamp holder with lamp socket. Contact factory with detailed specs.
Lamp adapter and lamp holder for UMBB-1000 and UMBB-1600 available by request		

Precision Machined Integrating Spheres

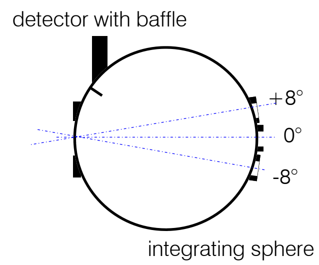
In cases where a high precision spherical form and precise alignment of sphere ports is critical, machined integrating spheres are a better choice than spheres formed out of aluminum sheets.
In smaller diameter spheres the spherical shape is important to produce a uniform light distribution inside the sphere.
Precise port alignment is a requirement in all kinds of transmittance, reflectance and absorbance measurements. Exact port positions produce optimum sample illumination and more accurate measurement of directional reflection and transmission.
Three different coatings are offered for UP Series Spheres:
1. **UPB** Barium Sulfate
2. **UPG** Gold
3. **UPK** OP.DI.MA.

Three different standard port arrangements are offered:
–L type spheres are designed for the measurement of directional emitting light sources. A knife-edge measurement port opening offers a large acceptance angle for diverging light sources. Special baffle designs prevent any direct or first reflection illumination of the detector.
–F type spheres are designed for flexible use in measurement of reflectance (8°/D), transmittance and power. The knife-edge design of the measurement port ensures that any diffuse reflected or transmitted light enters the sphere. The back side ports allow 8° sample illumination. To measure diffuse reflection, the -8° port can be opened so that directional glow radiation can pass out. Special light traps are offered. The back-side central port permits the separation of diffuse and directional transmitted light. An additional substitution port may help to reduce the substitution error during calibration and measurement. The back-side and substitution ports are supplied with coated port plugs (same coating as used in sphere).
-US type spheres for uniform light source set-up based on LEDs.

Besides catalog products, Gigahertz-Optik offers custom design modification, custom labeling and complete new product development service. Please contact the factory to

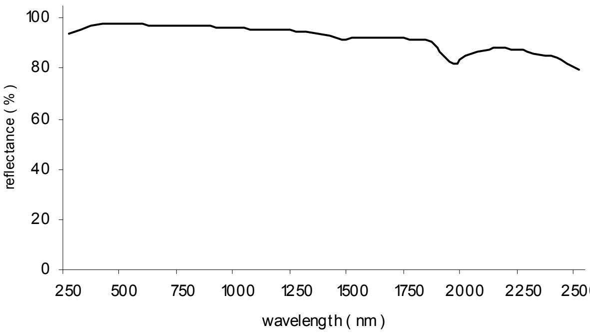


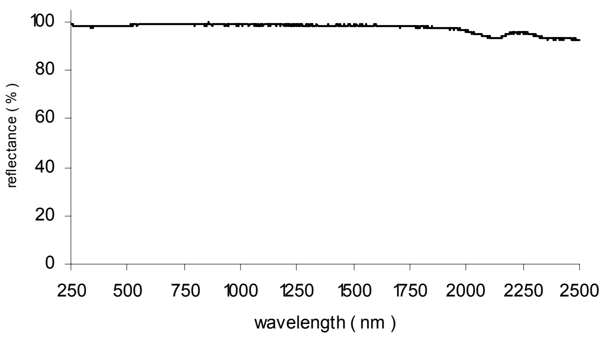
-L set-up

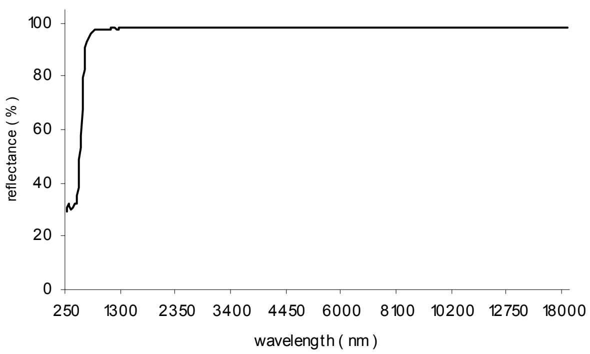


-F set-up

Coatings for UP Series







UPB: Spheres with Barium Sulfate Coating

Barium sulfate is an economical coating offering a ~ 97 % (600 nm) diffuse reflectance characteristic within the wavelength range from 300 nm to 2400 nm. For photometric applications the reflectance can be reduce to ~ 80 % to reduce substitution effects errors produced by high reflectance.

UPB-50-L

UPK: Spheres with OP.DI.MA. Coating

OP.DI.MA. is Gigahertz-Optik's own white plastic with an excellent diffuse reflectance characteristic and high durability.
Its diffuse reflectance is close to that of a perfect lambertian reflector ensuring a highly uniform light distribution across the inner walls of the integrating sphere.
The spectral reflectance covers a wide spectral range from ultraviolet to IR, 250 nm to 2500 nm with > 95 % reflectance and a peak reflectance of > 98 % in the VIS/NIR spectral range.

UPK-100-L

UPG: Spheres with Gold Coating

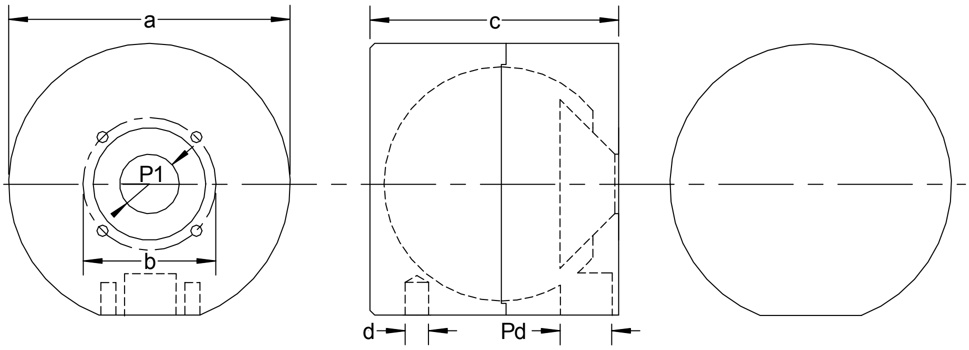
Uncoated gold outperforms all other uncoated metallic reflectors at infrared wavelengths. Gold's high reflectivity in the red portion of the visible spectrum is apparent by it's yellow hue. With a reflectance of ~ 95 % in the wavelength range from 800 nm to 20 μm, gold is the best choice for surface coating of integrating spheres used in IR applications. A proprietary interior surface preparation creates the diffuse reflectivity required for uniform light distribution inside the sphere .

UPG-75-F & ULT

Gigahertz-Optik

UP Series

Model UPB-50-L



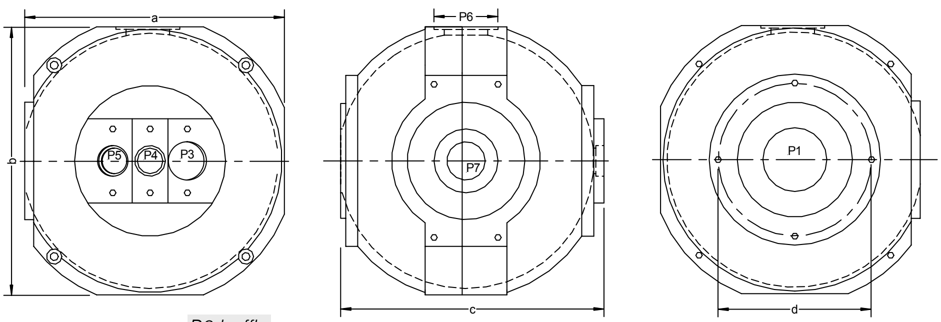
The UPB-50-L is a compact size 50 mm (2 in.) diameter integrating sphere coated with barium sulfate.
11-type detectors or 11-type fiber connectors can be directly mounted to the detector port which is baffled to prevent direct illumination from the 12.5 mm (0.5 in.) measurement port.
A threaded M6 hole are provided to mount the sphere onto a bench post.
The UP-50-L can be supplied with two detector ports to accommodate either two 11-type detectors or one detector and one UFC-11 series fiber optic adapter.

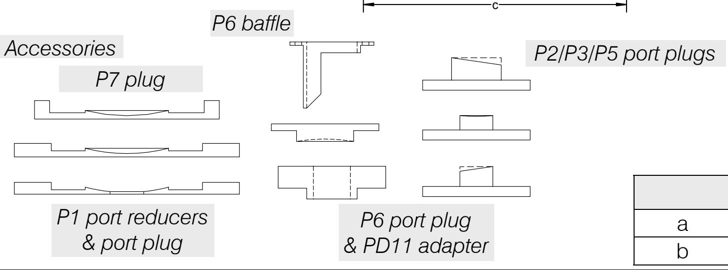
Dimensions (mm):			
a	60	c	53
b	20	d	M6

Ordering Information & Specifications					
	Sphere	Port			
Model	Dia.*)		Diameter*)	Plug	Coating**)
UPB-50-L	50 / 2	P1	12.5 / 0.5	No	BaSO4 / 97 / 300-2400
		Pd	11-type	No	
DP-11	-	Pd	11-type	No	Additional port for 11-type detectors &accessories
*) dimension in mm / in. **) type / reflectance in % / wavelength in nm					
Accessory Components: PD-11 & TD-11 detectors; **UFC-11** fiber adapter					

Model UPB-100-F

The UPB-100-F is a compact size 100 mm (4 in.) diameter integrating sphere coated with barium sulfate.
11-type detectors or 11-type fiber connectors can be directly mounted to the detector port which is baffled to prevent direct illumination from the 15 mm (0.6 in.) diameter measurement port.
The back-side +8°, 0° and –8° ports and substitution port are supplied with port plugs for universal use.
A threaded M6 hole allows post mounting of the sphere.

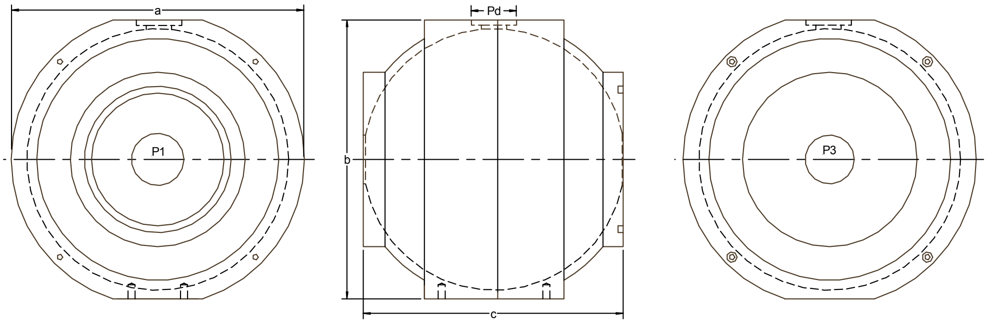




Dimensions			
a	102	c	103
b	105	d	60

Ordering Information & Specifications					
	Sphere	Port			
Model	Dia.*)		diameter*)	Plug	Coating**)
UPB-100-F	100 / 4	P1	10 / 0.39	No	BaSO4 / 97 / 300-2400
		P 3,4,5	15,10,12 / 0.59, 0.39,0.47	Yes	
		P6	17 / 0.68	Yes	
		P7	15 / 0.59	Yes	
*) dimensions in mm / in. **) type/reflectance % / wavelength nm					
UPB-100Z-F01		-	-	-	Plug-in baffle P6 to P1 or P 6 to P3/4/5
UPB-100Z-F02		-	-	-	Port reducer / plug set for P1
Accessory Components ULT: light trap for –8° port					

UPB-150-F



The UPB-150-F is a compact size 150 mm (6 in) diameter integrating sphere coated with barium sulfate.
This large diameter sphere is made exclusively to order offering complete freedom for individual design.
Contact the factory to discuss your sphere requirement.

Dimensions mm	
a	168
b	160
c	149

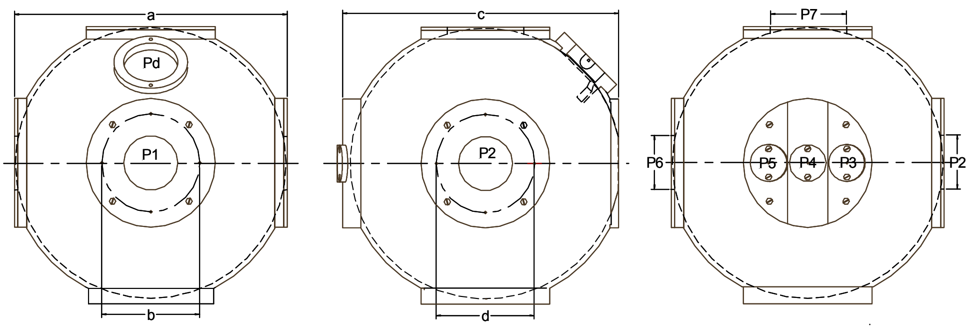
Ordering Information & Specifications

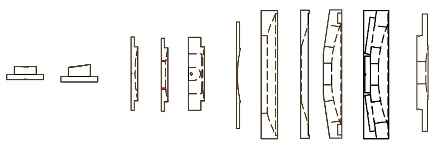
	Sphere	Port			
Model	**Dia.*)**		**Diameter*)**	**Plug**	**Coating**)**
UPB-150-F	150 / 6	P1	tbc	No	BaSO4 / 97 / 300-2400
		P2	tbc	Yes	
		P3	tbc	Yes	
		P4	tbc	Yes	
		P5	tbc	Yes	
		Pd	tbc	No	
DP-11	-	Pd	11-type	No	Additional port for 11-type detectors & accessories

*) dimensions in mm / in. **) type / reflectance in % / wavelength in nm

Accessory Components MD-11 & MDT-11 detectors; **UFC-11** fiber adapter; **ULT**: light trap.

UPB-250-F





Dimensions			
a	252	c	255
b	90	d	90

Ordering Information & Specifications

	Sphere	Port			
Model	**Dia.*)**		**Diameter*)**	**Plug**	**Coating**)**
UPB-250-F	250 / 10	P1	50 / 2	No	BaSO4 / 97 / 300-2400
		P2/6/7	50 / 2	Yes	
		P3/4/5	25 / 1	Yes	
		Pd	1	No	

*) dimensions in mm / in. **) type / reflectance in % / wavelength in nm

Accessory Components 37 & 45-type detector heads e.g. VL-37, RW-37, TD-37, CT-4501. **ULT**: light trap.

The UPB-250-F is a compact size 250 mm (10 in) diameter integrating sphere coated with barium sulfate.
37-type or 45-type detectors can be mounted to the detector port with optional adapters. The measurement port is baffled to prevent direct illumination from the 50 mm (2 in) measurement port.
The back-side +8°, 0° and –8° ports and the three substitution ports are supplied with Barium Sulfate coated port plugs for universal use.

Gigahertz-Optik

UP Series

UPB-500-F

The UPB-500-F is a 500 mm (20 in.) diameter sphere with barium sulfate coating. A wide range of accessory components are available for use on the UP-500-F making it one of the most flexible sphere designs available. CNC machined ports guarantee best possible port alignment, a requirement for precise reflectance and transmittance measurements.
Both a measurement port and a additional top port for use as a substitution or 'load' port for lamps and sample holders are provided. Both ports offer a free aperture of 150 mm (6 in.) diameter and are supplied with port reducers with 50 mm (2 in.) free aperture and knife edge design. This allows DIN 5036 and CIE 130 traceable transmission and reflection measurement of thin and thick diffuse samples! The back-side +8°, 0° and –8° ports are supplied with port plugs for universal use of the UPB-500-F.

Available accessory parts allow set-ups for:

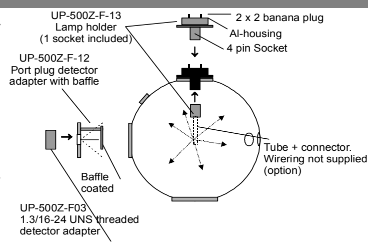
1. Reflectance measurements
2. Transmittance measurement
3. Luminous flux measurement
4. Radiant power measurement
5. Uniform light source

Please contact the factory for more detail information and pricing for your sphere set-up.

UPB-500-F Standard Accessories

The UPB-500-F offers several standard accessories for flexible set-ups. Measurement and top port apertures are 150 mm (6 in.) in diameter and can be reduced to 50 mm (2 in.) or closed with port plugs. The detector port is supplied with a port plug and a baffle plug to shield the detector from direct illumination from the measurement port. The +8°, 0° and –8° ports are supplied with port plugs.

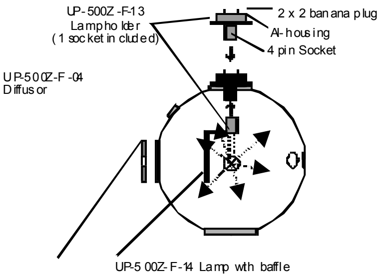
UPB-500-F Luminous Intensity/Radiant Power Set-up



The UPB-500-F can be simply set-up for luminous flux and spectral radiant power measurements with extra components. The UPB-500-F-Z13 lamp holder base fits onto the top port. A rugged connector allows both mounting and electrical connection of the lamp holder itself. Several lamp holders with different lamp sockets can be used. A baffle is provided on the **UPB-500-F-Z12** plug-in adapter for the measurement port. Detector and light guide adapters are available.

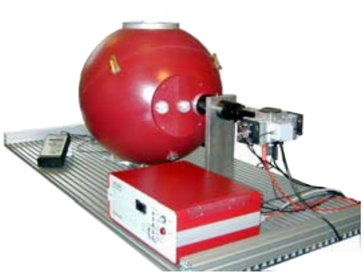
UPB-500-F Uniform Light Source Set-up

The **UPB-500-F-Z14** quartz halogen lamp combined with the **UPB-500-F-Z04** diffuser allows the UPB-500-F to be set-up as a uniform light source. A lamp holder baffle prohibits direct illumination of the diffuser window. The quartz diffuser window is 48 mm in diameter. Electrical connections are made with banana plugs mounted on the base holder.



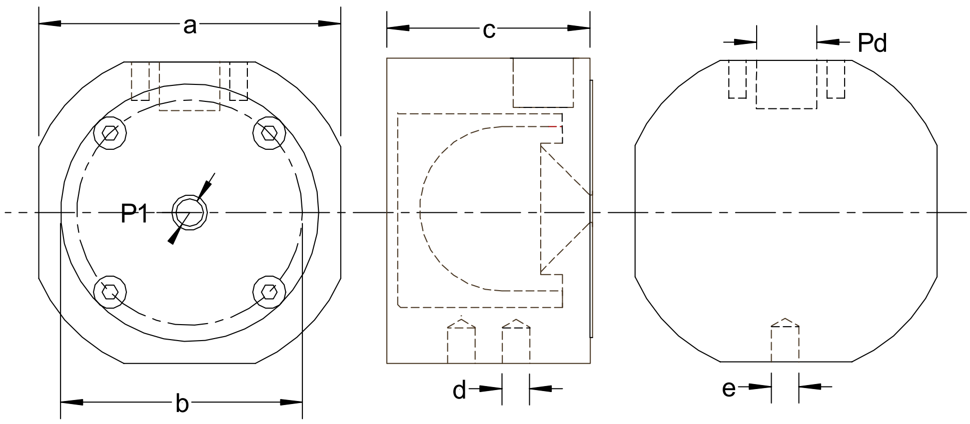
Ordering Information & Specifications:					
Model	**Sphere**	**Port**			
	Dia.*)		**Diameter*)**	**Plug**	**Coating**)**
UPB-500-F	500 / 20	P1	150 / 6 & 50 / 2	No	BaSO4 97 300-2400
		P3	50 / 2	Yes	
		P4	25 / 1	Yes	
		P5	25 / 1	Yes	
		P7	150 / 6 & 50 / 2	Yes	
		Pd	1	Yes	
*) dimension in mm / in. **) type / reflectance in % / wavelength in nm					
Accessory:					
UPB-500-F-Z01	37 mm detector adapter				
UPB-500-F-Z04	Diffuser window adapter				
UPB-500-F-Z12	Detector baffle adapter				
UPB-500-F-Z13	Lampe holder base				
UPB-500-F-Z14	100 W QH lamp with baffle (requires UPF-500-F-Z04)				
UPB-500-F-Z15	Base plate with goniometric rotating stage				

UPB-500-F Reflectance & Transmittance Set-up



DIN 5036 and CIE 130 recommend the use of an integrating sphere with different measurement port diameters for the measurement of reflectance and transmittance of diffuse and non-diffuse samples.
The **UPB-500-F** is available with two sizes of measurement port at 50 mm or alternatively 150 mm diameter free aperture. The knife edge design of the port frame guarantees the large acceptance angle required to ensure that light from all directions enters the sphere.
The **UPB-500-F-Z15** base plate is the right tool for a DIN 5036 and CIE 130 conformal set-up of a reflectance and transmittance measurement system. A rugged goniometric rotating stage holds the sphere and allows precise positioning of the entrance port or +8° port to the collimated light source (optionally available). The LS-CB-50 emits a precisely collimated beam to ensure low stray light levels in the sphere for best possible signal to noise ratio.
Along with spheres and collimated light sources Gigahertz-Optik offers power supplies, photometric and radiometric detector heads and optometers for complete measurement system set-ups.

UPK-30-L



UPK-30-L with PD-1101-2 light detector

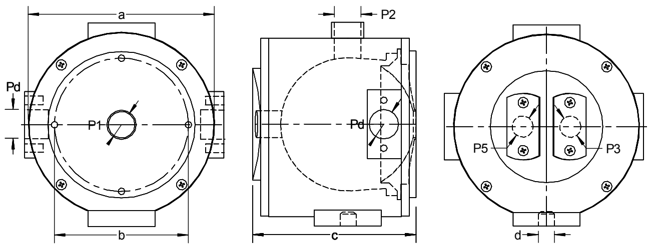
Dimensions (mm):			
a	55	c	37.5
b	41	d	M6 & 1/4”

Ordering Information & Specifications:					
	Sphere	**Port**			
Model	**Dia.*)**		**diameter*)**	**Plug**	**Coating**)**
UPK-30-L	30 / 1.2	P1	5 / 0.2	No	ODM98 / 98 / 250-2500
		Pd	1 x11-type	No	
DP-11		Pd	11-type	No	Additional ports for 11type detectors & accessories
*) dimension in mm / in. **) type / reflectance in % / wavelength in nm.					
Accessory:		**PD-11 & TD-11** detectors; **UFC-11** fiber adapter			

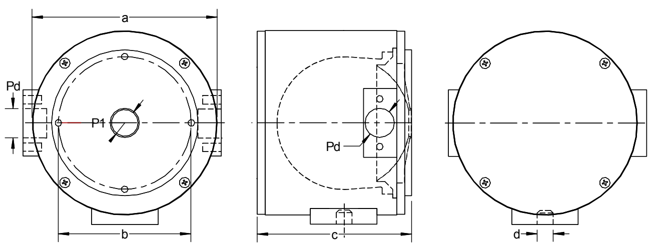
The UPK-30-L is a compact 30 mm (1.2 in.) diameter integrating sphere with OP.DI.MA. coating. The small diameter and high reflectance of 98 % in the wavelength range from 400 to 1700 nm result in a low attenuation which allows to build high sensitive sphere detectors with small area and therefore low price Si– and InGaAs photodiodes. The unique baffle design combined with the good diffuse reflectivity of ODM98 makes this sphere insensitive against different light incident angles and reduces effects by polarization and re-reflected light. One, alternative two 11-type detectors or UFC fiber connectors can be assembled.

UPK-50-F, UPK-50-L & UPK-50-ULS

UPK-50-F



UPK-50-L



Dimensions (mm):			
a	70	c	61
b	50	d	M6

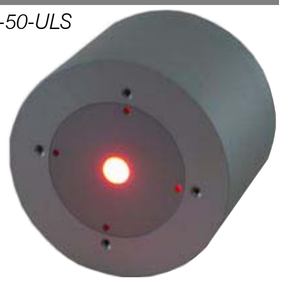
UPK-50-L

The UPK-50 is a very popular compact size integrating sphere for many radiometric and photometric applications requiring sphere mounted integral detectors or diode array spectrometers.

The OP.DI.MA. coating is highly reflective from 250 nm to 2500 nm. In combination with its small 50 mm (2 in) diameter a low attenuation factor results which makes the UPK-50 series ideal for sensitive measurement applications.

The nearly ideal lambertian reflectance characteristic of OP.DI.MA. offers best light distribution by the multiple reflections, which is very important for small diameter spheres.

UPK-50-ULS



The knife-edge and unique baffle designs plus good diffuse reflectivity enable a large measurement port acceptance angle.

Model UPK-50-L is designed to measure the intensity of directional light. One or more detectors, or alternatively fiber optics, can be adapted to the sphere to increase the wavelength range.

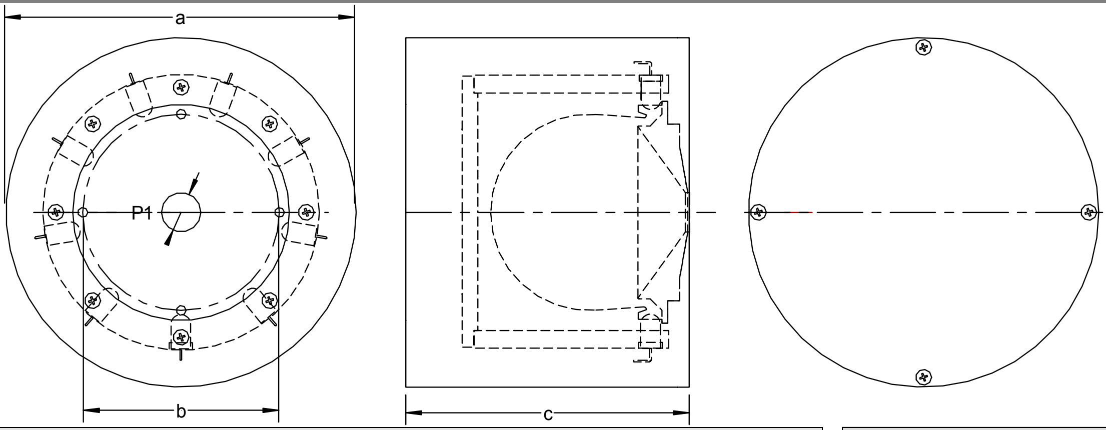
Model UPK-50-F is a more flexible version for reflectance and transmittance measurements. One or more detectors, or alternatively fibers, can be adapted to the sphere to increase its wavelength range.

Model UPK-50-ULS is designed for uniform light source set-ups using multiple standard LEDs.

UP Series

UPK-50-F,

UPK-50-ULS

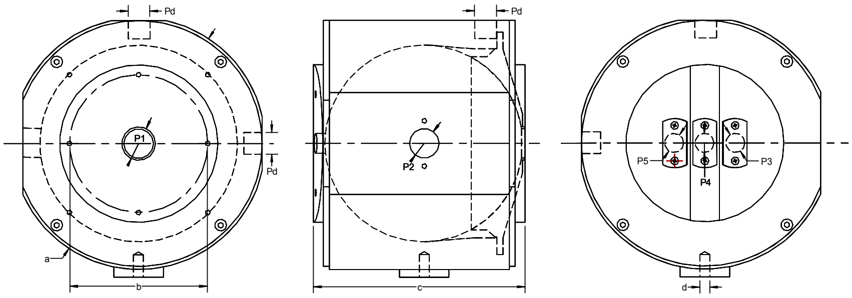


Ordering Information & Specifications:					
	Sphere	**Port**			
Model	**Dia.*)**		**diameter*)**	**Plug**	**Coating**)**
UPK-50-L	50 / 2	P1	10 / 0.4	No	ODM98 98 / 250-2500
		Pd	1 x 11-type	No	
UPK-50-F	50 / 2	P1	10 / 0.4	No	
		P2/3/5	10 / 0.4	Yes	
		Pd	1 x 11-type	No	
UPK-50-ULS	50 / 2	P1	10 / 0.4	No	
		PLED	8 x 5 mm	No	
DP-11 (only –L & -F)		Pd	1 x 5 mm	No	Additional ports for 11type detectors & accessories
*) dimensions in mm / in. **) type/reflectance %/wavelength nm					
Accessory (only –L & –F): **PD-11 & TD-11** detectors; **UFC-11** fiber adapter					

Dimensions (mm):	
a	89
b	50
c	72

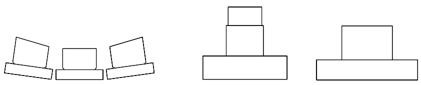
UPK-100-F & UPK-100-L

UPK-100-F



The UPK-100 is a 100 mm (4 in) diameter sphere made from machined OP.DI.MA. Its compact size and high reflectance from 250 nm to 2500 nm results in low attenuation making it suitable for sensitive measurement applications. A knife-edge and unique baffle design plus good diffuse reflectivity enable a large acceptance angle measurement port **Model UPK-100-L** is designed to measure the intensity of directional light.
Model UPK-100-F is a more flexible version for intensity, reflectance and transmittance measurements. Optional detectors or fibers can be added to both sphere models.

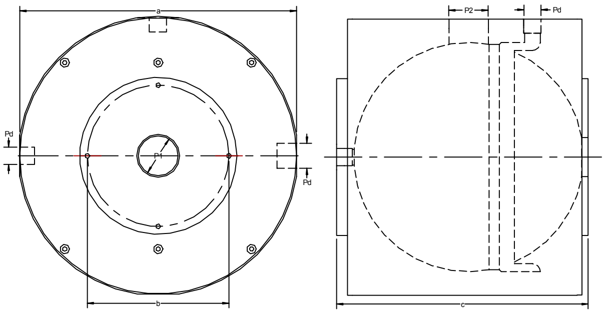
Dimensions (mm):			
a	128	c	107
b	70	d	M6



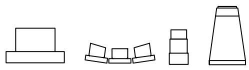
Ordering Information & Specifications					
	Sphere	**Port**			
Model	**Dia.*)**		**diameter*)**	**Plug**	**Coating**)**
UPK-100-L *)**	100 / 4	P1	15 / 0.6	No	ODM98 / 98 / 250-2500
		Pd	1 x 11-type	No	
UPK-100-F	100 / 4	P1	15 / 0.6	No	
		P2	15 / 0.6	Yes	
		P3/4/5	10 / 0.4	Yes	
		Pd	1 x 11-type	No	
DP-11		Pd	1 x 11 type	No	Additional detector port
*) dimensions in mm / in. **) type/reflectance %/wavelength nm ***) as UPK-100-F without P2,P3, P4, P5					
Accessory Components PD-11 & TD-11 detectors; **UFC-11** fiber adapter					

UP Series

UPK-150-F



Dimensions (mm)			
a	176	c	160
b	90		

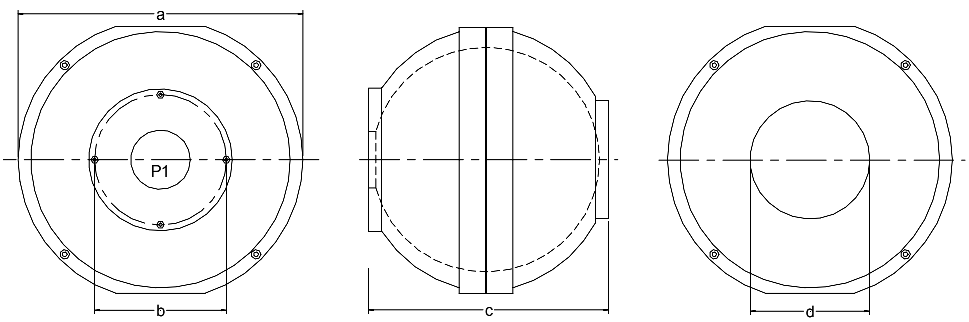


Ordering Information & Specifications:

	Sphere	Port			
Model	**Dia.*)**		**diameter*)**	**Plug**	**Coating**)**
UPK-150-F	150 / 6	P1	25 / 1	No	ODM98 / 98 / 250-2500
		P2	25 / 1	Yes	
		P3	15/ 0.6	Yes	
		P4/5	10 / 0.4	Yes	
		Pd	1 x 11-type	No	
*) dimension in mm / in. **) type / reflectance in % / wavelength in nm					
DP-11		Pd	1 x 11 type	No	Additional detector port
DP-37		Pd	1 x 37 type	No	Additional detector port
Accessory:		**MD-11 & MDT-11** detectors; **37type** detectors; **UFC-11** fiber adapter			

The UPK-150 is a 150 mm / 6 in. diameter sphere with OP.DI.MA. coating. The high reflectance from 250 nm to 2500 nm offers a low attenuation for sensitive measurement application. The knife-edge design, the unique baffle design and good diffuse reflectivity offer a large acceptance angle of the measurement port.
Large diameter ODM98 spheres are only made on order which offers all freedom in the individual design such as show in the above picture which shows a custom design sphere for reflectance measurements based on the UPK-150-F. Pls. Contact the factory to discuss your need.

UPK-190



Drawing shows a weight reduced version

Dimensions (mm)			
a	238	c	200
b	110	d	100

Ordering Information & Specifications

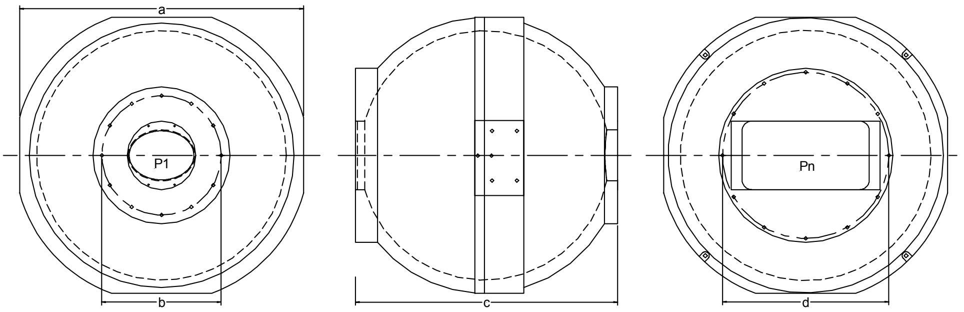
	Sphere	Port		
Model	**Dia.*)**	**Type**	**diameter*)**	**Coating**)**
UPK-190	190 / 7.5	P1 to Pn	custom	ODM98 / 98 / 250-2500
		Pd	custom	
*) dimensions in mm / in. **) type / reflectance in % / wavelength in nm				
Customization to end-user specifications				

The UPK-190 is a 190 mm (7.5 in) diameter sphere made from OP.DI.MA. Low attenuation for sensitive measurement applications or high intensity uniform light sources is made possible by ODM98's high reflectance from 250 nm to 2500 nm. The ODM98 is directly formed as a hollow sphere to reduce material and machining cost.
Large diameter ODM98 spheres are made exclusively to order offering complete freedom for individual design. Pictured is a custom designed high intensity uniform light source based around the UPK-190 sphere.
Contact the factory to discuss your sphere requirements.

UP Series

UPK-250

The UPK-250 is a 250 mm (10 in) diameter sphere made from OP.DI.MA. Low attenuation for sensitive measurement applications or high intensity uniform light sources is made possible byODM98's high reflectance from 250 nm to 2500 nm. The ODM98 is directly formed as a hollow sphere to reduce material and machining cost.
Large diameter ODM98 spheres are made exclusively to order offering complete freedom for individual design. Pictured is a custom designed sphere based around the UPK-250 sphere.
Contact the factory to discuss your sphere requirements.



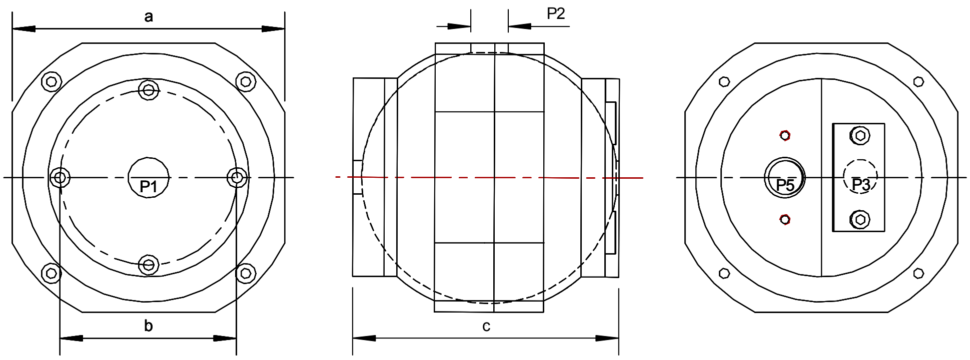
Example of UPK-250 with custom specified port layout

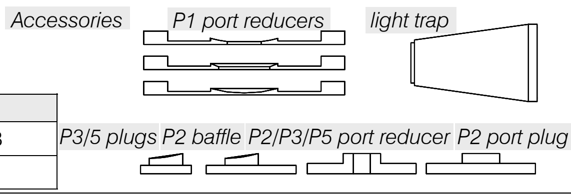
Dimensions			
a	290	c	268
b	122	d	170

Ordering Information & Specifications				
	Sphere	Port		
Model	**Dia.*)**	**Type**	**diameter*)**	**Coating**)**
UPK-250	250 / 10	P1 to Pn	custom	ODM98 / 98 / 250-2500
		Pd	custom	
*) dimensions in mm / in. **) type/reflectance %/wavelength nm				
Customization to end-user specifications				

UPG-75-F

The UPG-75-F is a 75 mm (3 in) diameter sphere with a gold coating. Its compact size and high reflectance from 1 to 20 μm provides for a low attenuation factor for sensitive measurement applications. A diffuse surface preparation offers good uniform radiation distribution inside the sphere. The knife-edge design measurement port creates a large acceptance angle .
Besides intensity measurement of directional radiation and transmittance, the +8° and –8° ports allow reflectance measurement opportunities as well. Accessory port reducers, baffles and port plugs are available.

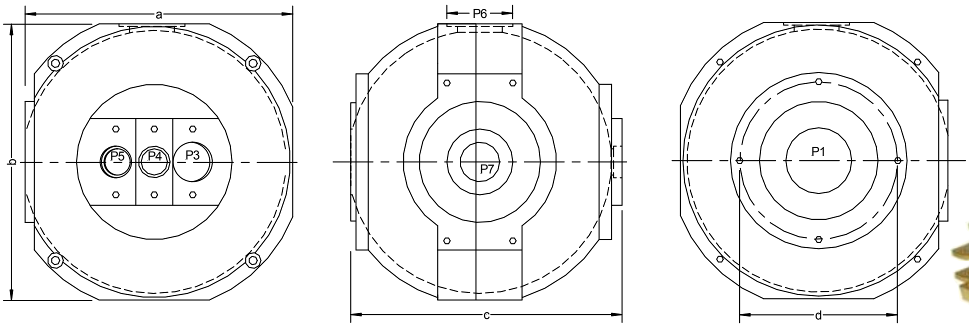


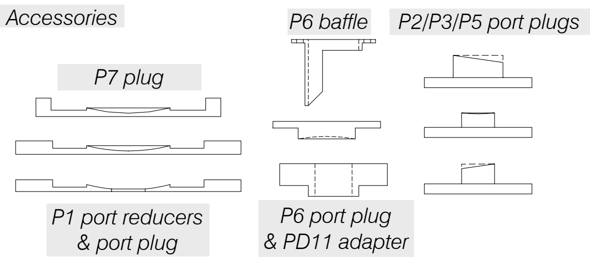


Dimensions			
a	80	c	78
b	52		

Ordering Information & Specifications					
	Sphere	Port			
Model	**Dia.*)**	**type**	**diameter*)**	**Plug**	**Coating**)**
UPG-75-F	75 / 3	P1	12 / 0.47	No	ODG95 / 95 / 1-20
		P2	11 / 0.43	Yes	
		P3/5	10 / 0.39	Yes	
UPG-75Z-01		-	-	-	Plug-in baffle port P2 to P1 or to P3/5
UPG-75Z-02		-	-	-	Port reducer set for P1, P2, P3 and P5
*) dimensions in mm / in. **) type/reflectance %/wavelength μm					
Accessory Components ULT: light trap P5 port					

UPG-100-F



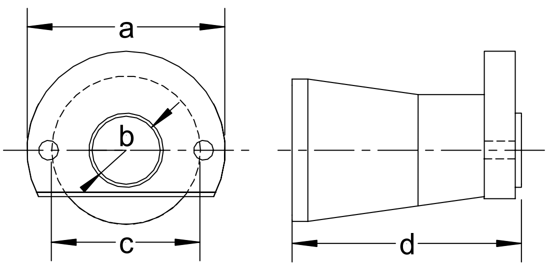


The UPG-100-F is a 100 mm (4 in) diameter gold coated sphere. Low signal attenuation is achieved through compact size and high reflectance from 1 to 20 μm for measurement applications requiring higher sensitivity. Surface preparation creates a diffuse surface for good uniform radiation distribution inside the sphere. A knife-edge measurement port creates a large acceptance angle. Besides intensity measurement of directional radiation and transmittance, the +8° and –8° ports allow reflectance measurement opportunities as well. Accessory port reducers, baffles and port plugs are available.

Dimensions			
a	102	c	103
b	105	d	60

Ordering Information & Specifications					
	Sphere	Port			
Model	Dia.*)		diameter*)	Plug	Coating**)
UPG-100-F	100 / 4	P1	10 / 0.39	No	ODG95 / 95 / 1 - 20
		P 3,4,5	15,10,12 / 0.59, 0.39,0.47	Yes	
		P6	17 / 0.68	Yes	
		P7	15 / 0.59	Yes	
*) dimensions in mm / in. **) type/reflectance % / wavelength μm					
UPG-100Z-F01		-	-	-	Plug-in baffle P6 to P1 or P 6 to P3/4/5
UPG-100Z-F02		-	-	-	Port reducer / plug set for P1
Accessory Components ULT: light trap for –8° port					

ULT Light Trap



Light traps are designed for reflectance and transmittance measurements with integrating spheres. They are used to fully absorb the directionally reflected or transmitted part of the light signal. The ULT light trap's internal design with black coating offers high absorbance with minimal re-reflected light.

Ordering Information & Specifications					
Model	**Aperture Diameter b**	**Interface**	**a**	**c**	**d**
ULT-11	11 mm	11-type	32 mm	24 mm	37 mm

UP Series

UFC, Fiber Connector Adapter

Fiber adapters are used to couple fibers with standard fiber optic connectors to integrating spheres.
The UFC-11 adapter fits all integrating spheres with 11 type interface ports.
Four different models are offered.

Ordering Information:	
Model	**Description**
UFC-11/FC	FC type adapter
UFC-11/SC	SC type adapter
UFC-11/ST	ST type adapter
UFC-11/SMA	SMA type adapter

ODP97 Barium Sulfate Paint

Coating with optional sprayer set

For touch-up repairs or self applied coating jobs, Gigahertz-Optik offers barium sulfate coating. The solution is water based for less toxicity and safer application and transport.
Please see chapter *Diffuse Reflectors* for additional information about the coating and accessories..

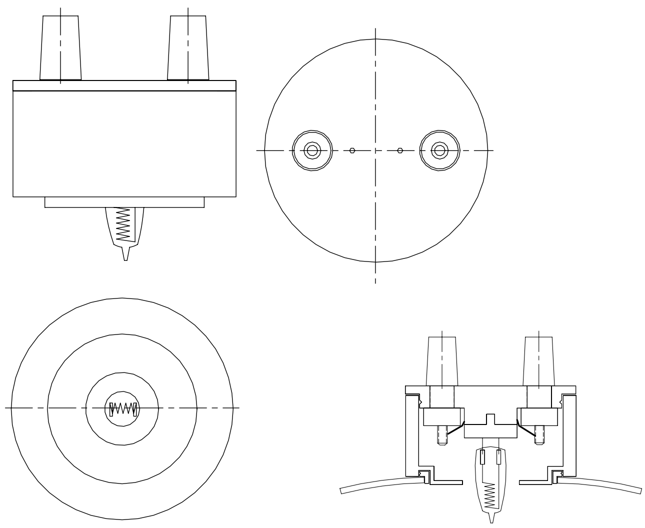
Ordering Information & Specifications:	
Model	**Description**
ODP97-1.0	Barium Sulfate Paint . 1.0 l bottle.

Accessories

Light Sources

Light sources are needed in application where integrating spheres are used as uniform light sources or in reflectance transmittance measurements. Gigahertz-Optik offers three different kinds of light sources as well as lamp power supplies and stepping motor drives for accessories used with light sources.

LS-IS1.5



Integrating spheres are the ideal tool to build uniform light sources. The most economic way to set-up a uniform light source is to place lamps inside of the hollow sphere and baffle them against the light output port.

One or more LS-IS1.5 can be mounted to the UM spheres to reach the expected luminance level at the output port.
The lamp housing of the UMLS-IS is compact and easy to assemble to one of the UMPF-1.5 port frames. The lamp exchange is simple because of the remove able cap. Different quartz-halogen tungsten lamps with 10 W to 100 W radiant power are offered. The electrical connection is done by banana jacks.
The number of lamps and their total power is limited by the max. operation temperature of the sphere. Optional fans, direct mounted to the lamp housing are offered to increase the max. power.

Ordering Information & Specification:							
Model	Power (W)	Wavelength Range (nm)	Luminous Flux lm	Color Temperature	Life Time h	Operation Voltage (V)	Operation Current (A)
LS-IS1.5	-	-	-	-	-	-	-
LH-5	5	380 - 2500	60	3000	4000	12	?
LH-10	10		130	3000	4000	12	?
LH-35	35		600	3000	4000	12	?
LH-75	75		1450	3000	4000		
LH-50	50		930	3000	4000	12	?
LH-90	90		1800	3000	4000	12	?
LH-10-UV	10		?	?	?	12	?
LH-50-UV	50	250-2500	1000	?	1100	12	?
LH-100-UV	100		2800	?	2000	12	?
Accessory: Power Supplies, Temperature stabilized detector heads,							

Accessories

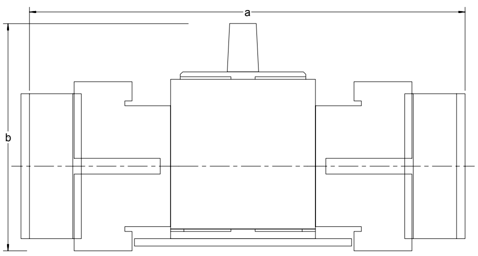
LS-OK30 Light Source Series

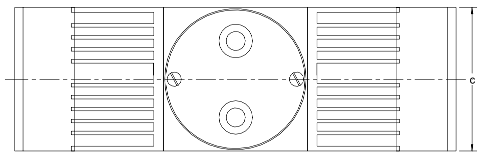
LS-OK30 assembled to UPK-190

In applications were the light output intensity of a uniform light source needs to be controlled or the light has to be spectrally filtered the light source needs to be placed outside of the sphere to allow to place a variable aperture and/or optical filter between lamp and hollow sphere.
The LS-OK offers an unique reflector design which increases the intensity and uniformity of their light output. This reflector does also work like a 'simple satellite sphere' which effects an increased uniformity.
Different lamps from 10 to 100 W radiant power are offered. The electrical connection is done by banana jacks.
Fan's, direct to the lamp housing reduces the operation temperature of the lamp socket.
LS-OK30-VA with 1:6 gear drive and **LS-OK30-MIR** with a micrometer drive work as variable attenuators if they are placed between lamp and sphere.
The **LS-OHK30-FH** filter holder fits between lamp and sphere and allows optical filters placed into the light beam of the LS-OK30. The **LS-OK30-FHI** changeable filter inserts carry 50 mm dia filters with up to 2 mm thickness.
Filter holder and variable attenuator, which can be combined as well will give a fix attenuation to the effective flux of the lamp given by the distance.

Dim.	mm / in.	Dim.	mm / in.
A	66 / 2.6	C	70 / 2.8
B	60 / 2.4	D	185 / 7.4

Accessories



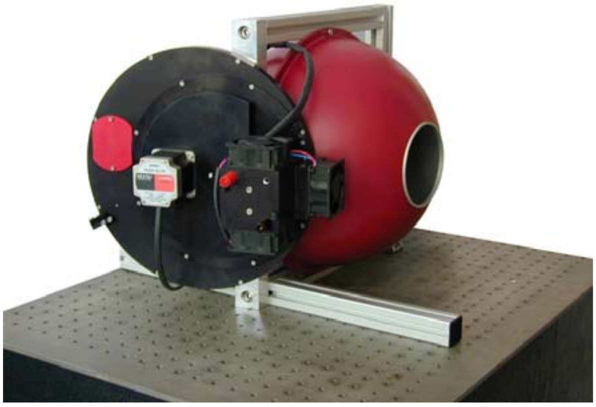


Dimensions mm			
A	271	C	90
B	141	D	

Ordering Information & Specification:

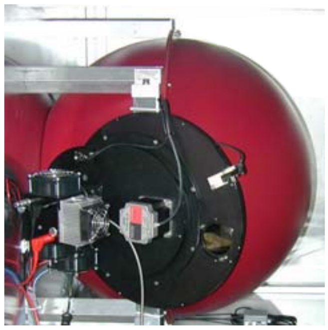
Model	Power (W)	Wavelength Range (nm)	Illuminance with 150 mm dia sphere	Illuminance with 300 mm dia sphere	Illuminance with 500 mm dia sphere	Life Time h	Operation Voltage V	Operation Current A	No. of Fan
LS-OK30	No		-	-	-	-	-	-	2
LH-5	5	380 - 2500	8.2 klx	2 klx	0.7 klx	4000	12	$I_{nominal}$	-
LH-10	10		11	2.9	1	4000	12	$I_{nominal}$	-
LH-35	35		71	17	6.5	4000	12	$I_{nominal}$	-
LH-50	50		116	28	10	4000	12	$I_{nominal}$	-
LH-75	75		183	45	16	4000	12	$I_{nominal}$	-
LH-90	90		237	58	21	4000	12	$I_{nominal}$	-
LH-10-UV	10	250-2500	16	4.1	1.5	tbc	12	$I_{nominal}$	-
LH-50-UV	50		143	35	13	1100	12	$I_{nominal}$	-
LH-100-UV	100		333	81	30	2000	12	$I_{nominal}$	-
LS-OK30-VA	Variable aperture manual controlled								
LS-OK30-MIR	Variable aperture high resolution drive								
LS-OK30-FH	Filter holder with changeable filter inserts.								
LS-OK30--FHI	Filter insert for LS-OK30-FH. Max. filter size 50 mm dia x 2 mm								

LS-OK45: Light Source Series



Ordering Information & Specification:	
Model	**Description**
LS-OK45 *)	External light source for lamps up to 250 W
LS-OK45-LG *)	Light guide adapter to couple P-9801/CT-3701 luminous color meter to LS-OK45 for color temperature controlled lamp operation for stable emission spectrum
VAM-45 *)	Remote controlled variable aperture
FWM-12/2 *)	Remote controlled filter wheel
HSS-65 *)	Remote controlled high speed shutter for typical exposure times of > 40 ms
LPS-250	Lamp power supply up to 24V / 250 W
*) Availability for System set-ups only	

In application were the light output intensity of an uniform light source needs to be controlled or the light has to be spectrally filtered the light source needs to be placed outside of the sphere to allow to place a variable attenuator and/or optical filter between lamp and hollow sphere.
The LPS-OK45 offers an unique reflector design which increases the intensity and uniformity of their light output.
Quartz halogen lamps up to 250 W can be used in the LS-OK45. Fans with an effective heat conduction effect a low temperature for long lamp operation time.
The lamp can be adapted direct to UM integrating spheres with the UMPF-LSOK45 port frame.
Additional accessories such as a remote controlled filter wheel, remote controlled variable aperture, remote controlled > 40 ms shutter and a filter holder allow the manipulation of the light intensity and lamp emission spectrum.
In combination with the remote



controlled lamp power supply LPS-250, stepping motor drive SMC-01, light– and color meters, supplied by Gigahertz-Optik, complete remote controlled uniform light sources and standard lamps can be build.

Because of the set-up complexity of high intensity large dynamic range light sources please contact the factory to discuss your need and offer the best possible system solution for your application.

LS-CB: Collimated Beam Light Source

LS-CB18 with UPK-150-F in a set-up for reflectance measurements

LS-CB50

Collimated light sources are needed in transmission and reflectance measurements.
The LS-CB18 and LS-CB50 are designed with different diameter lenses which allow light beam diameters for small or large diameter integrating spheres.
The LS-CB18 offers a maximum 18 mm / 0,71 inch diameter beam which is useful for integrating spheres up to 200 mm / 8 inch diameter.
The LS-CB50 offers a maximum 50 mm / 2 inch diameter beam which is useful for integrating spheres up to 500 mm / 20 inch diameter.
The beam diameter of both light sources can be reduced for individual system set-ups.
The precise aperture in combination with the achromatic corrected optics and several stray light baffles ensures a precise light beam without diffraction stray light.
A temperature stabilized reference detector, with beam splitter in the collimated beam offers the possibility of precise light intensity operation in combination with our lamp power supplies.
Please contact the factory or your local representative to discuss your need.

Ordering Information & Specification:	
Model	**Description**
LS-CB18	Light source with 18 mm diameter beam for reflectance transmittance measurements
LS-CB50	Light source with 50 mm diameter beam for reflectance transmittance measurements
LPS-250	Lamp power supply up to 24V / 250 W. RS232 und RS485 interface

Accessories

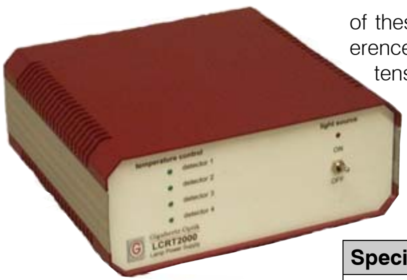
LPS-250 Lamp Power Supply

The LPS-250 Lamp Power Supply is specially designed to operate lamps in the power range up to 250 W which are used in uniform light sources, collimated light sources and as calibration standard lamps.
The power supply can be operated in current controlled or light intensity controlled mode. In the light intensity controlled mode a reference detector is needed which can be connected to the signal input at the BNC-socket on the back side.
The LPS-250 offers a **16 bit D/A converter** which allows a precise current set-up of 0.3 mA. The current set-up can be manually controlled at the front panel or alternative by the RS232 or RS485 interface.
For long lamp life time the LPS-250 offers a adjustable ramp function in on and off mode.
All electrical connectors are offered on the back side which makes the LPS-250 useful for rack mount applications.
The stand alone 1/2 19” case of the LPS-250 can be build into the **BTH-19/2** 1/2 width 19” rack-mount housing which accept one LPS-250 case.
The **LPS-250** is designed for lamps up to 270 W at 160 to 240 VAC or up to 150 W at 85 to 160 VAC main voltage whereas the **LPS-250-A** offers 270 W from 100 to 240 VAV and 220 W from 85 to 100 VAC.

Specifications LPS-250 & LPS-250-A	
Output Power LPS-250	Main Voltage 160 VAC to 240 VAC: 270 W, 0 to 15 ADC, max. 26 VDC
	Main Voltage 85 VAC: 150 W, 0 to 15 A, max. 26 V
Output Power LPS-250-A	Main Voltage 100 VAC to 240 VAC: 270 W, 0 to 15 ADC, max. 26 VDC
	Main Voltage 85 VAC: 220 W, 0 to 15 A, max. 26 V
Resolution of Lamp Current	0.3 mA
Temperature Stability	+/- 0.3 mA / °K
Warm-up Stability	+/- 1 mA (30 minutes after switch on of output current, constant environmental) for 8 hours
Display	LCD-Graphic Display 97 x 32 Pixel Display Size 14.3 x 35.8 mm LED Backlight (switch on/off) Text Display 4 lines each 14 characters
Manual Use	3 buttons (enter, menu, up/down, Backlight on/off
Interface	RS232 or RS485: 19200 Bd, 8D, 1S, N
Main Voltage	85 VAC to 240 VAC (main voltage depending output power!)
Temperature Range	Operation: 10 to 35 °C Storage: 5 to 50 °C
Size	3HE, 42TE, Depth 236.5 mm
Weight	3 kg
Specifications BTH-nn	
Size	
Weigt	.. kg (without LPS-250)
Color	

Ordering Information	
LPS-250	Lamp power supply for manual and remote controlled operation.
LPS-250-A	Lamp power supply for manual and remote controlled operation.
BTH-19/2	Bench top housing for one LPS-250 module

LCRT-2000 Lamp Power Supply



The LCRT-2000 Lamp Power Supply is designed to operate lamps up to 10 W power. It can be operated in current controlled mode or light intensity controlled mode (requires a reference detector). The LCRT-2000 allows temperature stabilization of four external detectors at +40 °C to avoid drift effects due to ambient temperature instability. One of these detectors may be a reference detector for the light intensity control mode of the LCRT-2000. An additional output voltage for a cooling fan at the external lamp is available.

Features:

- ramp mode on lamp power up and down
- LED operation indentification of the detector temperature stabilization
- LED operation identification of the lamp
- fine tuning of the lamp current fine tuning of the light intensity

Specifications	
Main Voltage	88-132 and 170-264 VAC / 47 – 63 Hz
Output power	12 V lamps up to 10 W
Operation/Stability	Current controlled mode / sensor current ≤ 2.5 * 10^{-3} /°K
	Light intensity controlled mode / lamp current ≤ 1.5 * 10^{-3} /°K
ON/OFF	Ramp function (ca 40 sec.)
Output signals	4 x heating output for external detectors (ea. 2 W)
	Fan (12 V DC)
Dimension	185 x 80 x 175 / 7.3 x 3.2 x 6.9 in (width x height x depth)
The LCRT-2000 configuration is individually set-up based on the application its ordered for!	

Ordering Information	
LCRT-2000	Lamp power supply in individual operation mode factory set-up. 115/230 V / 50/60 Hz

SMC-01 Stepping Motor Controller

Specification:	
Main Voltage	230 VAC +/- 10 %, 50 to 60 Hz 120 VAC +/- 10 %, 50 to 60 Hz
Interface	RS 485 or RS 232
Output Channels	4
Max. Current	1500 mA per Channel
Motor Type	2-Phase Stepping Motor (bi polar)
Interface Type Motor	RJ45
Size	3 HE,42 TE, Depth 236.5 mm
Weight	3 kg
Temperature	Operation: 10 to 35 °C Storage: 5 to 50 °C
Specifications BTH-19/2	
Size	
Weight	
Color	

The Stepping Motor Controller SMC-01 offers remote controlled operation of up to four 2-phase stepping motors. Its specially designed to operate the filter wheel FWM-12/2 and the variable aperture VAM-45. Together with the Lamp Power Supply LPS-250 and Optometer P-2000 or P-9801 the SMC-01 is the right tool to set up fully remote controlled uniform light sources.
Beside that application the SMC-01 can be used for custom set-ups with linear and rotary stages.
Special features of the SMC-01 are:

- micro steping
- automatic ramp function with program able parameters
- user specified ramp parameter
- RS 485 or RS 232 interface

Because of the custom design status of such set-ups please contact the factory to discuss your need and offer the best possible system solution for your application.

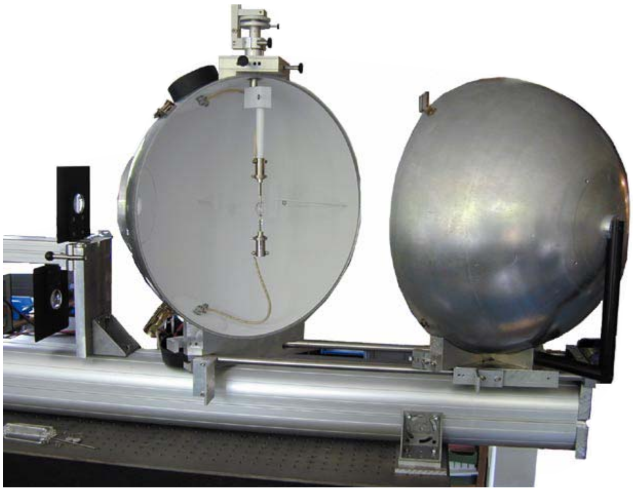
Ordering Information	
SMC-01	Four channel stepping motor controller in 1/2 19”.
BTH-19/2	Bench top housing for one LPS-250 module

Custom Design Sphere Systems

Gigahertz-Optik offers full custom design for application set-ups based on integrating spheres.
This service includes:

- Integrating spheres in custom design configuration
- OEM design integrating spheres
- Uniform light source set-ups manually controlled
- Uniform light source set-ups remote controlled
- Luminous Flux measurement systems for lamps
- Radiant Power measurement systems for lamps
- Luminous Flux measurement systems for LEDs, back-light panels. displays
- Luminance Standards
- Spectral Radiant Standards
- CIE conform Light Transmission measurement systems
- CIE conform Light Reflectance measurement systems
- Your request

Custom Luminous Flux & UV-A Radiant Power Measurement System



Custom Luminous Flux, UV-A Radiant Power & Luminance Measurement System

Custom Integrating Sphere with OP.DI.MA. Coating

Custom Light Transmittance Measurement System for Large Size Windows

Universal Light Reflectance and Light Transmittance Measurement System with 50 cm / 20 inch Diameter

Essentials of Reflection

Reflection describes the redirection of optical radiation when it reaches a boundary between two different media. A basic distinction is drawn between diffuse and specular reflection.

In **diffuse reflection**, the reflection of directional incoming radiation flux is scattered in many directions. This is caused by roughness at the boundary surface where the ***roughness is of the same order of magnitude as the wavelength***. Lambert's cosine law applies, to a good approximation, to perfectly diffusing surfaces. This law states that the radiant intensity I at the emission angle e of a perfectly diffusing surface A of radiance L has a magnitude given by $I = L\ A \cos e$. It follows that the radiance of a ***Lambert surface*** is the same in all directions. Such a completely matte, white material scatters evenly in all directions, reflecting (transmitting) the radiation independently of the angle, and has a reflection factor (transmission factor) with the value 1.

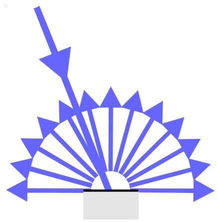
Directed or **specular reflection** results when the roughness of the boundary is small in comparison with the wavelength of the reflected radiation. According to the law of reflection which applies in this case, the angle of the incident and reflected rays form the same angle with the normal in reference to the reflecting surface at the point of incidence. The angle α is known as the angle of incidence, and the angle α' is known as the angle of reflection.

Reflectance describes the relationship of the reflected radiation power (luminous flux) to the incident radiation power (luminous flux). When the reflectance is the same for all wavelengths this is known as ***non-selective reflectance***. If the reflectance of a boundary surface depends primarily on the wavelength, or if reflection only takes place at in a very narrow range of wavelengths, the reflectance is selective.

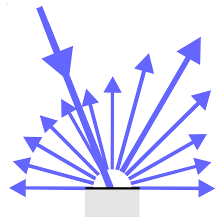
Diffuse Reflecting Surfaces are required in applications where light needs to be nearly perfectly diffusely reflected independent of its incident angle to the surface. Typical applications are:

- Integrating spheres used for luminous flux and radiant power measurements
- Integrating spheres used for uniform light sources
- Diffuse reflectance standards for uniformity calibration of imaging sensors
- Diffuse reflectance standards for reflectance measuring systems
- Calibration standards for light based remote control systems
- Calibration standards for optical distance sensors
- Large area reflectors for uniform back lighting
- Projection screens

Standard forms and sizes are available as described in this chapter. Gigahertz-Optik also offers full custom service for machined parts and surface coatings.



Ideal diffuse reflection (Lambertian surface)

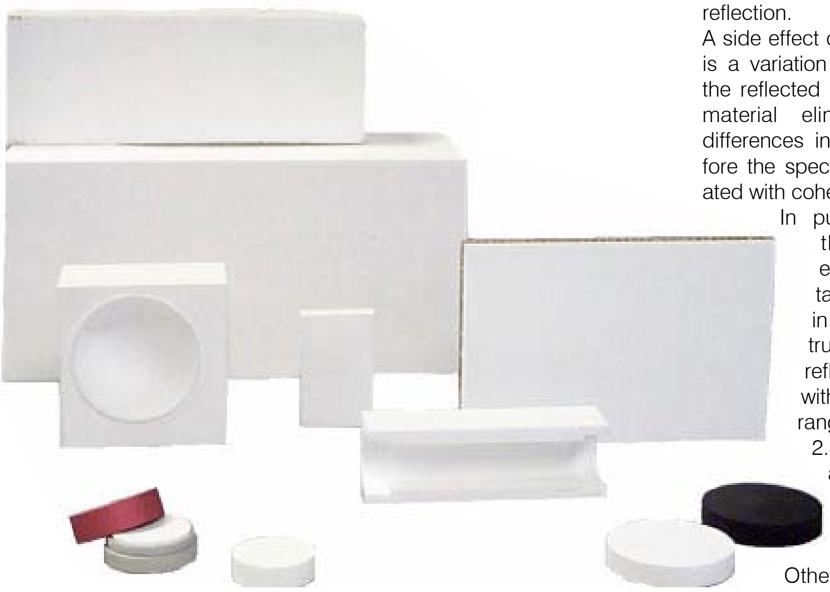


Diffuse reflection with directional component

Table of Contents						**Page**
Model	Type	Wavelength Range	Reflectance %	Size mm	Size inch	Specification
ODM: Optical Diffuse Material (OP.DI.MA.)						
OP.DI.MA. Optical Diffuse Material: General Description and Specifications						124-126
ODM98-B01				200 x 200 x 200	7.8 x 7.8 x 7.8	
ODM98-B02				120 x 120 x 250	4.7 x 4.7 x 9.8	
ODM98-B03				120 x 120 x 120	4.7 x 4.7 x 4.7	
ODM98-B04				65 x 65 x 500	2.5 x 2.5 x 19.6	
ODM98-B05			98 @ 555 nm	65 x 65 x 245	2.5 x 2.5 x 9.6	
ODM98-B06				65 x 65 x 120	2.5 x 2.5 x 4.7	
ODM98-B07	Raw Block Material	250-2500 nm		170 dia x 190	6.6 dia x 7.4	
ODM98-B08				76 x 76 x 250	2.9 x 2.9 x 9.8	
ODM50-B11			50 @ 555 nm	65 x 65 x 150	2.5 x 2.5 x 5.9	126-127
ODM03-B11			3 @ 555 nm	65 x 65 x 150	2.5 x 2.5 x 5.9	
ODM98-B13			98 @ 555 nm	52 dia x 250	2.0 dia x 9.8	
ODM98-P01				520 x 260 x 12	20.4 x 10.2 x 0.47	
ODM98-P02				310 x 310 x 12	12.2 x 12.2 x 0.47	
ODM98-P03	Raw Plate Material	250-2500 nm	98 @ 555 nm	260 x 260 x 12	10.2 x 10.2 x 0.47	
ODM98-P04				135 x 135 x 12	5.3 x 5.3 x 0.47	
ODM98-P05				55 x 55 x 12	2.1 x 2.1 x 0.47	
ODMxx-P01	Raw Plate Material gray scaled	250-2500 nm	xx @ 555 nm Availability on request	520 x 260 x 12	20.4 x 10.2 x 0.47	
ODMxx-P02				310 x 310 x 12	12.2 x 12.2 x 0.47	

Table of Contents / OP.DI.MA. Optical Diffuse Material

General Description



OP.DI.MA. is a plastic material which works as a volume reflector. This means that radiation reflects from many boundaries within the material itself. This results in a nearly perfect diffuse reflection.

A side effect of volume reflection is a variation in transit times of the reflected radiation within the material eliminating constant differences in phase and therefore the speckling effect associated with coherent radiation.

In pure form, 10 mm thick OP.DI.MA. exhibits a reflectance of up to 98.5% in the visible spectrum and a minimum reflectance of 93% within the wavelength range from 250 nm to 2.5 μm. Additives allow a reduced graduation in reflectance from 98.5% to 2 %.

Other properties of OP.DI.MA. include a maximum operating temperature of up to 280° C, insolubility in water and resistance to UV degradation.

The surface of the material can be re-machined and cleaned prolonging its operational life.

Careful selection of the base material and execution of the manufacturing process inhibit the occurrence of fluorescent effects.

Of course, these outstanding properties are accompanied by some limitations: the material can only be manufactured in block form. This generally necessitates performing cutting operations to shape the material to the desired form. As a volume reflector, the reflection factor depends on the material thickness. The material can not be applied as a coating so successful use of ODM requires correct implementation and processing strategy.

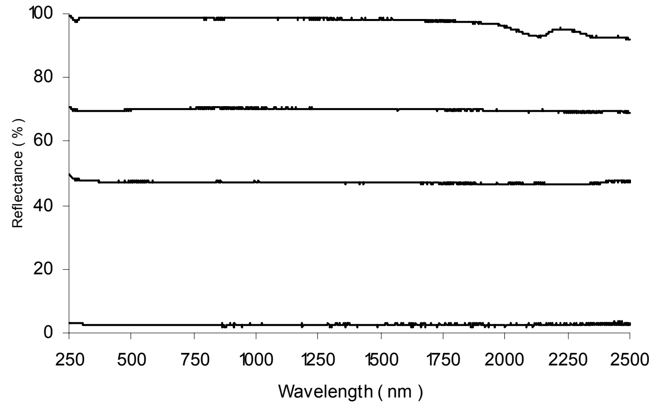
This chapter provides assistance for the proper application of ODM.

Please contact the factory for personalized service.

OP.DI.MA. Optical Diffuse Material

Specifications

OP.DI.MA. Reflectance - 10 mm thick



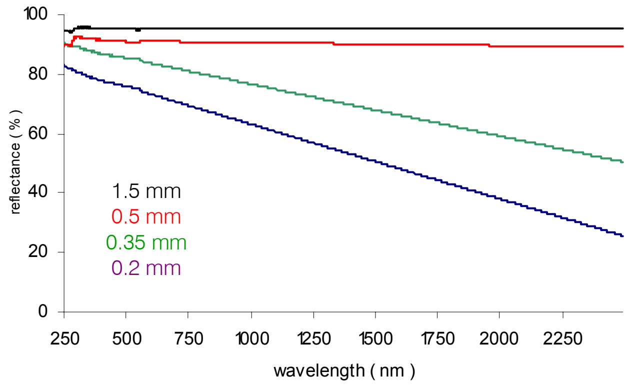
ODM98 is OP.DI.MA. in its purest form offering the highest possible reflectance.
A reflectance of 98% +/- 1% is specified in the visible wavelength range from 400 to 800 nm, whereas a minimum reflectance of 93 % is specified within the entire useful wavelength range from 250 nm to 2.5 μm.
Level and quality of reflectance depends on material properties, surface conditions and thickness. Any mechanical abrasion of the surface may result in specular reflections. Also, penetration by volatile substances alters ODM98's reflective behavior. The adverse optical effects caused by surfaces soiled from grease (fingerprints) or oil are similar to those of other optical components. If the surface cannot be cleaned using distilled water (without pressure), material must be removed. After cleaning with water or if it is suspected that liquids have been absorbed into the material, the plastic must be baked.
ODMxx Gray Scale OP.DI.MA. (xx = reflectance value) is produced by using an appropriate additive in different quantities. Reflectance values down to a minimum of 2% are possible. Gigahertz-Optik offers gray-scale OP.DI.MA. from deep black (ODM03) to brilliant white (ODM98). Available shapes and sizes supplied on request.

OP.DI.MA. Reflectance - less than 10 mm thick

Light is partially reflected within the material itself. As a result, a minimum thickness of 10 mm is recommended to obtain the optimum reflectance as specified.
A 10 mm minimum thickness is also recommended for all types of reflectance standards.
In some applications OP.DI.MA. less than 10 mm thick is required. Examples are:

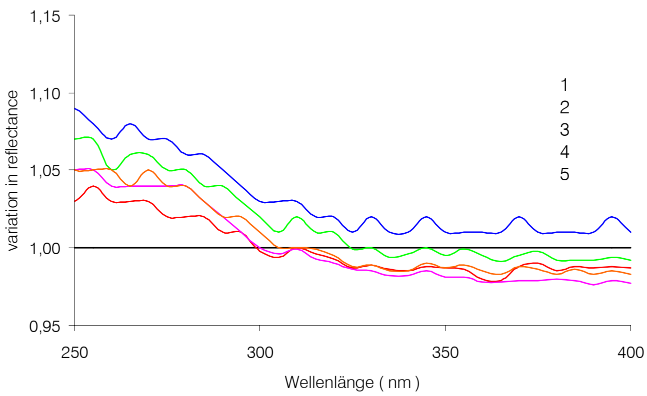
- Replacement of printed cardboard reflectance standards
- Knife-edge integrating sphere port design
- Large size reflectors
- Diffuser windows

As a is a volume reflector, OP.DI.MA. reflectance decreases with thickness.
But since about 70% of the reflectance in the visible spectrum is accomplished within the first few hundred micrometers of the material, the slight reduction is acceptable for many applications .



OP.DI.MA. spectral reflectance as a function of thickness

Ageing Characteristics



The anti-ageing characteristic of OP.DI.MA. is one deciding criteria for its selection above other materials in many applications. Its fundamental long term stability results from the basic material itself, in association with a careful manufacturing process employing ISO 9001 certified Quality Management, and has no real limitations. Quantitative data on UV resistance is only provisional, because of the many factors which actively influence practical applications. One test, as shown in the adjacent graph, shows an ageing test on an OP.DI.MA. reflection standard with a 420 W halogen-metal vapor lamp operating in the 250 to 400 nm wavelength range. Field reports involving applications using high-powered pump chambers, excimer lasers and on-line fluorescence sensors confirm minimal ageing under exposure to UV.
Other factors of a proprietary nature involving material handling are also responsible for the good ageing characteristics.

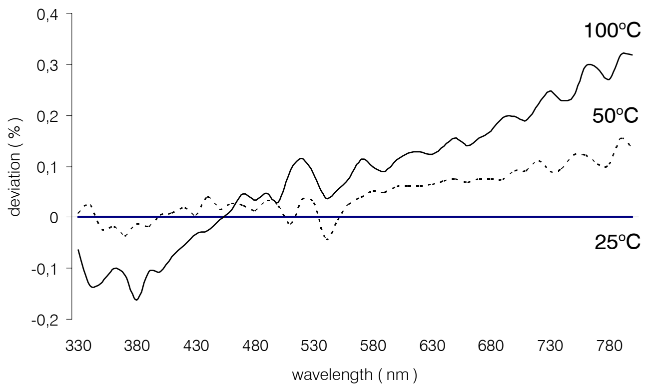
Typical changes in reflectance resulting from UV radiation with a 420 W halogen-metal vapour lamp ((ULTRATECH 400/OSRAM). (1) = Beginning of measurement, 2) = 15 min, 3) = 2 hrs. 4) = 5 hrs., 5) =7 hrs.. After about 100 hours of ageing the characteristic output was approximately reached. This result agrees with the research results from the NPL (UK) for this kind of material.

Maximum Permissible Radiation Flux Density

The maximum permissible radiation flux density for OP.DI.MA. can, like many other parameters, only be described through particular examples.
In a series of tests an ODM reflection standard was exposed to pulsed laser radiation. The wavelength of the laser was 1064 nm, the focus diameter 200 μm, the pulse length 200 μs, the repetition rate 25 Hz and the mean power was 21 W. The peak power of 4.2 kW resulting from this, representing a radiation flux density of 13.3 GW/m^2 did not yield any detectable alterations. Surface impurities were removed by the laser itself at the start of the test series.

OP.DI.MA. Optical Diffuse Material

Temperature Behavior



Typical change in spectral reflectance vs. temperature. The spectral reflection factor at 25° C is represented by the reference line.

OP.DI.MA. is capable of operating in high temperatures up to 280° C. This allows the material to be used in intense applications environments. Investigations of the reflection factor dependency on the operating temperature indicate that it is highly stable.
The adjacent graph shows that the reflection factor during temperature cycles from room temperature up to +100° C remains stable. In fact the measured deviation was within the repetition accuracy of the experimental set-up used. Using temperature cycles up to +170° C the second diagram shows a constant change in the reflection factor of about 1%. Thus it is recommended for applications involving high operating temperatures that the material be subjected to an appropriate stabilization process.
Of course, at very high temperatures, the mechanical stability of all plastics must be considered.

ODM - Optical Diffuse Material

Machining OP.DI.MA. is not difficult for those with some experience with processing plastics. All machining methods such as lathe work, drilling, sawing, milling, etc., are possible. Block material for customer processing is presented later in this chapter.

Cleaning

OP.DI.MA. is chemically inert, and is stable against acids, bases and other organic solvents. A special manufacturing process also gives it high mechanical stability. These properties mean that dust, for instance, can be removed with paper tissues (lint-free, no pressure). Other impurities can be removed with water/alcohol mixtures or with methylene chloride or hexane (hexane is appropriate for organic impurities). When cleaning with solvents, these penetrate into the micro-porous (amorphous) structure of the plastic. After cleaning, which can, for instance, be carried out using solvent-soaked paper tissues, the plastic must be "baked" at a temperature near the solvent's boiling point. Scratches and "polished" areas which diminish the reflective properties can be removed by removing the top layer with fine-grained abrasive paper. It is recommended that calibrated reflection standards be re-calibrated after cleaning.

Specifications

ODM98		
Density	g/cm^3	1.5
Hardness	Shore D	30-40
Max. Operating Temp.	°C	280
Coefficient of Thermal Expansion		$75\text{-}150 \cdot 10^{-6}$
Thermal Conductivity	kcal/mh°C	0.2
Resistivity (DIN 53482)	Ωcm	10^{16}
Water Solubility*		insoluble
Resistance to Chemicals		high**

Reflectance			
Material	Reflectance % @ 555 nm	400-800 nm	250-2500 nm
ODM98	98	98 % +/- 1 %	min. 93 %
ODM70	70	70 % +/- 5 %	-
ODM50	50	50 % +/- 5 %	-
ODM25	25	25 % +/- 5 %	-
ODM03	3	3 % +/- 1.5 %	-

*Material is porous, reflectance properties will change with absorption of liquids **A list of materials which OP.DI.MA. is resistant to is available

ODM-B & ODM-P: Raw Block and Raw Plate Material

OP.DI.MA. is produced in raw blocks and raw plates.
Gigahertz-Optik or "do-it-your-self" customers can manufacture the desired end product by machining these blocks and plates.
For fast lead times on small quantities, Gigahertz-Optik keeps various standard sizes in stock.
Along with the **ODM98** high reflectance grade material a smaller selection of **ODM gray scale** raw stock is available.
Subject to a minimum batch size, other block dimensions can be produced on custom order. This allows block dimensions to be more appropriately adapted to the dimensions of the end product, thus reducing waste.

Please contact our technical sales department to discuss your application requirements.

OP.DI.MA. Optical Diffuse Material

Ordering Information & Specifications

Raw Block Material		Raw Plate Material		Reflectance		
Model	**min. Dimension (mm)**	**Model**	**Dimension (mm)**	@ 555 nm	400-800 nm	250-2500 nm
ODM98-B01	200 x 200 x 200	**ODM98-P01**	520 x 260 x 12	98	98 +/- 1 %	min. 93 %
ODM98-B02	120 x 120 x 250	**ODM98-P02**	310 x 310 x 12			
ODM98-B03	120 x 120 x 120	**ODM98-P03**	260 x 260 x 12			
ODM98-B04	65 x 65 x 500	**ODM98-P04**	135 x 135 x 12			
ODM98-B05	65 x 65 x 245	**ODM98-P05**	55 x 55 x 12			
ODM98-B06	65 x 65 x 120					
ODM98-B07	170 dia. x 190					
ODM98-B08	76 x 76 x 250					
ODM98-B13	52 dia. X 250					
ODMxx-B11	65 x 65 x 150	**ODMxx-P01**	520 x 260 x 12	*)	Typical Values	-
		ODMxx-P02	310 x 310 x 12		70 % +/- 5 %	-
		ODMxx-P03	260 x 260 x 12		50 % +/- 5 %	-
		ODMxx-P04	135 x 135 x 12		25 % +/- 5 %	-
		ODMxx-P05	55 x 55 x 12		3 % +/- 1.5 %	-

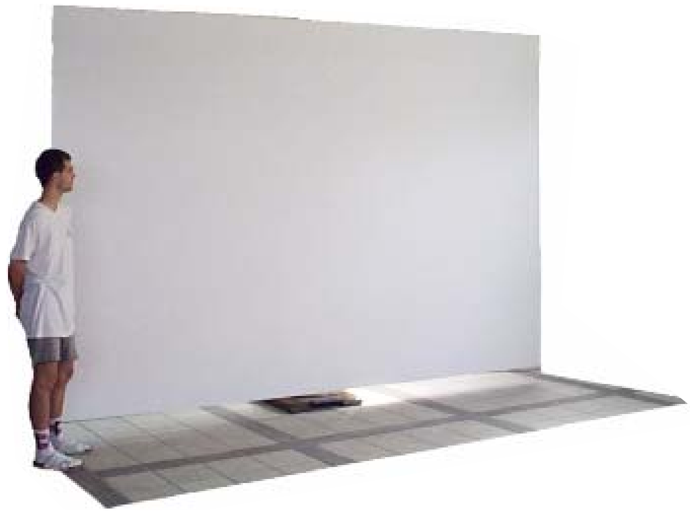
**) available in different gray scale reflectance values. Please contact the factory for stock status*

Raw Foil Material

In addition to its high reflectance and its diffuse reflectance characteristic, a further advantage of OP.DI.MA. is the high level of uniformity of these parameters. This makes it an appropriate material for the construction of large-area diffuse reflectors. A few examples of the many applications of this type are white-comparison standards in opto-electronic scanner systems, projection screens in large viewing angle applications, and white standards for image processing systems. The differing reflecting ray transit times associated with a volume-diffusing material reduces laser speckling effects.

Gigahertz-Optik offers OP.DI.MA. foil sheets with a material thickness of 1.5 mm which can be bonded to a substrate. The example application shown is a projection screen about 3 m x 4 m in size.
Another application for these sheets is coating the inner surfaces of large diameter integrating spheres (Ulbrichtsche Kugel).

To learn more about ODM, please contact our technical sales department who will be happy to personally advise you.



Ordering Information and Specifications

Model	**Basic Material**	**Dimensions**			**Reflectance**	
		Thickness (mm)	**Width (mm)**	**Length (m)**	**Wavelength**	**@ 555 nm**
ODM98-F01	ODM98	ca. 1.5 +/- 0.1	300	In Rolls of min. 1 meter	250-2500 nm	95 %
ODM98-F02		ca. 0.2 +/- 0.05	105			75 %
ODM98-F03		ca. 0.5 +/- 0.1	105			90 %

Machined Reflectance Plates

OP.DI.MA. is used in many applications as a reflectance standard because of its diffuse, spectrally flat, reflective properties.
Gigahertz-Optik carries various sizes and shapes with one side in high quality optical finish as standard components
Besides standard sizes with fast lead time based on small quantities, custom sizes and thicknesses are available on request. All plates can be supplied with an adhesive backing. Absolute spectral reflectance calibration service is available.

10 mm thick reflectance plates and disks

2 mm thick reflectance standards with adhesive backing for fast and easy surface mounting

OP.DI.MA. Optical Diffuse Material

Ordering Information and Specifications

Model	Dimension: Size (mm)	Dimension: Thickness (mm)	Dimension: Optical Finish	Reflectance %: 400-800 nm	Reflectance %: 250-2500 nm
ODM98-MP01	50 x 50 +/- 0.2	10.5 +0/-1	1 side	98+/-1 %	min 93 %
ODM98-MP02	100 x 100 +/- 0.2				
ODM98-MP03	200 x 200 +/- 0.2				
ODM98-MP04	300 x 300 +/- 0.2				
ODM98-MD01	31.7 dia. +0/-0.1 (back side faced 0.3/45 deg.)				
ODM98-MD02	50.8 dia. +0/-0.1 (back side faced 0.3/45 deg.)				

Custom Service

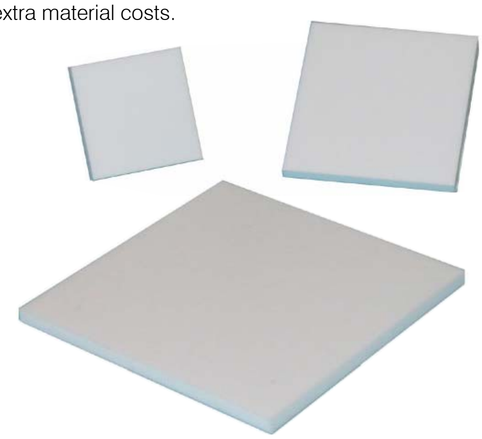
Besides standard parts and machined components Giga-hertz-Optik will custom design and machine OP.DI.MA. according to customer specifications starting with the most suitable and cost effective raw stock size and form.

Machining processes include simple cutting of plates to size as well as full CNC machining in single and O.E.M. quantities. Please contact the factory for help in the selection of the most cost effective process for your

Gigahertz-Optik Custom Services

Formed ODM:
The OP.DI.MA. manufacturing process does not permit molding of complex parts, but larger size parts in simple shapes such as hemispheres can be formed saving extra material costs.

Self-Adhesive:
Gigahertz-Optik offers OP.DI.MA. reflectance plates with an adhe-sive backing for fast and simple mounting especially for thin plates.



ODM Foil Cutting Service:
Gigahertz-Optik offers a cost effective sheet cutting service.

ODM Plate Shape Cutting:
Gigahertz-Optik offers precision shape cutting services for ma-chined plates.

ODM Block Machining:
In-house full custom machining service including drilling, milling and lathe work operations are available.
CNC processing to customer design drawings or CAD draw-ings made by Gigahertz-Optik to customer specifications is of-fered.

OP.DI.MA. Integrating Spheres

Gigahertz-Optik manufactures a wide range of OP.DI.MA. inte-grating spheres.
OP.DI.MA. offers substantial improvements over barium sul-fate coatings:

- Improved diffuse multiple internal reflections for better uniformity
- Higher operating temperature for high power light measure-ments
- Higher reflectance for high intensity uniform light sources
- More rugged coating charac-teristic
- High UV reflectance

Please refer to catalog section ‘Integrating Spheres’ and ‘Cali-bration Standards & Uniform Light Sources’ for more details.

UMBK Series:
Cost effective integrating sphe-res using spun aluminum hous-ings. Sphere diameters from 7.5 to 18 inch (190 to 460 mm).
Contact our sales engineers to discuss custom sizes and de-sign services.

UPK Series:
Precision CNC machined Al housing integrating spheres with high tolerance multiple port lay-outs. Sphere diameters from 0.3 to 10 inch (8 to 254 mm).
Contact our sales engineers to discuss custom sizes and de-sign services.

Application Service:
Gigahertz-Optik offers uniform light sources, luminance and spectral radiance standards as well as light intensity (laser power, radiant power, luminous flux) measurement systems based on the UMBK and UPK series integrating spheres. Con-tact us for personal assistance.

OP.DI.MA. Optical Diffuse Material / ODP Optical Diffuse Paint

OP.DI.MA. Reflectance Standards

BN-Rxx-D Series:
2 inch (50.8 mm) diameter spectral reflectance standards are available with and without 8/D hemispherical reflectance calibration certificate

BN-Rxx-SQ Series:
Reflectance standards from 2 x 2 to 18 x 18 inch (50 x 50 to 457 x 457 mm) are available with and without 8/D hemispherical reflectance calibration certificate

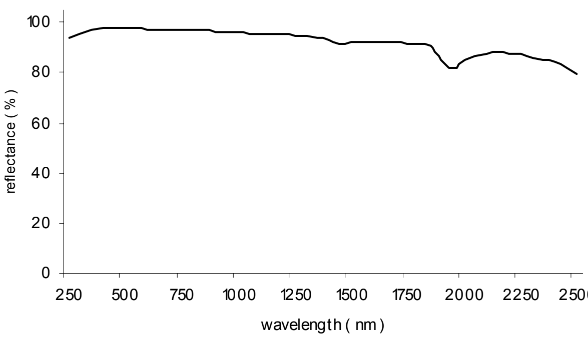
Reflection Standards:

Gigahertz-Optik offers reflectance standards made from machined OP.DI.MA. in different shapes and sizes.
Standards are supplied in housings with a removable cap for safe storage. NIST and NRC traceable calibration service for spectral reflectance from 250 to 2500 nm is available.

Refer to the 'Calibration Standards' section for more details.

ODP97: Optical Diffuse Paint

General Description



ODP97 is a white diffuse reflecting mixture used for coating integrating spheres, sphere components, large size panels and irregular surfaces.
The coating is based on pure barium sulfate and supplied in a proprietary solution including a binder. The binder is needed for good adhesion of the coating to the applied surface. Binder concentration is kept low to avoid any optical effect.
The paint is ready for instant application as supplied. 4 to 8 coats are needed to get the best diffuse and high reflectance. Instructions concerning surface preparation and coating procedure are included.
A ODP97 repair kit is available which includes a glass bottle and air pressure unit for coating of small surface areas and accessories.
Gigahertz-Optik offers a full custom coating service. Custom paint for rugged applications or gray scale additives for photometric applications are also available on request.
Please contact the factory to discuss your project.

ODP97 Optical Diffuse Paint

Ordering Information & Specifications			
Model	**Description**	**Reflectance**	
ODP97-1.0	ODP97 in 1000 ml bottle	400-800 nm	~ 97 %
500 ml covers about 200 square inches / 1200 cm²			

ODP97 exhibits a typical reflectance of 97 % in the visible spectral range with a useable range specified from 300 nm to 2400 nm. The mixture is supplied ready for instant and non-toxic application.
Gigahertz-Optik's proprietary barium sulfate solution can be shipped anywhere without special permits and comes in 1000 ml plastic bottles.

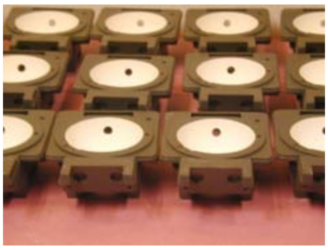
ODP97-RS High Viscosity Laboratory Sprayer

Ordering Information & Specifications	
Model	**Description**
ODP97-LS	High Viscosity Laboratory Sprayer. 1 pc. bottle and 1 pc. pressure unit
ODP-RSB	1 pc. 90 ml bottle
ODP-RSP	1 pc. pressure unit

The ODP97-RS laboratory spray bottle can be used for service purposes or for coating small components.
The complete unit includes one 90 ml bottle and one pressure unit for applying ODM97 coating or other high viscosity fluids.

ODP Optical Diffuse Paint / ODG95 Optical Diffuse Gold

Custom Coating Service



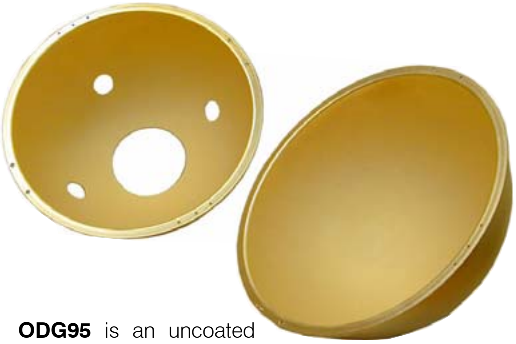
Custom coating services for new components as well as recoating service of Gigahertz-Optik or other manufacturer's products is available. The service is offered for single units as well as for O.E.M. quantities.
Please contact the factory to discuss the most economic coating service for your particular application requirements.

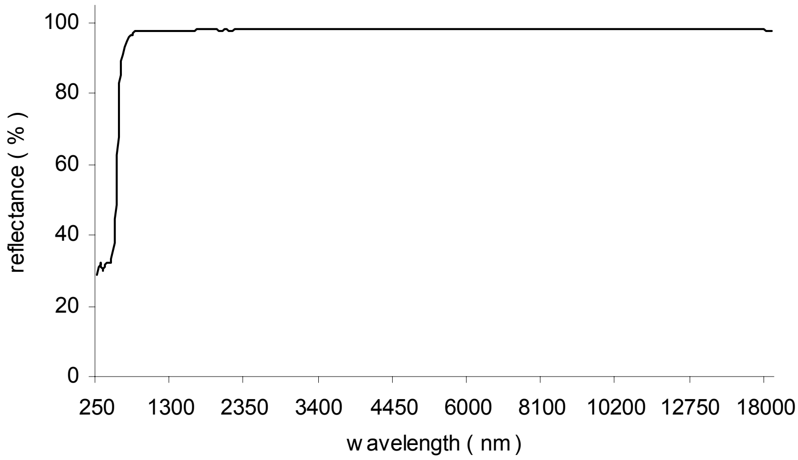
Integrating Spheres with Barium Sulfate Coating

Gigahertz-Optik manufactures a wide range of ODP97 barium sulfate coated integrating spheres.
Barium sulfate offers an economical coating solution, especially for larger diameter spheres.
The **UMBB sphere line** represents one of the most flexible and cost effective design concepts for individual sphere set-ups. Accurate reflection and transmittance measurement applications require the higher tolerances of the precision machined **UPB sphere line.**

Please refer to sections 'Integrating Spheres' and 'Calibration Standards & Uniform Light Sources' for more information.

ODG95: Optical Diffuse Gold





ODG95 is an uncoated gold which outperforms all other uncoated metallic reflectors at infrared wavelengths. Gold's high reflectivity in the red portion of the visible spectrum is apparent by it's yellow hue.
With its ~ 95 % high reflectivity in the wavelength range from 1 μm to 20 μm, gold is the best choice for surface coating of integrating spheres and reflectance standards in IR applications. Its highly diffuse reflectivity is a result of a proprietary pre-coating surface preparation.
Gigahertz-Optik supplies both gold coated integrating spheres and reflectance standards.
Please check sections 'Integrating Spheres' and 'Calibration Standards & Uniform Light Sources' for more information.
Standard products and custom design components are offered.

Integrating Spheres with Gold Coating

ODG95 gold coated integrating spheres are designed for applications in the infrared spectral range.
The **UMBG sphere line** represents one of the most flexible and cost effective design concepts for individual sphere set-ups. Accurate reflection and transmittance measurement application require the higher tolerances of the precision machined **UPG sphere line**.

Please refer to chapter Integrating Sphere for more information.

General Information

Calibration standards are employed in determining the correlation between an input and an output quantity for all types of measurement instrumentation.
By supplying a signal of known quantity, the difference between the output signal of the test device and the calibration standard can be evaluated. From these differences calibration correction factors can be calculated allowing adjustment of the test device for absolute readings.
Transfer standards are used to transfer the values of the primary standard, often certified by a national calibration laboratory, to the secondary calibration facility. This fulfills the traceability requirement for an unbroken chain of transfer comparisons back to the national primary standard.
Calibration uncertainty depends on the calibration hierarchy of the standards employed and the technically competency of the calibration laboratory (see Calibration Chapter).
Proper care and use of the calibration standards is critical to long term success in the calibration transfer method.

Photometric and radiometric light measurement applications involve many different measurement quantities such as:

- Illuminance / Irradiance
- Luminance / Radiance
- Luminous Flux /Radiant Power
- Luminous Intensity / Radiant Intensity

Each quantity requires its own calibration standard.

For optical radiation calibration of light detectors calibration standards in the form of light detectors are used. Calibration is accomplished using the transfer method described previously. Absolute sensitivity is confirmed in a calibration certificate that includes other descriptive and procedural information .
A typical example of a detector based calibration is the spectral sensitivity calibration of photodiodes employing a tunable monochromatic light source with its output compared to the known spectral sensitivity of a standard detector.

For the calibration of light sources calibration standards in the form of light sources are used. Here reference standard light sources are used to calibrate the light measurement system which in turn is used to calibrate the unknown light source.
This method is used for the calibration of spectral radiometers with a spectral irradiance standard source for example.
In imaging applications the uniformity in sensitivity of the imaging detection system is very important. Light sources with a uniform light emitting area are needed as reference standards in this type of calibration to determine the non-uniformity of a lens system or imaging detection system. **Uniform light sources** built around integrating spheres are the best known solution for setting up uniform light sources.

Gigahertz-Optik offers a wide selection of calibration standards and uniform light sources.
For the measurement quantities of spectral sensitivity and spectral irradiance Gigahertz-Optik's calibration laboratory is ISO EN 17025 accredited.

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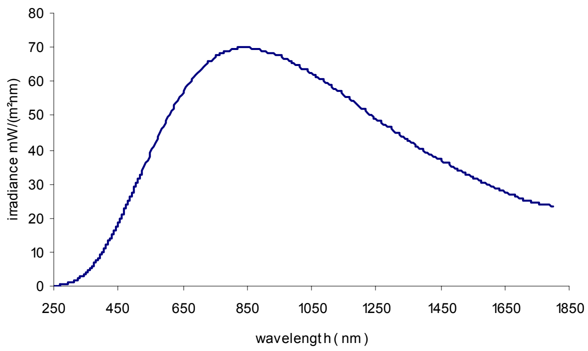
Gigahertz-Optik

Spectral Irradiance

BN-LH250: 250 W Spectral Irradiance Standard Lamp



Typical Spectral Irradiance at 3100 K

The **BN-LH250** spectral irradiance standard lamp is a precise transfer standard for spectral irradiance in the wavelength range from 250 to 2500 nm.

The lamp standard consists of a carefully selected 250 W tungsten halogen lamp with a diffuse quartz envelope and stable filament mounted into a ceramic lamp base to help with temperature equalization. The lamp base allows free standing and post mounted operation. The two banana sockets provided to supply power to the lamp are mounted so that they are shielded from light and heat irradiation by the lamp.

The **BN-LH250-BC** is qualified as a reference transfer standard. The BC version of the BN-LH250 undergoes a burn-in procedure where the lamp current, operating voltage and irradiance are documented during burn-in. The Gigahertz-Optik calibration engineers evaluate this data to decide if the lamp qualifies for use as a reference standard lamp. If the lamp qualifies a burn-in certificate that includes this data is issued.

Calibration of spectral irradiance is done using a double-monochromator spectral radiometer at a distance of 50 cm to the reference plane of the standard lamp. Description and specifications for this KLW-S1 spectral irradiance calibration procedure is listed in the *Calibration Service* chapter.

A BHO-10 carrying case is a required component for all BN-LH250 standard lamp deliveries.

To power the BN-LH250 and BN-LH250-BC lamps Gigahertz-Optik recommends the LPS-250 lamp power supply which is specially designed for the operation of light emitting standards.

LPS-250 Power Supply

LPS-250 in Bench-Top Housing BTH-19/2

The LPS-250 lamp power supply is specially designed for stable operation of lamps. It offers a maximum operating voltage of 26 V and a maximum lamp current of 15 A.

A high resolution 16 bit digital to analog converter provides a high level of lamp current control with a resolution of 0.3 mA at the nominal current of 15 A. The current stability is specified at $0.1x10^{-4}$ A at the nominal current within 8 hours. An on/off ramp function prevents lamp filament shock during the on/off procedure.

The RS232 or RS488 interface enables full remote control operation. In the manual control mode an alphanumerical four line display shows the set-up parameters. Manual set-up is accomplished via menu selection.

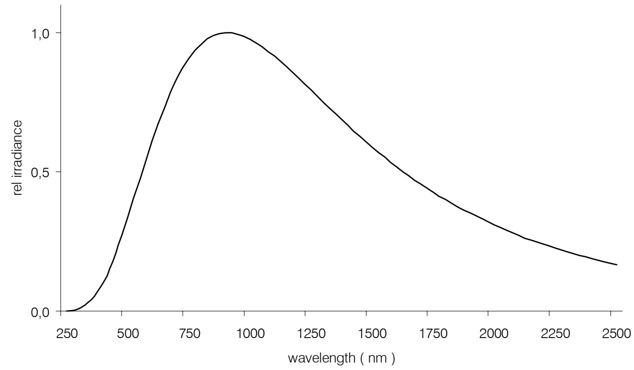
The power supply is offered in a 1/2-19” housing which allows rack-mounting. For laboratory use an optional bench top housing is offered. Full specifications are listed in the *Integrating Spheres* section.

Typical Specifications and Ordering Information:

Model	Lamp				Spectral Irradiance at 50 cm in mW/(m² nm)			
	Type	Power	Voltage	Current	250 nm	1100 nm	1800 nm	Distance
		@ 3100 K						cm
BN-LH250	Halogen Lamp	250 W	~ 24 V	10.5 A	1.19 E-01	5.93 E+1	2.35 E+01	50
BN-LH250-BC	Halogen Lamp with Burn-in Certificate							
BHO-10	Hard case for up to 3 of BN-LH250. Required part for either BN-LH250 order.							
BPC-2	Banana-plug cable with 2 m length. Available in red, blue and black color							
LPS-250	Precise current controlled power supply. Current ramp function. RS232 or RS488 interface. 230 V / 50 Hz							
LPS-250A	Precise current controlled power supply. Current ramp function. RS232 or RS488 interface. 100 to 230 V / 50 to 60 Hz							
BTH—19/2	1/2 19” width bench top housing for LPS-250 and LPS-250A							
KLW-S1	Calibration of spectral Irradiance							

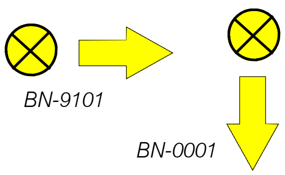
BN-9101 & BN-0001: 1000W Spectral Irradiance Standard Lamps

BN-9101 & BN-0001 spectral irradiance standard lamps are precise spectral irradiance transfer standards for use in the wavelength range from 250 to 2500 nm.
Both lamps feature a large diameter filament which is essential for a long operating life and stable irradiance. These 1000 W spectral irradiance standard lamps have been supplied and calibrated by the Gigahertz-Optik calibration laboratory for optical measurement quantities since 1991 and are in world wide use in industrial and metrological applications.



Typical Spectral Irradiance at 3100 K

BN-9101: 1000 W FEL or Sylvania tungsten halogen lamp and precision lamp socket for horizontal light orientation..
BN-0001: 1000 W DXW tungsten halogen lamp mounted in a precision lamp socket for vertical light orientation.
Common features include hardwiring of the leads to the lamp pins in order to reduce measurement error caused by voltage drops across the connections. Also lamp position is fixed in a temperature stable ceramic base.
An optional transparent window target marks the position on the filament used for the irradiance calibration. This allows precision alignment in the application or for re-calibration.
Each lamp undergoes a burn-in procedure with burn-in certificate. Several lamp parameters are documented by a on-line data logger. By examination of the burn-in data, only those lamps which display the expected trends are qualified to be used as reference standards. A burn-in certificate is supplied with each qualified lamp.

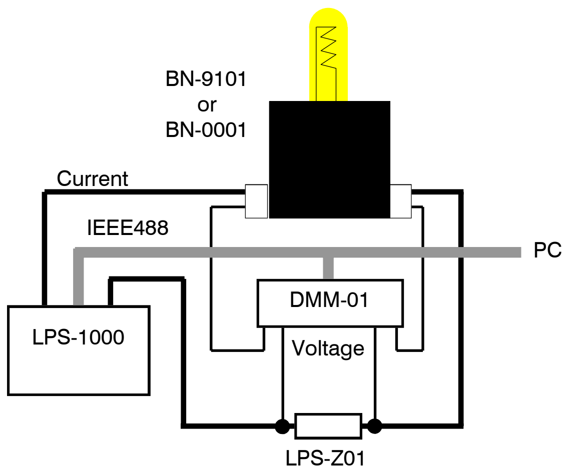


The BN-9101 is available in two versions:

- FEL type with filament support offers more intensity in the blue and UV spectral range than the Sylvania type
- Sylvania type is recommended for universal use due to its excellent long term stability.

Calibration of spectral irradiance with DKD certificate or traceable factory certificate is available through Gigahertz-Optik's DIN EN ISO/IEC 17025 accredited calibration laboratory. Descriptions and specifications of the KLW-S1 and KLD-S1 spectral irradiance calibrations is available in the *Calibration Service* section.

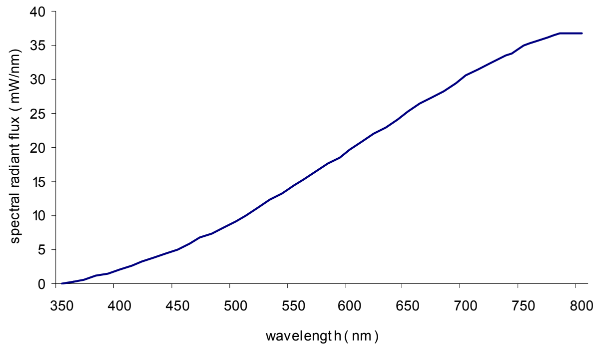
Set-up for Remote Control Operation



Typical Specifications and Ordering Information:								
Model	**Lamp with Burn-in Certificate**				**Spectral Irradiance at 70 cm in W/cm² nm-¹**			
	Typ	Power	Voltage	Current	250 nm	1100 nm	2500 nm	Distance
					@ 3100 K			cm
BN-9101-1	Halogen Lamp FEL Type	1000 W	110 V DC	8.000 A	0.11 mW/m²	116 mW/m²	18 mW/m²	70
BN-9101-2	Halogen Lamp Sylvania Type	1000 W	101 V DC	8.100 A	0.07 mW/m²	96 mW/m²	16 mW/m²	70
BN-0001	Halogen Lamp DXW Type	1000 W	115 V DC	8.000 A	0.18 mW/m²	219 mW/m²	-	50
BN-9101Z-01 and BN-0001Z-01		Transparent cross-hair target for precise alignment onto the filament reference spot						
BHO-10	Hard case for up to (3) BN-9101 and (2) BN-0001. Required part for BN lamp orders.							
BPC-2	Banana-plug cable, 2 m length. Available in red, blue and black color							
LPS-1000	Precise current controlled 1000 W power supply. Current ramp function. IEEE488 interface. 230 V / 50 Hz							
LPS-Z01	High-power shunt resistor with DKD certificate for precise current measurements in combination with DMM-01							
DMM-01	High resolution digital multimeter with IEEE488 interface and input port multiplexer							
OS-LPS1000	Software to control and document BN-9101 & BN-0001 operation with LPS-1000, LPS-Z01 and DMM-01							
KLD-S1 & KLW-S1		Calibration of spectral Irradiance with DKD or traceable factory certificate						

Spectral Radiant Power & Luminous Flux

BN-0104: Spectral Radiant Power and Luminous Flux Standard Lamps



Typical Spectral Radiant Power at 2856 K

The BN-0104 standard lamp is a precise transfer standard for the quantities of spectral radiant power and luminous flux.
Carefully burned-in tungsten halogen lamps are mounted into a UMLA-300 or UMLA-500 lamp adapter for use in the UMBB-300 and UMBB-500 integrating spheres (see *Integrating Spheres* section). The holder and lamp socket mounting plates are coated with barium sulfate (ODP-97) with 97 % reflectance. The UMLA lamp holder's PG type connector allows simple mounting and connection of the lamp to the UMLA-1.5B lamp adapter base.
The BN-0104 is available in three different power ranges.
Calibration of spectral radiant power in W/nm within the wavelength range from 400 nm to 1000 nm is supplied by Gigahertz-Optics calibration laboratory for optical radiation measurement quantities.
The standard lamps are supplied in a special carrying case which safely holds and protects the lamp and coated parts.

To power the BN series lamps Gigahertz-Optik recommends the LPS-250 lamp power supply which is specially designed for the operation of light emitting standards.

Carrying Case

LPS-250 Lamp Power Supply

The LPS-250 lamp power supply is specially designed for stable operation of lamps. It offers a maximum operating voltage of 24 V and a maximum lamp current of 13 A.
A high resolution 16 bit digital to analog converter provides a high level of lamp current control with a resolution of 0.3 mA at the nominal current of 13 A. The current stability is specified at 0.1×10^{-4} A at the nominal current within 8 hours. An on/off ramp function prevents lamp filament shock during the on/off procedure.
The RS232 or RS488 interface enables full remote control operation. In the manual control mode an alphanumerical four line display shows the set-up parameters. Manual set-up is accomplished via menu selection.
The power supply is offered in a 1/2-19" housing which allows rack-mounting. For laboratory use an optional bench top housing is offered. Full specifications are listed in the *Integrating Spheres* section.

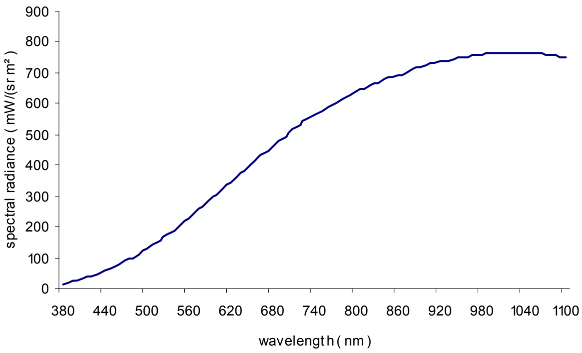
Typical Specifications and Ordering Information:

Model	**Lamp**				**Spectral Radiant Power (mW/nm)**			**Luminous Flux (lm)**
	Type	Power	Voltage	Current	400 nm	800 nm	1000 nm	
		@ 2856 K						
BN-0104-LH90 1)	Halogen Lamp	90 W	12 V DC	7.17 A	2	37	-	1100
BN-0104-LH50 1)	Halogen Lamp	50 W	12 V DC	4.16 A	1.11	20.55	-	550
BN-0104-LH35 1)	Halogen Lamp	35 W	12 V DC	2,91 A	0.78	14.38	-	370

1) Lamp supplied in special carrying case mounted on lamp holder UMLA-300 or UMLA-500 for use in UMBB-300 or UMBB-500

BPC-2	Banana-plug cable, 2 m length. Available in red, blue and black color
LPS-250	Precise current controlled 250 W power supply. Current ramp function. RS232 or RS488 interface. 230 V / 50 Hz
LPS-250A	Precise current controlled 250 W power supply. Current ramp function. RS232 or RS488 interface. 100 to 230 V / 50 to 60 Hz
BTH-19/2	19"/2 width bench top housing for LPS-250 and LPS-250A
KLW-S2	Calibration of spectral radiant power with calculated luminous flux

BN-0102: Compact Spectral Radiance Standard Source

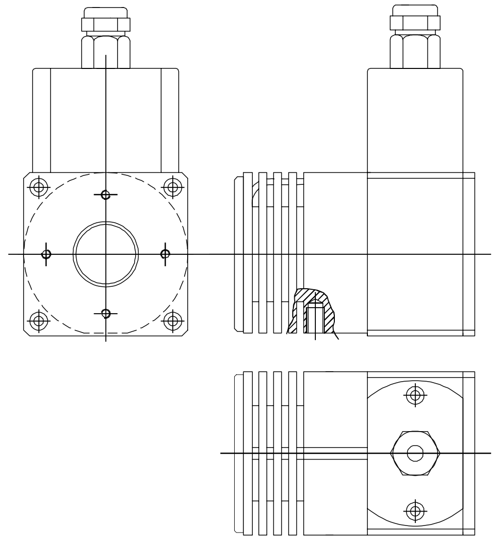


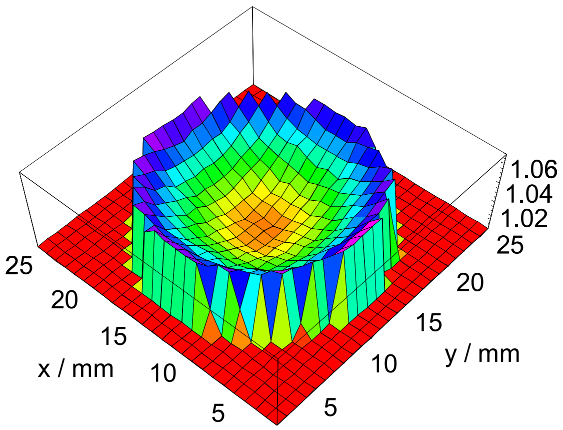
Typical Spectral Radiance

The BN-0102 standard source is a precise spectral radiance transfer standard. Its compact size makes it ideal in applications with limited space.
The unit is built around a small diameter OP.DI.MA.* integrating sphere with a symmetrical OP.DI.MA. baffle between lamp and light output port. This offers the best possible uniformity within the 20 mm diameter light emitting area.
The small diameter sphere in combination with the large diameter light port limits the use of the radiance standard to light detection systems having a narrow field-of-view.
OP.DI.MA. is a nearly perfect white diffuse reflecting plastic material with excellent long term stability.
A carefully burned-in 5 W tungsten halogen lamp operated in constant current mode functions as the light source.
The compact LCRT-2000 power supply is specially designed to run the BN-0102 lamp at a constant current.
Spectral radiance calibration is supplied by Gigahertz-Optik's calibration laboratory for optical radiation measurement quantities and supported by a factory calibration certificate.

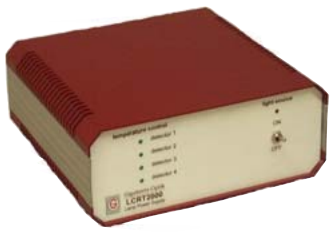
*Gigahertz-Optik's Optically Diffuse Material

Dimensions





LCRT-2000: Lamp Power Supply



The LCRT-2000 Lamp Power Supply is designed to operate lamps up to 10 W power. It can be operated in current controlled mode or light intensity controlled mode (requires a reference detector). The LCRT-2000 allows temperature stabilization of four external detectors at +40 °C to avoid drift effects due to ambient temperature instability. One of these detectors may be a reference detector for the light intensity control mode of the LCRT-2000. An additional output voltage for a cooling fan at the external lamp is available.

Typical Specifications and Ordering Information:

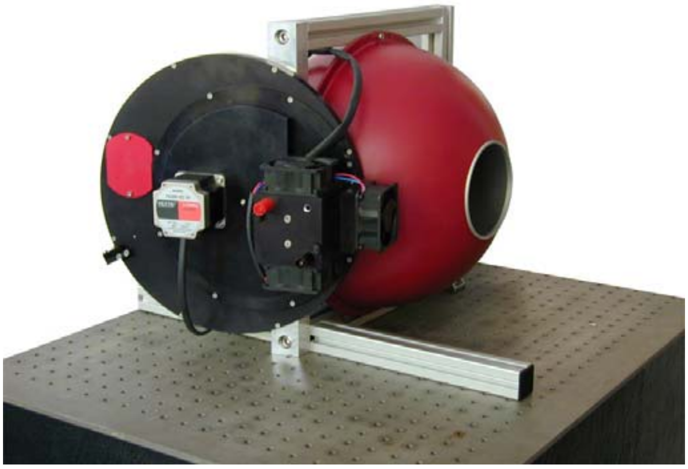
Model	Integrating Sphere		Lamp				Spectral Radiance (mW/m² sr nm)			Luminance
	Sphere	Port	Type	Power	Voltage	Current	350 nm	1100 nm	2500 nm	cd/m²
	Diameter (mm)			@ 2700 K						
BN-0102	40	20	Halogen Lamp	5 W	12 V DC	417 mA	6	750	-	16000
LCRT-2000	Lamp power supply									
KLD-S3	Calibration of spectral Radiance with traceable factory certificate									

Spectral Radiance, Luminous and Uniformity

BN-ULS-M Series: Spectral Radiance, Luminance and Uniformity Standards

BN-ULS-500 with for internal lamps

The BN-ULS-M Series radiance, luminance and uniformity standards offer the utmost flexibility in constructing a system to individual customer requirements. The design concept is based on providing the highest possible level specifications



BN-ULS-300 with external lamp and remote controlled filter wheel

without adding more than is needed. This modular approach gives the customer exactly what he requires without the added cost of unnecessary parts.

Integrating Spheres with different diameters from 4 in. (100 mm) up to 67 in. (1700 mm), form the base units for each set-up. The main selection criteria for determining the sphere size is how big the light emitting port must be. A rule of thumb for the maximum acceptable port diameter is no more than 5 % of the total sphere surface area including detector and lamp ports.

How high a luminance output is required is the only selection criteria for small diameter spheres.

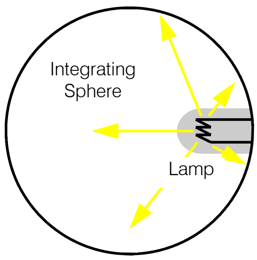
A wide range of **Sphere Accessory Components** support configuration of the basic sphere. In-stock status of all items limits the delivery time of the spheres to the time of assembly.

Standard bench-top **Sphere Stands** are constructed using modular aluminum rails that can be easily customized to the individual application.

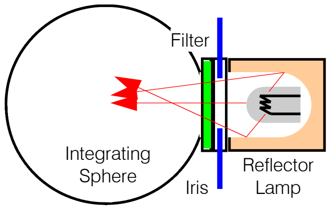
Port Frames with free aperture diameters from 0.5 in. (12.7 mm) up to 5 in. (127 mm) provide the foundation for all accessory components assembled to the sphere.

Two different kinds of light sources are available for assembly onto the port frames:

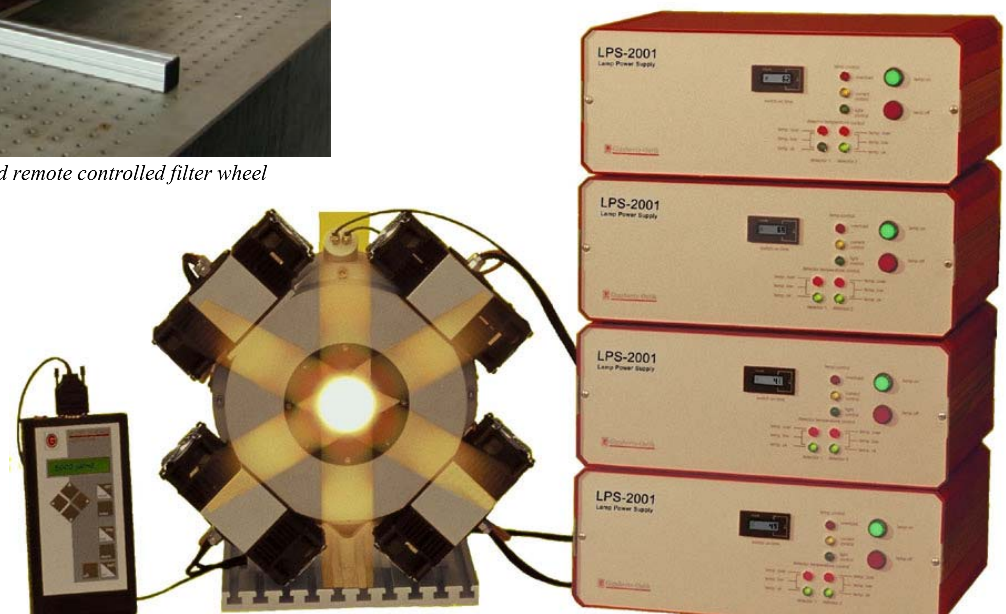
Internal Sources are positioned inside of the sphere. The advantage of this type of light source is that all of the luminous flux is emitted inside the sphere offering the highest possible light intensity. Baffles are required to block direct illumination of the light exit port by the internal lamp. The resulting losses in uniformity and acceptance angle can be reduced by the use of multiple internal lamps.



External Sources are directional lamps which transfer their luminous flux through a sphere port into the sphere. The advantage of this type of light source is the ability to place light manipulators like iris diaphragm attenuators, optical filters and fast shutters into the light beam. The restriction with this light source is the lower light intensity. Gigahertz-Optik's unique lamp design employing a diffuse reflector offers high luminous flux efficiency combined with a diffuse light input into the sphere. In combination with its diffuse-baffle, light uniformities equal to that of satellite sphere light sources are achieved at higher light intensities.

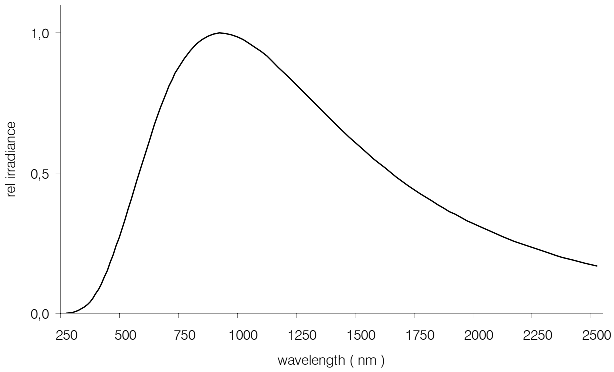


All **available components** for the construction of standard light source systems are described and specified in the *Integrating Spheres* section .



BN-ULS-300 with 4 external lamp

BN-USM Series: Unit Construction System



Typical Spectral Radiance

Halogen Lamps are similar in construction to conventional gas filled tungsten filament lamps except that a small trace amount of halogen is added. The addition of this halogen results in a regenerative cycle of the evaporated tungsten. These lamps exhibit:

- long operation time
- broad band spectral radiation ranging from the UV through IR
- stable light emittance characteristic

making them ideal for use as calibration standard lamps.

Gigahertz-Optik supplies halogen lamps with and without UV-blocking quartz envelopes. Note that lamps without UV blocking exhibit a substantially shorter life time.

The following table shows the lamp specifications in combination with different size Gigahertz-Optik integrating spheres and lamp housings.

For the precise operation of halogen lamps Gigahertz-Optik lamp power supplies are recommended.

Typical Lamp and Light Source Specifications:

Halogen Lamp					Inside Source				Outside Source			OS + Iris			
Model	Power	UV Blocker	Operation at		Sphere Diameter Depending Illuminance in klx . Sphere Diameter in mm 1)										
	W		V	K	150	300	500	T_C (K)	150	300	500	150	300	500	T_C (K)
LH-5	5	√	12	3100	13	3.3	1.2	2850	8.2	2	0.7	4.4	1	0.4	2800
LH-10	10	√	12	3100	21	5.1	1.9	2850	11	2.9	1	6.6	1.6	0.6	2800
LH-35	35	√	12	3100	97	24	8.9	2950	71	17	6.5	39	9.6	3.5	2900
LH-50	50	√	12	3100	156	38	14	2950	116	28	10	62	15	5.6	2900
LH-75	75	√	12	3100	248	61	22	2950	183	45	16	95	23	8.7	2900
LH-90	90	√	12	3100	315	77	28	2950	237	58	21	122	29	11	2900
LH-10-UV	10		6	3100	25	6.2	2.3	3050	16	4.1	1.5	9.9	2.4	0.9	3000
LH-50-UV	50		12	3100	190	46.6	17	3050	143	35	13	77	18	7	3000
LH-100-UV	100		12	3100	436	107	39	3050	333	81	30	179	44	16	3000
LH-250-UV	250		24	3100	-	-	-	-	On Request						
1) Typical values only. Illuminance (Luminance) may vary with port size and additional accessories. Please contact the company for more details															

Light Detectors and Optometers

Gigahertz-Optik offers a wide range of light detectors and optometers which can be combined with the integrating sphere based light sources for precise radiance and luminance measurement.

Temperature stabilized TD-11 light detectors are the right choice to avoid drift in readings caused by changes in ambient temperature.

In applications that require long term stability of the emission spectra, **color temperature controlled operation** of the halogen lamp is possible using one of Gigahertz-Optik's luminous color detectors. The color temperature stabilization can be done by manual or remote control current variation of the LPS-250 lamp power supply. If the intensity variation in color temperature controlled mode is not acceptable, an iris diaphragm or motorized attenuator can be used to control the light output intensity. Complete remote controlled systems are offered by Gigahertz-Optik.

More information and specifications are available in the *Light Detectors* and *Optometers* sections.

LPS-250 Lamp Power Supply

The LPS-250 lamp power supply is specially designed for the operation of halogen lamps. It offers a variable voltage from 0 to 24 V . A 16 bit digital to analog converter allows precise current set-up from 0 to 15 A with a resolution of 0.3 mA. The current stability is specified at $0.1x10^{-4}$ A at the nominal current over 8 hours. An on/off ramp function prevents shock of the lamp filament during the on/off procedure. RS232 or RS488 interface allows full remote control operation of single and multiple units.

The power supply is offered in a 1/2-19” rack-mount housing.

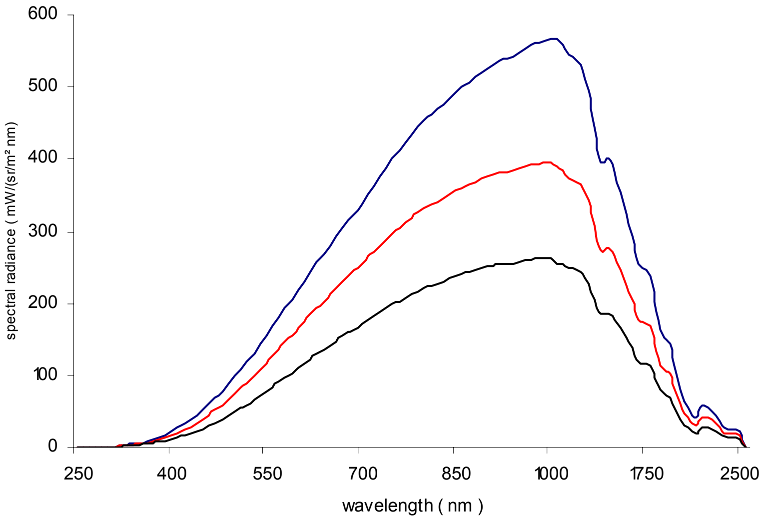
For laboratory use an optional bench top housing is available.

Full specifications are shown in the *Integrating Spheres* chapter .

Gigahertz-Optik

Spectral Radiance, Luminous and Uniformity

BN-ULS-K190: Spectral Radiance Standard



Typical Spectral Radiance at 100%, 75% and 50%

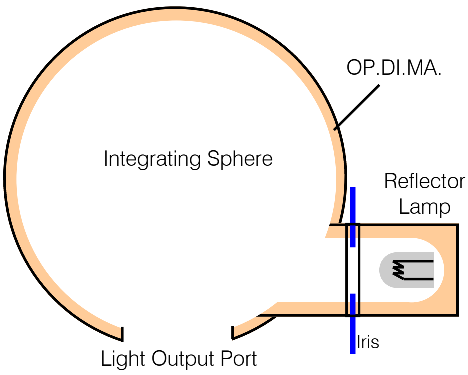
The **BN-ULS-K190** spectral radiance standard offers high and controllable intensity and a uniform radiant output from 300 to 2500 nm.

The BN-ULS-K190 is built around a compact precision machined aluminum housing featuring an inlet made out of Gigahertz-Optik's white diffuse plastic material, OP.DI.MA.

This material offers very good diffuse reflectance combined with high spectral reflectance from 250 to 2500 nm. In comparison to barium sulfate coatings OP.DI.MA. exhibits greater irradiation stability in the ultraviolet to infrared spectral ranges with better mechanical stability as well.

Another key feature is that the light source is externally positioned allowing the use of a variable attenuator mounted between the lamp and sphere. An adjustable shutter eliminates changes in color temperature as found with electronically controlled intensity methods.

To ensure high intensity output the halogen lamp is placed within a diffuse reflector for best flux coupling efficiency as well as diffuse sphere illumination for high radiance uniformity at the light output port.



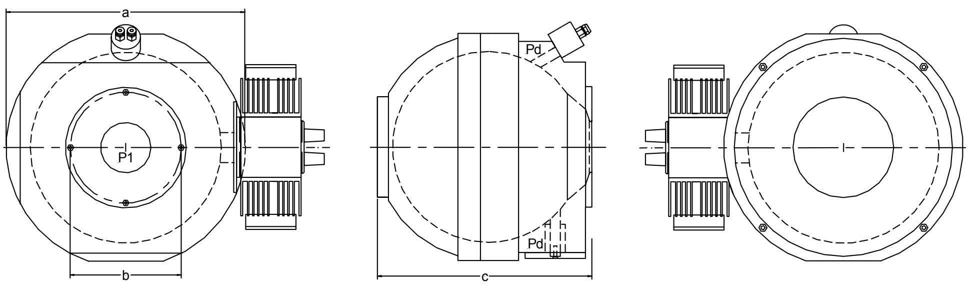
A precise photometrically corrected reference detector is mounted to the integrating sphere for connection to a Gigahertz-Optik optometer to read out luminance values (see *Optometer* chapter).

The lamp is operated by the LPS-250 lamp power supply for high resolution lamp current control and long term stability (see *Integrating Spheres* chapter).

Calibration of spectral radiance at three different intensity levels is done by Gigahertz-Optics Calibration Laboratory and traceably confirmed in a factory calibration certificate.

Dimensions			
a	238	c	210
b	110		

Dimensions (mm):

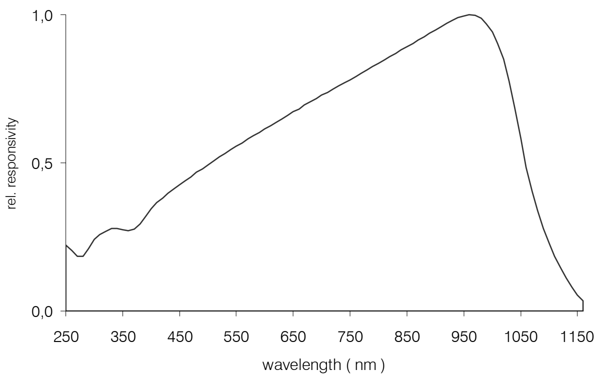


Typical Specifications and Ordering Information:

	Integrating Sphere		Light Source			Radiance in mW/(m² sr nm)				
	Sphere ∅	Port ∅	Power	Lamp	Source	Wavelength	Iris 100 %	Iris 75 %	Iris 50 %	CT
BN-ULS-K190-1	190 mm	50 mm	100 W	Halogen	LS-OK30	@ 1100 nm	1230	850	560	3050 K
BN-ULS-K190-2	190 mm	50 mm	50 W	Halogen	LS-OK30	@ 1100 nm	550	380	240	2800 K

Including LPS-250 power supply, VL-1101-2 light detector, P-9710-1 optometer, KLW-S3 calibration from 300 to 2500 nm at three different intensities (Iris 100%, 75% and 50% open) and luminance calibration of light detector.

BN-DSR-100 Spectral Radiant Power Sensitivity Standard Detector



Typical Spectral Sensitivity

The **BN-DSR-100** calibration standard detector is a precise transfer standard for spectral radiant power sensitivity in A/W in the wavelength range from 200 to 1160 nm.

It's 10 x 10 mm active area silicon photodiode is mounted in the 37 mm diameter MD-37 type detector housing. A machined V-groove and side M6 threaded hole are provided in the housing for detector mounting. See *Light detector* section for more details.
Photodiode linearity between incident light and photocurrent signal is up to 1 mA.
The spectral sensitivity range is 200 to 1160 nm.
A 2 m long coaxial cable with BNC connector enables the detector to be used with an optometer or signal amplifier. Alternatively a (type–2) calibration data connector or (type–4) connector for compatibility with Gigahertz-Optik's P-9710 or X1, X9 meters respectively are available.

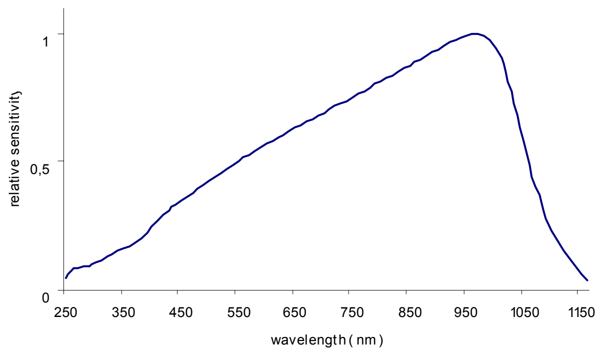
The BN-DSR-100 is available with either a DKD ISO-EN 17025 calibration from 248,4 to 1160 nm or with a factory calibration from 200 to 1100 nm. See *Calibration* chapter for more details.

Typical Specifications and Ordering Information:

Model	Photodiode			Detector		Calibration	
	Type	Area	Size mm	Aperture	Package	Wavelength Range	Unit
BN-DSR-100D	Si	100 mm^2	10 x 10	10 x 10 mm	MD-37	1)	A/W nm
BN-DSR-100F	Si	100 mm^2	10 x 10	10 x 10 mm	MD-37	200-1100 nm in 10 nm steps 2)	A/W nm

1) DKD calibration certificate . Calibration at 248.4; 265.3; 280.4; 289.4; 302.2; 313; 334.2; 366; from 380 to 1160 in 20 nm steps.
2) Factory calibration certificate

BN-DSI-33 Spectral Irradiance Standard Detector



Typical Spectral Sensitivity

The **BN-DSI-33** calibration standard detector is a precise spectral irradiance sensitivity [A/(W/m^2)] transfer standard for the wavelength range from 250 to 1100 nm.
The 33 mm^2 active area silicon photodiode is mounted in a 37 mm diameter MD-37 type light detector housing. A machined V-groove and side M6 threaded hole allow mounting of the detector. The entrance window is composed of a spectrally neutral broadband 11 mm diameter RADIN* diffuser.
The photodiode linearity between incident and detector signal is up to 1 mA. The spectral sensitivity range is 250 to 1100 nm.

A 2 m long coaxial cable with BNC connector enables the detector to be used with an optometer or signal amplifier. Alternatively a (type–2) calibration data connector or (type–4) connector for compatibility with Gigahertz-Optik's P-9710 or X1, X9 meters respectively are available.

The BN-DSR-33 is available with a calibration of its spectral irradiance sensitivity from 250 to 1100 with a factory certificate. See *Calibration* chapter for more details.

* Gigahertz-Optik Radiation Integrator

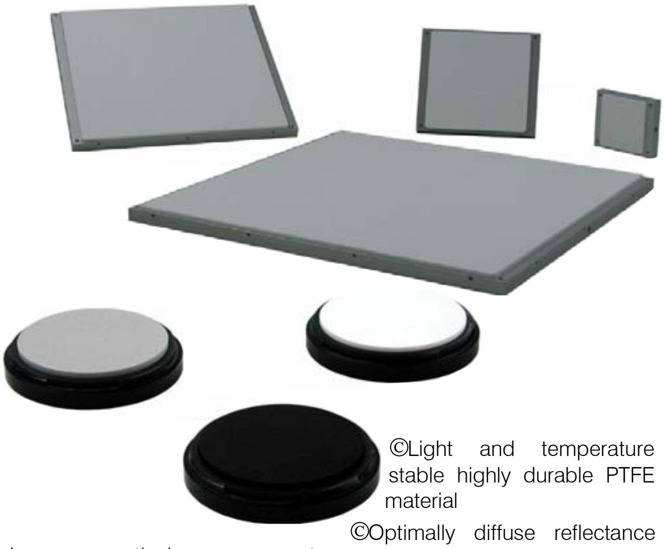
Typical Specifications and Ordering Information:

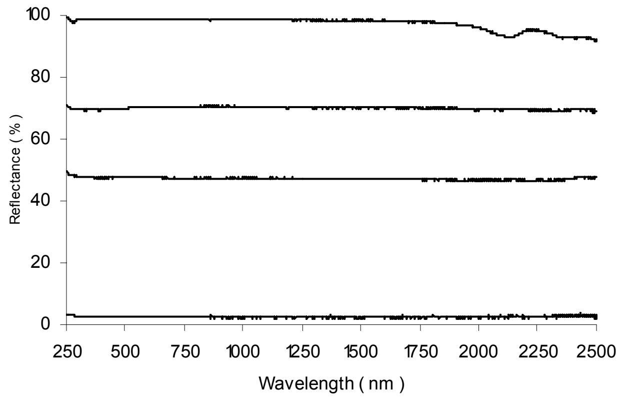
Model	Photodiode			Detector		Calibration 1)	
	Type	Area	Size mm	Aperture	Package	Wavelength Range	Unit
BN-DSI-33	Si+RADIN	33 mm^2	5.6 x 5.6	11 mm ∅ RADIN	MD-37	250-1100 nm in 10 nm steps	A/(W/m^2)

1) Relative spectral sensitivity absolute scaled at 555 nm

Spectral Reflectance

BN-R: Spectral Reflectance Standards





Typical Spectral Reflectance of BN-R98, 70,50 and 03

In many optical measurement tasks, optically diffuse reflectors for system calibration and/or adjustment are required. These standards should exhibit a maximally diffuse pattern of reflection. Also, in applications involving spectrally broadband light sources and detectors the reflectance characteristic of the standard should be spectrally neutral across the entire spectral bandpass of interest. For calibration of spectrophotometers the absolute spectral reflectance of the standard must be known. **Gigahertz-Optik's BN-R** Reflectance Standard fits this specification profile nearly perfectly. The standard is made from OP.DI.MA. which stands for Optically Diffuse Material and features:

- ©Light and temperature stable highly durable PTFE material
- ©Optimally diffuse reflectance (Lambertian reflector)
- ©Different reflectance of 98 %, 50 % and 3 %
- ©Spectrally neutral reflectance of 98 % +/- 1 % from 400 to 800 nm.

Different Sizes of reflectance standards are offered.

T**he BN-Rxx-D2** offers a reflectance of 2 in. (50.8 mm) diameter. A screw top cover protects the reflectance surface during storage and transportation.

The BN-Rxx-SQ reflectance standards are available in 2 x 2 in. (50 x 50 mm) to 18 x 18 in. (457 x 457 mm) sizes. All standards are supplied with a removeable cap

Each BN-R98-S5C Reflectance Standard can be ordered with a calibration certificate that includes a plot of spectral reflectance and data-set. Data is supplied over the spectral range from 250 nm to 2500 nm in 50 nm increments. Optionally, finer wavelength resolution is available. Calibration is performed using 8°/hemispherical measurement geometry. Gigahertz-Optik calibrations employ transfer standards traceable to the NRC National Research Council of Canada and NIST National Insti-

BN-R50-SQ18, 18 x 18 inch reflectance

Typical Specifications and Ordering Information:

Model	**Reflecting Area** dimension mm	in	**Model** 1)	**Reflectance** % @ 555 nm	**Model** 1)	**Reflectance** @ 555 nm	**Model** 1)	**Reflectance** @ 555 nm
BN-R-D2	50.8 ∅	2 ∅	**BN-R98-D2**		**BN-R50-D2**		**BN-R02-D2**	
BN-R-SQ50	50 x 50	2 x 2	**BN-R98-SQ50**		-		-	
BN-R-SQ100	100 x 100	3.9 x 3.9	**BN-R98-SQ100**		-		-	
BN-R-SQ200	200 x 200	7.9 x 7.9	**BN-R98-SQ200**	98 +/- 1 %	-	50 +/- 5 %	-	3 +/- 1.5 %
BN-R-SQ300	300 x 300	11.8 x 11.8	**BN-R98-SQ300**		-		-	
BN-R-SQ5	129 x 129	5 x 5	**BN-R98-SQ5**		**BN-R50-SQ5**		**BN-R02-SQ5**	
BN-R-SQ12	305 x 305	12 x 12	**BN-R98-SQ12**		**BN-R50-SQ12**		**BN-R02-SQ12**	
BN-R-SQ18 2)	457 x 457	18 x 18	**BN-R98-SQ18**		**BN-R50-SQ18**		**BN-R02-SQ18**	

1) Add –C to the model for calibration of the 8/D hemispherical reflectance from 250-2500 nm in 50 nm steps

2) The reflectance plate is build by two halfs

Optional calibration available in 1 nm steps with data on disk

General Information

Calibration is the determination of the correlation between an input and an output quantity. All measurement instruments, such as voltmeters, manometers, vernier calipers, etc., must be calibrated to determine the variation of its reading from the absolute quantity.
In light measurement, different types of calibrations are required based on a number of photometric, radiometric and luminous color measurement applications. These calibrations are typically done by comparison of the measurement values of a calibration standard to those of the test device.
The input quantity is provided by standard lamps and light detector standards. Because of the many different measurement quantities involved in light measurement, calibration standards for each quantity are needed.
The calibration of the standard itself must be traceable to national or international standards.
Since calibration standards are subject to change with use, the validity of the standards must be checked periodically or replaced to maintain the quality of calibration, traceability and stated uncertainties.

In Germany, the *Deutsche Kalibrierdienst – DKD (the German accreditation institution)* and the Physikalisch-Technische Bundesanstalt (the German national standard laboratory) offer an accreditation service for industrial calibration laboratories where the lab's calibration standards, calibration procedures and the stated re-calibration intervals are subject to audit.
This accreditation ensures that the traceability of the calibration and the calibration procedure is on an absolute level. The DKD also ensures the international acceptance of its accredited calibration laboratories. Gigahertz-Optik's calibration laboratory is **DIN EN ISO/IEC 17025** accredited for the measurement quantities *Spectral Sensitivity* and *Spectral Irradiance* under Registration Number DKD-K-10601.
The level of accreditation requires annual renewal through actual artifact calibration and intercomparison with the accrediting body. Besides spectral sensitivity and spectral irradiance calibration, Gigahertz-Optik offers optical radiation calibration in other light measurement quantities using calibration standards traceable to international calibration laboratories. By intercomparison to Gigahertz-Optik's in-house DKD for spectral sensitivity and spectral irradiance, long term stability and traceability of the non-DKD transfer standards is ensured.
Calibrations performed using standards from National Standard Laboratories e.g. NIST, PTB, NPL offer the lowest uncertainties and are therefore the preferable reference. Beside that factory level calibration standards with slightly higher uncertainties are used for some calibrations.
This chapter describes the different calibrations available.
Calibration standards are shown in the 'Calibration Standards & Uniform Light Sources' chapter.

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Gigahertz-Optik

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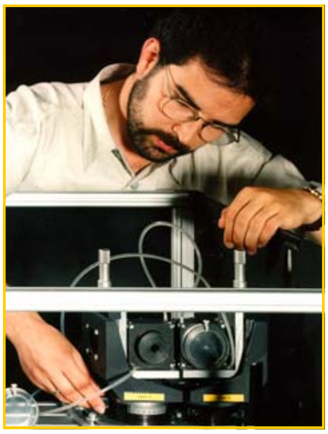
Traceability: an Unbroken Chain of Transfer Comparisons



Calibration is a prerequisite for maintaining accuracy in any type of measurement instrument. It is the foundation upon which subsequent measurements are based upon. Optical radiation calibration is typically done using the transfer method where the relationship between the reading of a device under test and that of a calibration standard is compared. The test device reading is then adjusted to that of the standard as needed, recorded and certified .
Since this is a direct comparison qualification of this transfer standard is of the highest importance.

A qualified standard should display an unbroken chain of transfer comparisons originating at a national standards laboratory. For example, the transfer standard of the national laboratory, primary standard (A) is used to calibrate the reference standard (B) at an accredited calibration laboratory. This reference standard is used to calibrate the laboratory work standard (C) to be used daily by the cal lab. This work standard is then used to calibrate the final product (D) or device under test. Accordingly, the calibration path is A-B-C-D. This path is called the chain of traceability.

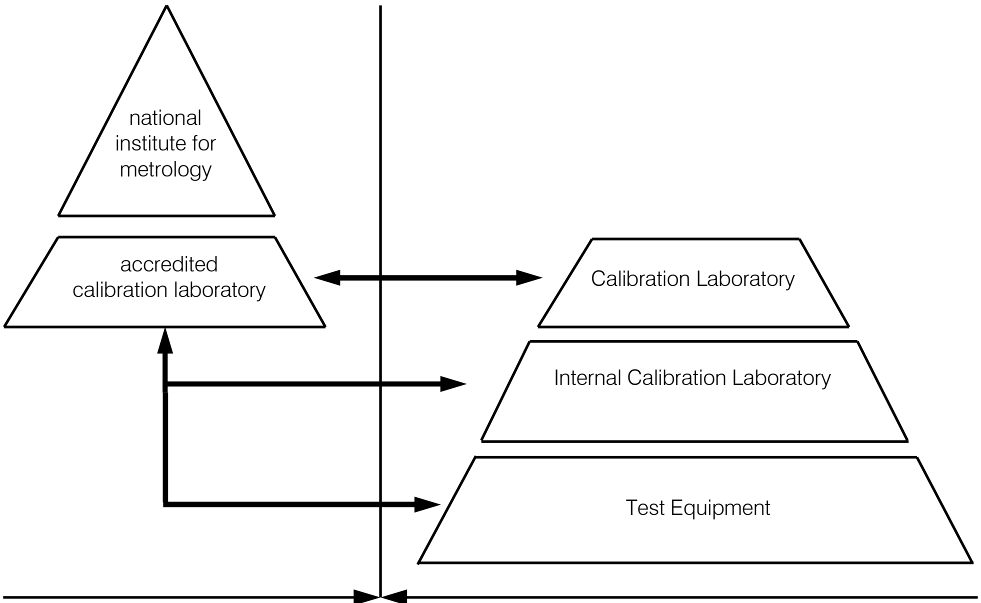
Each transfer device in the chain should be subjected to periodic examination to ensure its long term stability. The time span between examinations is typically set by the lab performing the calibration and is self-audited.

<u>Accredited calibration laboratories guarantee recalibration cycle times for their standards plus a review of their calibration procedures since they are subject to annual review by an official accreditation authority.</u>

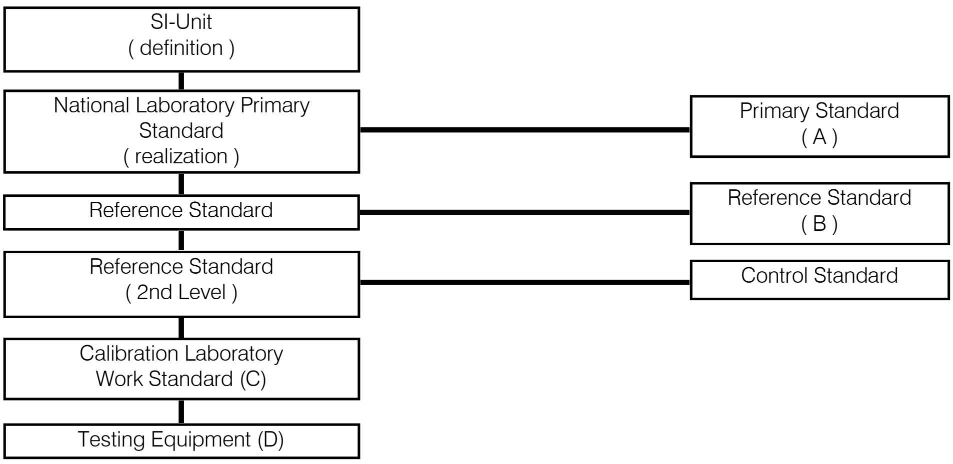
For the optical radiation measurement quantities of *Spectral Irradiance* and *Spectral Responsivity,* the Gigahertz-Optik calibration laboratory offers DKD calibration with direct comparison to its reference standards and fully documented procedures. This type of calibration, which offers the lowest available calibration uncertainty, is normally requested by high level industrial calibration laboratories or institutions who may in turn use the calibrated device as their own reference standard.

However, in the majority of applications, end-users only need a simpler more economically priced calibration, since their type of measurement may not demand the lowest possible measurement uncertainty. But they do demand calibration certificates showing a confirmed unbroken chain of traceability to a national standard. For this requirement Gigahertz-Optik offers a „factory calibration“ for Spectral Irradiance and Spectral Responsivity and all other calibrations which do not require the higher accreditation level.

To confirm traceability, every calibration is documented by a calibration certificate, which lists the calibrated device's identification data, calibration procedure, calibration uncertainty, environmental conditions as well as the traceability data back to the national standards laboratory.
The certificate is signed by the calibration engineer and stamped by the calibration laboratory manager.



Calibration Hierarchy from the Primary Standard to the Test Equipment



Hierarchy of Standards

Gigahertz-Optik's Calibration Laboratory

Gigahertz-Optik‘s Calibration Laboratory for Optical Radiation Measurement Quantities

Gigahertz-Optik's calibration laboratory for optical radiation measurement quantities owns, uses and maintains lamp, detector and reflector based reference standards traceable to PTB, NRC, NIST and NPL.

<u>Spectral Irradiance</u> E(λ) is the most basic radiometric measurement quantity and can be used to calculate many other quantities such as:

- Integral Irradiance ***E***, associated with spectrally broadband detectors
- Photobiological Actinic Irradiance E_{biol}
- Photosynthetically Active Irradiation E_{PAR}
- Illuminance E_v
- Colorimetric Quantities
- Radiant Power, Radiant Intensity, Radiance, Luminous Flux, Luminous Intensity and Luminance for known geometrical relationships

The DKD proofed reference standard used here are 1000W FEL-type quartz-halogen lamps that have been carefully selected after a burn-in procedure of about 80 to 100 hours. The useful spectral range of these sources is 250 to 2500 nm. This type of calibration standard is also offered to our customers under the model number BN-9101 (refer to Calibration Standards & Uniform Light Sources chapter for more information).

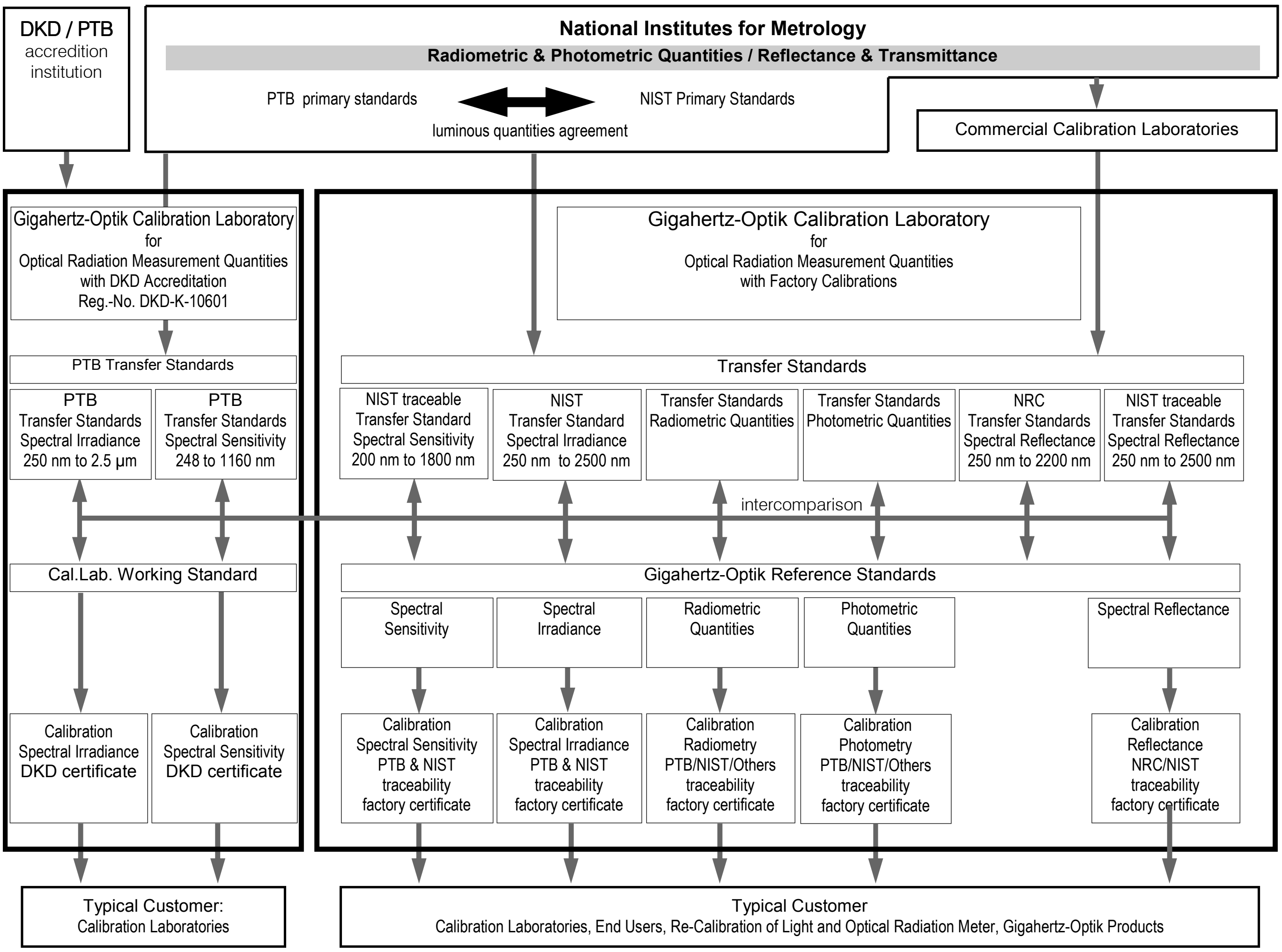
<u>Spectral Responsivity</u> of optical <u>radiation detectors</u> is a commonly required calibration and is supplied with each Gigahertz-Optik detector order.
The DKD reference standard used in this type of calibration are Si–Photodiodes with its operating temperature controlled by a thermal sensor during the calibration procedure. The useful wavelength range of this reference detector is 248 to 1160 nm. Beside that NIST calibrated Si and InGaAs photodiodes are used for factory calibration in the spectral range from 200 to 1800 nm.

Calibrations other than spectral sensitivity and spectral irradiance are performed using calibration standards from NIST and other national labs. By intercomparison to the accredited DKD standards, long term stability and therefore traceability of the non-DKD standards is ensured.

ISO/IEC/EN 17025 (formerly ISO/IEC Guide 25, known as ANSI/NCSL Z540-1, and EN45001) accreditation assures the competency of calibration laboratories to carry out specific tests or calibrations and forms the basis of the lab's quality system.

Accreditation Document for Gigahertz-Optik's Calibration Laboratory

Traceability Chart of Gigahertz-Optik's Calibration Laboratory for Optical Radiation Measurement Quantities



DKD Accrediting Authority

The German accreditation institution DKD (Deutscher Kalibrierdienst) was founded by the German trade and industry and the German state, represented by the Physikalisch-Technische Bundesanstalt (PTB), the German national standard laboratory.

The basic idea of the DKD is to transfer as many PTB responsibilities to industry as possible, including the calibration of measurement and testing equipment. The DKD ensures the traceability of measurement and testing equipment to national standards by the accreditation and continuous control of industrial calibration laboratories.

Therefore, calibration carried out by DKD accredited calibration laboratories offers a secured traceable link to national calibration standards. An uninterrupted traceability chain of calibration to national standards is of critical importance for instrument and testing equipment manufacturers in order to be competitive in national and international markets and is absolutely necessary for any quality management system.

The qualification of the traceability to national standards is the job of the Physikalisch-Technische Bundesanstalt (PTB), the German national standard laboratory. The PTB will define, realize, keep and transmit the physical quantities of the SI-system, such as a meter, a second, a kilogram, a candela, etc.

To ensure objective results, equal standards must be used. The calibration of measurement and testing arrangements based on SI-units is a basis for correct, comparable, recognizable and therefore measurable values, which can be audited.

Within the DIN ISO 9000 standard the relationship between quality management and calibration are intertwined in part for continuous control of measurement and testing equipment.

Without exception, DKD accredited calibration laboratories fulfill the requirements of DIN EN ISO/IEC 17025 (general criterions to operate a testing laboratory). DIN EN ISO/IEC 17025 replaced EN 45001 and ISO/IEC Guide 25 in 1999.

The European position of the DKD is noted by its membership in the *European Cooperation for Accreditation of Laboratories (EAL)* in Rotterdam, which was founded out of the Western European Calibration Cooperation (WECC) and the Western European Laboratory Accreditation Cooperation (WELAC) in 1994. Within the EAL different national accreditation institutes cooperate with the goal of international acceptance of calibration certificates of the EAL-calibration laboratories. In November 2000, 34 accreditation institutions from 28 countries, including the PTB, the accreditation institution of the DKD, signed a Mutual Recognition Arrangement (MRA) of the International Laboratory Accreditation Cooperation (ILAC). More information about this arrangement and the participating countries is available online at

www.ilac.org.

More information is available on

PTB - the German National Calibration Laboratory

The Physikalisch-Technische Bundesanstalt (PTB) is the highest technical authority for metrology in Germany. The PTB's responsibilities are to define, realize, keep and transmit the physical quantities of the SI-system, such as a meter, a second, a kilogram, a candela and many other standards.

The PTB is the official accreditation institution for DKD calibration laboratories such as the Gigahertz-Optik calibration laboratory for optical radiation measurement quantities. The PTB is also active in getting bilateral acceptance for international standards. Because of their activities in 1995, a Statement of Intent on Traceability of Measurement Standards was signed between the Physikalisch-Technische Bundesanstalt (PTB) and the National Institute of Standards and Technology (NIST) USA. The Equivalence of the National Standards of NIST and PTB for the SI Units of Luminous Intensity and Luminous Flux was officially recognized in April 1999.

More information is available on the internet at www.ptb.de

NIST - U.S. National Institute of Standards and Technology

As part of its responsibilities the Optical Technology Division of NIST's Physics Laboratory develops, improves, and maintains the national standards for radiation thermometry, spectroradiometry, photometry, colorimetry, and spectrophotometry; provides National measurement standards and support services to advance the use and application of optical technologies spanning the ultraviolet through microwave spectral regions; disseminates these standards by providing measurement services to customers requiring calibrations of the highest accuracy and performs research and publishes technical reports & procedures to further the base of knowledge.

For more information visit the NIST Physics Laboratory Optical Technology Division Home Page, www.physics.nist.gov

NPL - National Physical Laboratory UK

NPL's Optical Radiation Measurement (ORM) Group provides services which are the backbone for optical radiation measurements in the UK and internationally. Here the UK's Primary Standards and scales are maintained, and research in measurement science is carried out. ORM anticipates and responds to industrial and academic measurement requirements throughout the IR, Visible, and UV spectra.

Measurement and calibration services include the characterization and calibration of: all types of optical radiation sources, optical radiation detectors and associated devices, optical properties of materials and components & aspects of appearance including color, haze and gloss.
Visit NPL ORM Introduction Web Page www.npl.co.uk for more information.

NRC - National Research Council Canada

The NRC's Institute for National Measurement Standards Photometry and Radiometry Group maintains photometric, radiometric, spectrophotometric and colorimetric standards, and provides associated, high-accuracy measurement services to industry, university, and government clients involved with lighting, transportation, manufacturing, telecommunications, public health and safety, and the environment.
More information is available on the internet at the NRC INMS Photometry & Radiometry Home Page: www.nrc.ca/inms

K-xx Calibration & Re-Calibration of Gigahertz-Optik Light Detectors

K-xx-I, K-xx-S, K-xx-SR Integral & Monochromatic Calibration

Different types of light detector sensitivity calibrations are available:

Integral Calibration:
A broadband light source is used to irradiate the detector under test. The irradiation intensity of the light source is calibrated within the sample detectors spectral sensitivity range in the appropriate units of measurement. By comparing the detectors signal current to the given light intensity the test detector's sensitivity is calibrated.
Typical examples where integral calibration are employed:

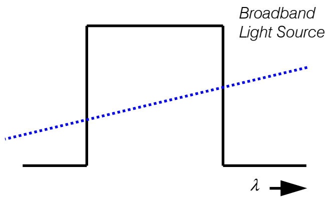
- Photometric light detectors where calibration is done with a standard Illuminant A light source at 2856 K.
- Integral radiometric detectors such as UV-A, VISIBLE, Erythema & PAR used in applications with broadband light sources.

Spectral Calibration:
A monochromatic light source is used to irradiate the test detector at a specified wavelength in the appropriate units of measurement. By comparing the detectors signal current to the given light intensity the test detector's sensitivity can be calibrated.
Typical examples where monochromatic calibrations are employed:

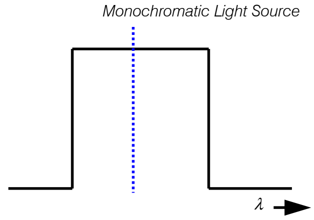
- Light detectors used to measure lasers or quasi monochromatic light sources. Calibration is performed at the laser wavelength or the peak wavelength of the quasi monochromatic light.
- Light detectors with narrow band pass filters. Calibration is done at the peak wavelength of sensitivity.

Spectral Calibration Dataset:
This calibration is identical to the spectral calibration with the except of a tunable monochromatic light source. This allows multipoint calibration of detector sensitivity over a series of different wavelengths. Typically the calibration is done in 10 nm steps within the spectral sensitivity range of the detector assembly.
Typical examples for the selection of spectral calibrations are:

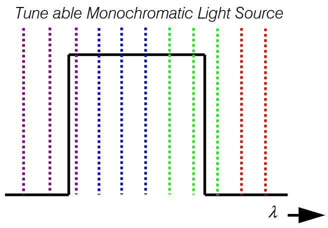
- Light detectors used to measure lasers or quasi monochromatic light sources at different wavelengths.



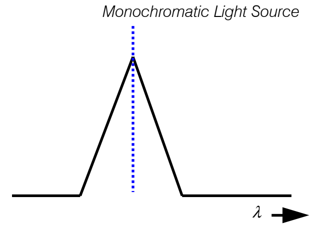
Integral



Monochromatic



Spectral



Peak Monochromatic

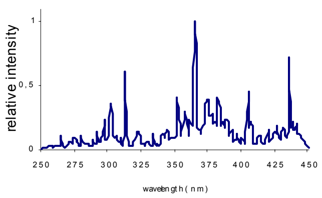
- Light detectors used for the calibration of tunable monochromatic light sources.
- In addition to integral calibrations of broadband detectors when used to measure light sources different than the lamp calibration standard. (See a(z) correction).

Relative Spectral Calibration:
All integral light detectors supplied by Gigahertz-Optik with certified absolute integral or monochromatic calibrations include an additional relative spectral sensitivity calibration. This spectral sensitivity data allows computation of estimated measurement uncertainty as well as calculation of the a(z) calibration correction factor.
On detector re-calibration the relative spectral sensitivity calibration is offered as an option.
- Consult the factory to discuss the appropriate calibration technique for your light detector application.

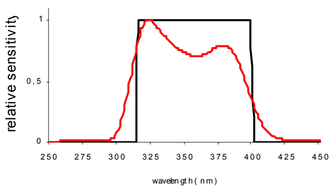
Ordering Information	
K-xx-I	Integral sensitivity calibration of a G-O light detector with a broad band light source. *), **)
K-xx-S	Spectral calibration of a G-O light detector at a single wavelength or at a series of wavelengths. **)
K-xx-SR	Relative spectral sensitivity calibration of a light detector. Only available in combination with a K-xx-I or K-xx-S calibration.
*) Includes one K-xx-SR calibration with new detector order. **) Example: K-UV3701-I for calibration of UV-3701 light detector	

a(z) Calibration Correction Factor for Known Light Sources

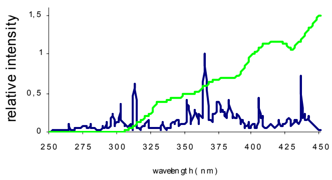
Integral light detectors are composed of photodiodes with optical edge and bandpass filter combinations used to correct or shape spectral sensitivity.
However, the complete detector's spectral sensitivity, e.g. UV-A, PAR, UV-Erythema, can never perfectly match the intended spectral sensitivity of the ideal actinic function plus tolerance limits in the filter batch processes exist. As such the measurement uncertainty of an integral detector may vary in applications involving light sources with emission spectra different than that of the reference lamp used in the detector calibration.
The a(z) method developed by Gigahertz-Optik makes it possible to calculate calibration correction factors if the emission spectrum of the calibration reference source, spectral sensitivity of the light detector and the application light source emission spectrum is known.
Background information on the a (z) correction method is available in the *Tutorial* section.



Spectrum Calibration Lamp



Spectral Sensitivity Detector



Spectrum Application Lamp

The simulated a(z) correction factor for the application lamp CEI IEC AM1,5 Sun.dat is

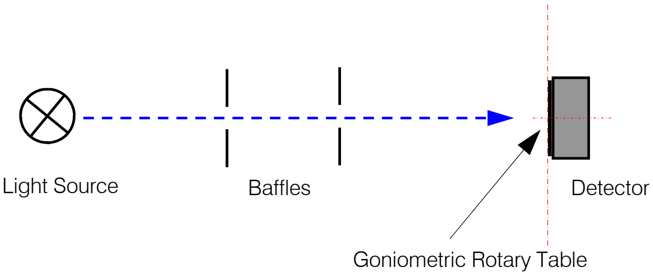
0.94976974

a(z) Correction Factor

Ordering Information	
K-SAZ-01	Computation of expected light detector measurement uncertainty for light sources different than calibration lamp. Computation with several typical light source spectra from G-O lamp library.
K-SAZ-02	Computation of uncertainty based on end-user supplied emission spectrum. Excel or ASCII file with 1 nm step must be supplied or can be measured by G-O as an option.

K-FOV Field-of-View; K-xx-C Current; KF Other Manufacturer Products

K-FOV Field-of-View Calibration of Gigahertz-Optik Light Detectors



Besides standard detector sensitivity calibration services, Gigahertz-Optik offers a field-of-view calibration service for G-O light detectors.
The F.o.V. calibration is offered for all irradiance and illuminance detectors employing diffuser windows for a cosine corrected measurement geometry.
The calibration is done with a spot light source at a distance of 2 m (78 inch) from the detector.
The test detector is mounted onto a goniometric rotary table. It's diffuser surface is aligned to the axis of the rotary table.
The signal as a function of the viewing angle is measured and compared with the ideal cosine spatial function. The measured characteristic as well as the calculated f_2 uncertainty is stated in the factory calibration certificate.

Ordering Information	
K-FOV-01	Field-of-View calibration of irradiance or illuminance light detectors with f2 uncertainty calculation. Factory calibration certificate

K-xx-C Current Calibration of Gigahertz-Optik's Optometers

Gigahertz-Optik's optometers are built around precision multi-gain range current amplifiers to process the light detector signal.
All optometers are calibrated and certified using a variable current source which itself is calibrated by an outside accredited calibration laboratory.
Correction factors are calculated based on the calibration values and used to adjust the display readings at each gain range.
This current calibration is offered as a re-calibration service for all of the different Gigahertz-Optik optometers.
Calibration uncertainty and traceability information is supplied in the factory calibration certificate.

Ordering Information	
K-xx-C	Current calibration and adjustment of Gigahertz-Optik optometers. xx = model number. Factory calibration certificate

KF Regular Re-Calibration Service for Other Manufactures Products

Calibration services are available for other light meter manufacturer's products as well.
But in order to perform the work some important information must be provided including:

- Spectral sensitivity
- Signal range
- Measurement units
- Old calibration certificate

If this data is available a comparable calibration such as KDW-S, -I or –P can be done.
In cases where this information is not available a one-time set-up procedure for the first calibration must be established. This means our experts must analyze the instrument by measuring it's spectral sensitivity, field-of-view geometry and other parameters. After this evaluation the instrument can be calibrated.
<u>Note</u>: This calibration may only confirm the correlation or non-correlation between an input and output quantity. An actual adjustment of the meter for direct reading is not always possible since calibration adjustment procedures differ from manufacturer to manufacturer.
Where a simple potentiometer adjustment or an eprom with open data format for programming the correction factor is used, we can supply the calibration and adjust for direct reading.
Over the last 15 years we have re-calibrated many manufacturers' light meters. A price list of the regularly calibrated units is available on demand. The list includes the:

- Part/model number
- Manufacturer
- Job description
- Annual recalibration plan.

If your specific instrument is not listed please contact the factory to see if it can be calibrated or to discuss the feasibility and cost involved to perform the one time pre-calibration product qualification.

Ordering Information	
KF-xx	Calibration of other manufacturers' standard light meters. Please contact the factory for price & description list or to discuss your special calibration requirements.

KLD-S1 & KLW-S1 Spectral Irradiance of Light Sources

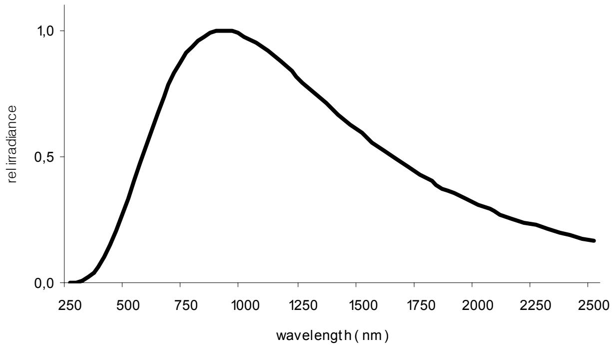
Calibration Traceability

Since July 1994, the Gigahertz-Optik calibration laboratory for optical radiation measurement quantities has been accredited by the DKD accreditation institution (Registration Number DKD-K-10601) for the calibration of Spectral Irradiance .
For quartz-halogen lamps and incandescent sources in the power range from 500 W to 2000 W, spectral irradiance calibration with an official DKD calibration certificate is available. These lamps are calibrated against one G-O calibration laboratory BN-9101 1000 W FEL Type quartz-halogen lamps (PTB calibration certification for wavelengths from 250 to 2500 nm). The reference

BN-9101

sources are periodically recalibrated by the PTB.
Intercomparison measurements of the source under test, such as the BN-9101 (See *Calibration Standards* section), to a reference standard source are performed. The complete calibration procedure follows accreditation regulations and is confirmed by a DKD calibration certificate supplied with the calibrated source.

BN-9101 relative spectrum



KLD Calibration in W/(m²nm) with DKD Certificate

The KLD calibration of spectral irradiance with DKD certificate is performed according to fixed accredited calibration procedures and specifications. The calibration is limited for lamps between 500 to 2000 W in the wavelength range from 250 nm to 2500 nm.
The calibration is done by direct comparison to a PTB Reference Standard and is confirmed in the official DKD calibration certificate supplied with the calibrated source.

KLW Calibration in W/m²nm with Factory Certificate

A more economically priced calibration with slightly higher calibration uncertainties called the KLW spectral irradiance calibration is available which includes a factory certificate. The device data, calibration procedure, calibration uncertainty, environmental conditions as well as the traceability data back to the national standards laboratory are confirmed in the certificate.
The lamp power range is unlimited. Wavelength range is from 250 nm to 2500 nm.

Wavelength Dependent Calibration Uncertainty

Measurement Quantity	Wavelength nm	**KLD-S1**		**KLW-S1**	
		Measurement Conditions	Relative Measurement Uncertainty with Reference Standard	Measurement Conditions	Relative Measurement Uncertainty
Spectral Irradiance in W/(m² nm) of Optical Radiation Sources	λ=250	Only for incandescent sources power range 500 W ≤ P ≤ 2000 W	± 10 %	Power range >100 W. Measurement uncertainty may increase depending on lamp type	± 12 %
	λ=260		± 7 %		± 8 %
	270 ≤ λ <400		± 4 %		± 4.5 %
	400 ≤ λ<800		± 3 %		± 3.5 %
	800 ≤ λ <2000		± 4.5 %		± 5.5 %
	2000 ≤ λ ≤ 2500		± 7 %		± 8.5 %
Calibration Steps: 10 nm from 250 to 300 nm; 20 nm from 320 to 800 nm; 50 nm from 850 to 2500 nm					

Ordering Information

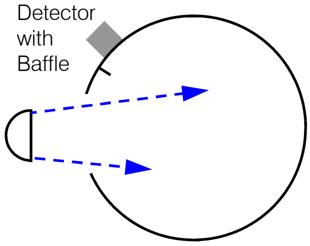
KLD-S1-01	Spectral Irradiance calibration within the wavelength range 250 to 400 nm with DKD certificate
KLD-S1-02	Spectral Irradiance calibration within the wavelength range 400 to 1100 nm with DKD certificate
KLD-S1-03	Spectral Irradiance calibration within the wavelength range 1100 to 2500 nm with DKD certificate
KLD-S1-04	Spectral Irradiance calibration within the wavelength range 250 to 1100 nm with DKD certificate
KLD-S1-05	Spectral Irradiance calibration within the wavelength range 400 to 2500 nm with DKD certificate
KLD-S1-06	Spectral Irradiance calibration within the wavelength range 250 to 2500 nm with DKD certificate
KLD-S1-RP	Set-up charge for non-Gigahertz-Optik sources
KLW-S1-01	Spectral Irradiance calibration within the wavelength range 250 to 400 nm with factory certificate
KLW-S1-02	Spectral Irradiance calibration within the wavelength range 400 to 1100 nm with factory certificate
KLW-S1-03	Spectral Irradiance calibration within the wavelength range 1100 to 2500 nm with factory certificate
KLW-S1-04	Spectral Irradiance calibration within the wavelength range 250 to 1100 nm with factory certificate
KLW-S1-05	Spectral Irradiance calibration within the wavelength range 400 to 2500 nm with factory certificate
KLW-S1-06	Spectral Irradiance calibration within the wavelength range 250 to 2500 nm with factory certificate
KLW-S1-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-S2, KLW-S3 & KLW-S4 Spectral Calibration of Light Sources

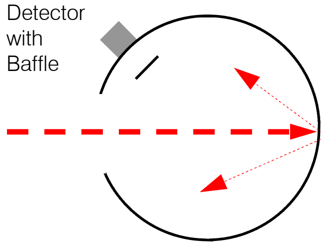
KLW-S2, Spectral Radiant Power (W/nm)

Radiant power is the total emitted radiation of light sources such as lamps, lasers, etc.
To measure radiant power the emitted light from the source must be detected independent of emitted direction.
For lamps that emit light in all directions a light integrator such as an integrating sphere or a goniometric scanner is required.

For spot lamps and directional sources, such as lasers, integrating spheres that can collect the light beam through a port in its wall are used.
Gigahertz-Optik's calibration laboratory offers calibration of beam emitter light sources over a restricted power range. Consult the factory to discuss your requirements.



Integrating Sphere for Spot Lamp Measurements

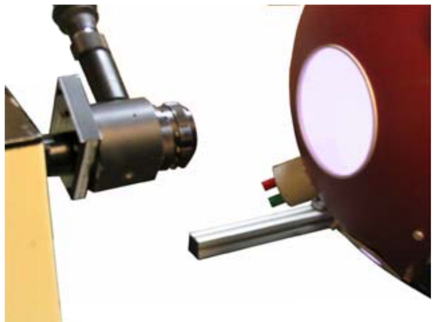


Integrating Sphere for Laser Power Measurements

Ordering Information	
KLW-S2-01	Spectral Radiant Power of Spot lamps. Contact the factory to discuss calibration details.
KLW-S2-02	Spectral Radiant Power of monochromatic, directional emitting light sources within the wavelength range 350 to 1100 nm. Maximum beam diameter 10 mm. Maximum power 1000 mW. Factory calibration certificate
KLW-S2-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-S3, Spectral Radiance (W/(m²sr nm))

Radiance in a given direction, at a given point of a real or imaginary surface is the radiometric measurement quantity used to calibrate area sources of optical radiation. Gigahertz-Optik's calibration laboratory offers calibration of spectral radiance within the wavelength range 300 nm to 2500 nm.
The calibration is done with a spectral radiometer equipped with a front lens. The spectrometer system is calibrated with an integrating sphere based spectral radiance transfer standard.
The photometric quantity, luminance can be calculated using the radiometric calibration values from 380 to 780 nm if required.
A factory calibration certificate is supplied.



Typical set-up to calibrate the spectral radiance of an integrating sphere based uniform light source

Ordering Information	
KLW-S3-01	Spectral Radiance within the wavelength range from 300 to 780 nm in 10 nm steps measured with a double monochromator DC spectrometer with photomultiplier tube. Factory calibration certificate.
KLW-S3-02	Spectral Radiance within the wavelength range from (380) 450 to 1100 nm in 10 nm steps measured with a single monochromator DC spectrometer with silicon detector. Factory calibration certificate.
KLW-S3-03	Spectral Radiance within the wavelength range from 1100 to 1700 nm in 10 nm steps measured with a single monochromator DC spectrometer with InGaAs detector. Factory calibration certificate.
KLW-S3-04	Spectral Radiance within the wavelength range from 1100 to 2500 nm in 50 nm steps measured with a single monochromator AC spectrometer with PbS detector. Factory calibration certificate.
KLW-S3-05	Spectral Radiance within the wavelength range from 300 to 1100 nm (KLW-S3-01 & 02) with factory calibration certificate.
KLW-S3-06	Spectral Radiance within the wavelength range from 300 to 2500 nm (KLW-S3-01, 02 & 04) with factory calibration certificate.
KLW-S3-07	Spectral Radiance within the wavelength range from (380) 450 to 2500 nm (KLW-S3-02 & 04) with factory calibration certificate.
KLW-S3-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-S4, Spectral Radiant Intensity (W/(sr nm))

The radiant intensity of a light source, is the emitted light in a given direction. Radiant intensity is the radiometric measurement quantity used to calibrate directionally emitted light from lamps.
Radiant intensity is measured with a irradiance detector equipped with precise front aperture then calculated from the measured irradiance and the solid angle resulting from the light source to aperture distance and the aperture diameter.
A factory calibration certificate is provided.

Ordering Information	
KLW-S4-01	Spectral Radiant Intensity of Spot lamps. Contact the factory to discuss calibration details.
KLW-S4-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-R & KLW-P Integral Radiometric & Photometric Calibration of Light Sources

Integral Radiometric Calibrations

KLW-R1, Irradiance (W/m²)

Irradiance is measured at a specified distance from the light source with a calibrated spectral radiometer. The spectrometer itself is calibrated in reference to a spectral irradiance standard which ensures the traceability of the calibration. The integral irradiance is calculated from the measured spectral data for the specified wavelength range. With the current lab irradiance standard lamps available, the spectral radiometer can be calibrated within the wavelength range from 250 to 2500 nm. A factory calibration certificate is supplied listing the light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-R1-01	Irradiance calibration within a specified wavelength range . Contact the factory to discuss calibration details.
KLW-R1-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-R2, Radiant Power (W)

Radiant power of spot lamps is measured with a spectral radiometer mounted to an integrating sphere. The spectrometer with integrating sphere is calibrated in reference to a spectral irradiance standard which is placed at a specified distance to the sphere. The radiant power entering the sphere through a precise aperture in its measurement port is calculated. The integral radiant power is calculated from the measured spectral data for the specified wavelength range. With the current lab standard lamps available, the spectral radiometer can be calibrated within the wavelength range from 300 to 2500 nm. A factory calibration certificate is supplied listing the light source data, measurement set-up, traceability and calibration uncertainty

Ordering Information	
KLW-R2-01	Radiant power calibration within a specified wavelength range . Contact the factory to discuss calibration details.
KLW-R2-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-R3, Radiance (W/(m²sr))

Radiance of uniform light sources is measured with a spectral radiometer mounted with a front lens. The spectrometer with front lens is calibrated in reference to a spectral radiance standard. The integral radiance is calculated from the measured spectral data for the specified wavelength range. With the current lab standard radiance lamps available, the spectral radiometer can be calibrated within the wavelength range from 300 to 2500 nm. A factory calibration certificate is supplied listing the light source data, measurement set-up, traceability and calibration uncertainty

Ordering Information	
KLW-R3-01	Radiance calibration within a specified wavelength range . Contact the factory to discuss calibration details.
KLW-R3-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-R4, Radiant Intensity (W/sr)

Radiant intensity of light sources is measured with a spectral radiometer mounted with a precision measurement aperture. The spectrometer is calibrated in reference to a spectral irradiance standard. The radiant intensity is calculated from the measured irradiance and the solid angle resulting from the light source to aperture distance and the aperture diameter. The integral radiant intensity is calculated from the measured spectral data for the specified wavelength range. With the current lab standard lamps available, the spectral radiometer can be calibrated within the wavelength range from 300 to 2500 nm. A factory calibration certificate is supplied listing the light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-R4-01	Radiant intensity calibration within a specified wavelength range . Contact the factory to discuss calibration details.
KLW-R4-RP	Set-up charge for non-Gigahertz-Optik sources

Integral Photometric Calibrations

KLW-P1, Illuminance (lx)

Illuminance of light sources is measured with an illuminance detector and an optometer. The illuminance detector is calibrated in reference to an illuminance standard source. The optometer is calibrated in reference to a DKD calibrated current source. A factory calibration certificate is supplied listing the light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-P1-01	Illuminance calibration of light sources. Factory calibration certificate.
KLW-P1-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-P, KLW-C, KLW-D Photometric, Colorimetric, Directional Calibration of Sources

Integral Photometric Calibrations

KLW-P2, Luminous Flux (lm)

Luminous flux of spot lamps is measured with an integrating sphere, photometric detector and an optometer.
The integrating sphere and detector combination is calibrated in reference to an illuminance standard lamp which is placed at a specified distance to the sphere. The luminous flux entering the sphere through a precise aperture of the sphere measurement port is then calculated. The optometer is calibrated in reference to a DKD calibrated current source.
A factory calibration certificate is supplied listing light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-P2-01	Luminous flux calibration of spot lamps. Contact the factory to discuss calibration details.
KLW-P2-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-P3, Luminance (cd/m²)

Luminance is measured with a luminance detector and an optometer.
The luminance detector is calibrated in reference to a luminance standard source. The optometer is calibrated in reference to a DKD calibrated current source.

A factory calibration certificate is supplied listing light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-P3-01	Luminance calibration of spot lamps. Factory calibration certificate
KLW-P3-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-P4, Luminous Intensity (cd)

Luminous intensity is measured with an illuminance detector equipped with a precise front aperture and an optometer.
The luminous intensity is calculated from the measured illuminance and the solid angle resulting from the light source to aperture distance and the aperture diameter.
The illuminance detector is calibrated in reference to an illuminance standard source. The optometer is calibrated in reference to a DKD calibrated current source.

A factory calibration certificate is supplied listing light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-P4-01	Luminous intensity calibration of spot lamps. Factory calibration certificate
KLW-P4-RP	Set-up charge for non-Gigahertz-Optik sources

Colorimetric & Directional Calibrations

KLW-CT, Luminous Color (x,y), Color Temperature (K)

The x,y chromaticity values and color temperature of tungsten light sources is measured with a RGB-color detector and an optometer.
The color detector is calibrated in reference to an illuminance standard source operated at a known color temperature. The optometer is calibrated in reference to a DKD calibrated current source.

A factory calibration certificate is supplied listing light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-CT-01	x,y chromaticity values and color temperature calibration of light sources. Factory calibration certificate
KLW-CT-RP	Set-up charge for non-Gigahertz-Optik sources

KLW-ID, Light Intensity Distribution

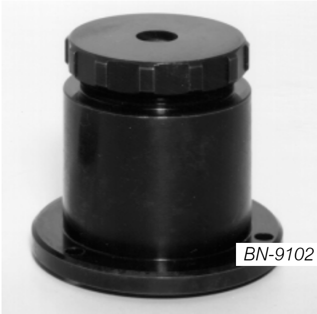
Uniform light sources based on integrating spheres can be calibrated in regard to their xy luminance/radiance uniformity and hemispherical emittance uniformity (lambertian light source).
A luminance detector head with an optometer is used for the uniformity measurement. Precise xy and goniometric positioning stages allows xy and viewing angle alignment of the luminance detector in front of the light emitting area.
The luminance detector is calibrated in reference to a luminance standard source.
The optometer is calibrated in reference to a DKD calibrated current source.
A factory calibration certificate is supplied listing light source data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KLW-ID-01	Calibration of the xy luminance uniformity of uniform light sources. Factory calibration certificate
KLW-ID-02	Calibration of the hemispherical luminance uniformity of uniform light sources. Factory calibration certificate
KLW-ID-03	Calibration of the xy and hemispherical luminance uniformity of uniform light sources. Factory calibration certificate
KLW-ID-RP	Set-up charge for non-Gigahertz-Optik sources

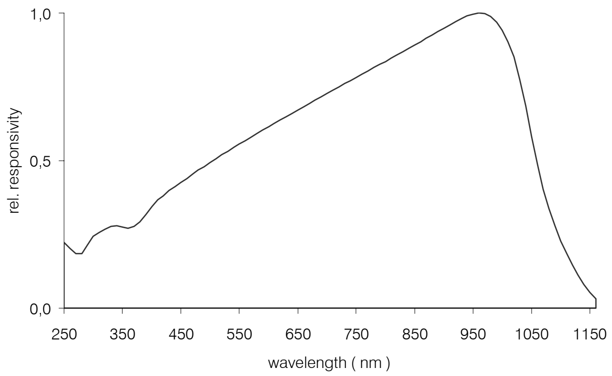
KDD-S1 & KDW-S1 Spectral Radiant Power Sensitivity of Light Detectors

Calibration Traceability

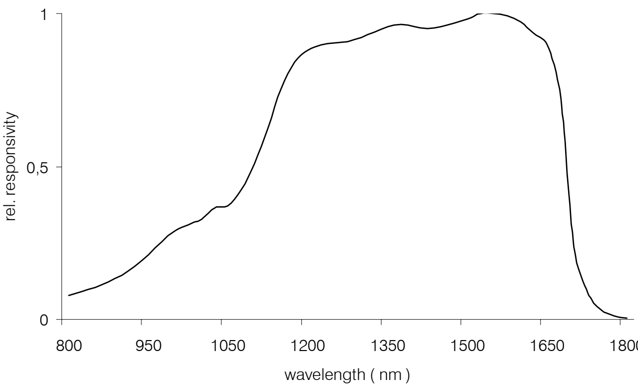
Since June 1993, the Gigahertz-Optik calibration laboratory for optical radiation measurement quantities has been accredited by the DKD accreditation institution (registration Number DKD-K-10601) for the calibration of spectral sensitivity of optical radiation detectors within the wavelength range from 248 nm to 1160 nm. Several BN-9102 transfer standards with PTB calibration certificates for the wavelength range from 248 to 1160 nm are available. These reference standards are periodically recalibrated by the PTB. Other detectors are calibrated by comparison measurements to this reference.



Besides transfer standards used for accredited levels calibrations Gigahertz-Optik maintains NIST calibrated transfer standards for the wavelength ranges from 200 to 1100 nm and 800 to 1800 nm which are used for calibrations requiring factory certificates.



BN-9102 spectral sensitivity



InGaAs standard spectral sensitivity

KDD Calibration with DKD Certificate

This detector calibration is done by comparison to a PTB reference standard and is documented in an official DKD calibration certificate supplied with the calibrated detector. The complete calibration procedure follows DKD accreditation regulations. During the calibration the detector's operating temperature is stabilized to ±0.5°C.
Calibrations are offered at the wavelengths listed or in 20 nm steps within the specified wavelength ranges.

Wavelength Dependent Calibration Uncertainty

Measurement Quantity	Wavelength nm	KDD-S1	
		Measurement Conditions	Relative Measurement Uncertainty
Spectral Radiant Power Sensitivity	248.4 ; 265.3 ; 280.4 ; 289.4 ; 302.2 ; 313 ; 334.2 ; 366	1 nW/cm² ≤ E ≤ 10 µW/cm² 18 °C ≤ t ≤ 28 °C 1 nm ≤ Δλ ≤ 11 nm	± 3%
	380 to 900 in 20 nm steps	0.1 µW/cm² ≤ E ≤ 100 µW/cm² 18 °C ≤ t ≤ 28 °C 1 nm ≤ Δλ ≤ 11nm	± 2%
	920 to 1040 in 20 nm steps		± 2.5%
	1060 ; 1080 ; 1100		± 3%
	1120 ; 1140 ; 1160		± 4%

KDW Calibration with Factory Certificate

Calibration of spectral sensitivity with a factory calibration certificate is offered for the wavelength range from 200 nm to 1800 nm in 10 nm increments.
The calibration is done by comparison to an PTB or NIST traceable transfer standard detector. A factory calibration certificate is supplied listing detector data, measurement set-up, traceability and calibration uncertainty.

Wavelength Dependent Calibration Uncertainty

Measurement Quantity	Wavelength nm	Light Spot Diameter	KDW-S1	
			Measurement Conditions	Relative Measurement Uncertainty
Spectral Radiant Power Sensitivity	200 to 400 in 10 nm steps	3 - 7 mm	1 nW/cm² ≤ E ≤ 10 µW/cm² 18 °C ≤ t ≤ 28 °C 1 nm ≤ Δλ ≤ 11 nm	200 - 240 nm ± 7 % 250 - 370 nm ± 4.5 % 380 - 400 nm ± 3.0 % 410 - 900 nm ± 3.0 % 910 - 1070 nm ± 4.5 % 1080 - 1100 nm ± 5 % 1110 - 1800 nm ± 5.5 %
	400 to 1100 in 10 nm steps		0.1 µW/cm² ≤ E ≤ 100 µW/cm² 18 °C ≤ t ≤ 28 °C 1 nm ≤ Δλ ≤ 11 nm	
	1100 to 1800 in 10 nm steps		0.1 µW/cm² ≤ E ≤ 100 µW/cm² 18 °C ≤ t ≤ 28 °C 2 nm ≤ Δλ ≤ 22 nm	

KDD-S1, KDW-S1, KDW-S2, KDW-S3 & KDW-S4 Calibration of Light Detectors

KDD-S1 & KDW-S1, Spectral Radiant Power Sensitivity (A/W)

Ordering Information Calibration with DKD Certificate	
KDD-S1-01	Spectral radiant power sensitivity calibration at all DKD wavelength (see KDD-S1-04) within 248 to 400 nm with DKD certificate
KDD-S1-02	Spectral radiant power sensitivity calibration at all DKD wavelength (see KDD-S1-04) within 366 to 1160 nm with DKD certificate
KDD-S1-03	Spectral radiant power sensitivity calibration at all DKD wavelength (see KDD-S1-04) within 248 to 1160 nm with DKD certificate
KDD-S1-04	Spectral radiant power sensitivity calibration at one of the following wavelength in nm; 248.8, 265.3, 280.4, 289.4, 302.2, 313, 334.2, 366 and 380 to 1160 all 20 nm. DKD calibration certificate
KDD-S1-05	Spectral radiant power sensitivity calibration at an additional wavelength to KDD-S1-04
KDD-S1-RP	Set-up charge for non-Gigahertz-Optik detectors

Ordering Information Calibration with Factory Certificate	
KDW-S1-01	Spectral radiant power sensitivity calibration in 10 nm steps from 200 to 400 nm with factory certificate
KDW-S1-02	Spectral radiant power sensitivity calibration in 10 nm steps from 350 to 1100 nm with factory certificate
KDW-S1-03	Spectral radiant power sensitivity calibration in 10 nm steps from 800 to 1800 nm with factory certificate
KDW-S1-04	Spectral radiant power sensitivity calibration in 10 nm steps from 200 to 1100 nm with factory certificate
KDW-S1-05	Spectral radiant power sensitivity calibration in 10 nm steps from 350 to 1800 nm with factory certificate
KDW-S1-06	Spectral radiant power sensitivity calibration in 10 nm steps from 200 to 1800 nm with factory certificate
KDW-S1-07	Spectral radiant power sensitivity calibration at one wavelength within 200 to 400 nm with factory certificate
KDW-S1-08	Additional wavelength to KDW-S1-07
KDW-S1-09	Spectral radiant power sensitivity calibration at one wavelength within 350 to 1100 nm with factory certificate
KDW-S1-10	Additional wavelength to KDW-S1-09
KDW-S1-11	Spectral radiant power sensitivity calibration at one wavelength within 800 to 1800 nm with factory certificate
KDW-S1-12	Additional wavelength to KDW-S1-11
KDW-S1-RP	Set-up charge for non-Gigahertz-Optik detectors

KDW-S2, Spectral Irradiance Sensitivity (A/(W/m²))

Spectral irradiance sensitivity is calibrated with a wavelength tune able monochromatic light source. The light output of the monochromatic light source overfills the active area of the irradiance detector.
The spectral irradiance sensitivity of the test device is compared to a spectral irradiance standard detector.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-S2-01	Spectral irradiance sensitivity calibration at one wavelength within 200 to 1100 nm. Factory calibration certificate
KDW-S2-02	Spectral irradiance sensitivity calibration at an additional wavelength with KDW-S2-01
KDW-S2-03	Spectral irradiance sensitivity calibration in 10 nm steps from 200 to 400 nm. Factory calibration certificate
KDW-S2-04	Spectral irradiance sensitivity calibration in 10 nm steps from 350 to 1100 nm. Factory calibration certificate
KDW-S2-05	Spectral irradiance sensitivity calibration in 10 nm steps from 200 to 1100 nm. Factory calibration certificate
KDW-S2-RP	Set-up charge for non-Gigahertz-Optik detectors

KDW-S3, Spectral Radiance Sensitivity (A/(W/m²sr))

Spectral radiance sensitivity of radiance detectors is calibrated with a uniform, wavelength tune able monochromatic light source.
The spectral radiance sensitivity of the test device is compared to a spectral radiance standard detector.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-S3-01	Spectral radiance sensitivity calibration of radiance detectors. Contact the factory to discuss your calibration requirement.
KDW-S3-RP	Set-up charge for non-Gigahertz-Optik detectors

KDW-S4, Spectral Radiant Intensity Sensitivity (A/(W/sr))

Spectral radiant intensity is measured with spectral irradiance detectors. The spectral radiant intensity is calculated from the measured irradiance and the solid angle resulting from the light source to aperture distance and the aperture diameter.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-S4-01	Spectral radiant intensity sensitivity calibration of irradiance detectors. Contact the factory to discuss your calibration requirement.
KDW-S4-RP	Set-up charge for non-Gigahertz-Optik detectors

KDW-R1, KDW-R2, KDW-R3, KDW-R4 & KDW-P1 Integral Calibration of Detectors

Integral Radiometric Calibration

KDW-R1, Radiant Power Sensitivity (A/W)

Radiant power sensitivity is calibrated using a broadband light source which irradiates the detector through a precise aperture to ensure that the detectors active area is under filled. The irradiance at the aperture is measured with a spectral radiometer. calibrated for absolute irrradiance. The integral radiant power is calculated from the spectral data within the specified wavelength range. The radiant power entering the detector is calculated using the known aperture area.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-R1-01	Radiant power sensitivity within a specified wavelength range. Contact the factory to discuss your calibration requirement
KDW-R1-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested. If not available the spectral sensitivity must be measured. See KDW-S1	

KDW-R2, Irradiance Sensitivity (A/(W/m²))

Irradiance sensitivity is calibrated with broadband light source which irradiates the irradiance detector. The irradiance at the detector is measured with a spectral radiometer calibrated in irradiance. The integral irradiance is calculated from the spectral data within the specified wavelength range.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-R2-01	Irradiance sensitivity calibration within a specified wavelength range. Contact the factory to discuss your calibration requirement
KDW-R2-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested. If not available the spectral sensitivity must be measured. See KDW-S1	

KDW-R3, Radiance Sensitivity (A/(W/m²sr))

The radiance sensitivity of radiance detectors is calibrated with a uniform light source.
The spectral radiance of the light source is calibrated with an absolute calibrated radiance spectral radiometer. The integral radiance s calculated by the spectral data within the specified wavelength range.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-R3-01	Radiance sensitivity calibration within a specified wavelength range. Contact the factory to discuss your calibration requirement
KDW-R3-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested. If not available the spectral sensitivity must be measured. See KDW-S1	

KDW-R4, Radiant Intensity Sensitivity (A/(W/sr))

Radiant intensity is derived from irradiance detector measurements. It is calculated from the measured irradiance and the solid angle resulting from the light source to aperture distance and the aperture diameter. The irradiance at the detector is measured with a calibrated spectral radiometer in irradiance. The integral irradiance is calculated from the spectral data within the specified wavelength range.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-R4-01	Radiant intensity calibration of irradiance detectors. Contact the factory to discuss your calibration requirement
KDW-R4-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested. If not available the spectral sensitivity must be measured. See KDW-S1	

Integral Photometric Calibration

KDW-P1, Luminous Flux Sensitivity (A/lm)

Luminous flux detectors are a combination of an integrating sphere with photometric detector. Calibration is done using a broadband light source which generates a known luminous flux inside the sphere.
A factory calibration certificate is supplied listing test device data, measurement set-up, traceability and calibration uncertainty.

Ordering Information	
KDW-P1-01	Luminous flux sensitivity within a specified wavelength range. Contact the factory to discuss your calibration requirement
KDW-P1-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested. If not available the spectral sensitivity must be measured. See KDW-S1.	

KDW-P2, KDW-P3 & KDW-P4 Photometry; KRW & KTW Reflectance & Transmittance

KDW-P2, Illuminance Sensitivity (A/lx)

Illuminance sensitivity is calibrated by comparing the measured values of the test detector to those of an illuminance standard detector. The reference source is a standard Illuminant A source at 2856K.
A factory calibration certificate is supplied listing the test device data, the measurement set-up, the traceability and the calibration uncertainty.

Ordering Information	
KDW-P2-01	Illuminance sensitivity calibration. Factory calibration certificate
KDW-P2-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested for the calibration uncertainty evaluation. If not available the spectral sensitivity must be measured. See KDW-S1	

KDW-P3, Luminance Sensitivity (A/(cd/m²))

Luminance sensitivity is calibrated by comparing the measured values of the test detector and a luminance standard detector. The reference source is a luminance light source at 2800K.
A factory calibration certificate is supplied listing the test device data, the measurement set-up, the traceability and the calibration uncertainty.

Ordering Information	
KDW-P3-01	Luminance sensitivity calibration. Factory calibration certificate
KDW-P3-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested for the calibration uncertainty evaluation. If not available the spectral sensitivity must be measured. See KDW-S1	

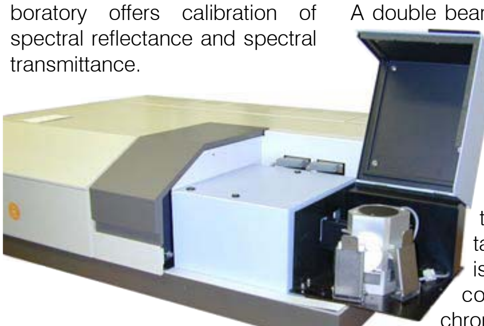
KDW-P4, Luminous Intensity Sensitivity (A/cd)

Luminous intensity is derived from illuminance detector measurements. The luminous intensity is calculated from the measured illuminance and the distance light source to detector aperture
A factory calibration certificate is supplied listing the test device data, the measurement set-up, the traceability and the calibration uncertainty.

Ordering Information	
KDW-P4-01	Luminous intensity calibration. Contact the factory to discuss your calibration requirement.
KDW-P4-RP	Set-up charge for non-Gigahertz-Optik detectors
The spectral sensitivity of the sample detector is requested for the calibration uncertainty evaluation. If not available the spectral sensitivity must be measured. See KDW-S1	

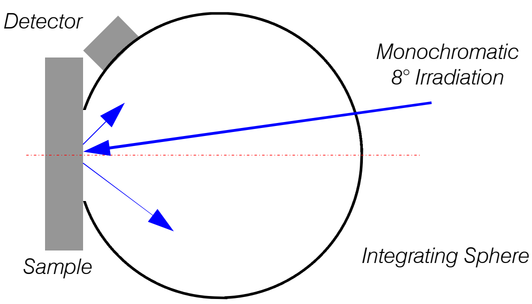
KRW & KTW, Spectral Reflectance and Spectral Transmittance Calibration

Gigahertz-Optik's calibration laboratory offers calibration of spectral reflectance and spectral transmittance.

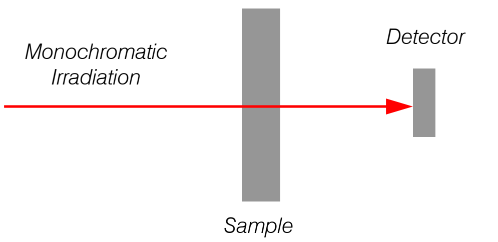


Spectral Reflectance:
A double beam photometer with directed 8 degree sample irradiation and hemispherical measurement set-up is used for the calibration of the spectral reflectance. The sample is irradiated with a collimated monochromatic light beam of 8 x 15 mm. The tunable wavelength range is 250 to 2500 nm.
The photometer is calibrated with spectral reflectance standards which are calibrated by the NRC and traceable calibrated to NIST.
A factory calibration certificate is supplied which confirms the reference data of the sample, the calibration measurement values, the calibration uncertainty and the traceability of the calibration.

Spectral Transmittance:
A very low stray-light double monochromator with collimated light beam is used to irradiate the sample for the calibration measurement. The tunable wavelength range is 350 to 1100 nm.
The light beam is focused to a flat field silicon photodiode.
The transmittance measurement set-up is useful for non-diffuse transmitting samples only.
A factory calibration certificate is supplied listing reference data of the sample, calibration measurement values, calibration uncertainty and traceability.



Principal Calibration set-up Spectral Reflectance



Principal Calibration set-up Spectral Transmittance

Reflectance & Transmittance; AM Measurement and Qualification Service

Spectral Reflectance & Transmittance Ordering Information	
KRW-S1-01	Calibration of 8/D spectral reflectance in 50 nm steps within the wavelength range 250 to 2500 nm. Factory calibration certificate
KRW-S1-02	Calibration of 8/D spectral reflectance in 1 nm steps within the wavelength range 250 to 2500 nm. Factory calibration certificate
KRW-S1-RP	Set-up charge for non Gigahertz-Optik samples
KTW-S1-01	Calibration of spectral transmittance in 1 nm steps from 350 to 1100 nm of non diffuse samples. Factory calibration certificate
KTW-S2-01	Calibration of spectral transmittance in 50 nm steps from 250 to 2500 nm of non diffuse samples. Factory calibration certificate
KTW-S1-RP	Set-up charge for non Gigahertz-Optik samples

Measurement and Qualification Service

With its technical expertise and experience in light measurements and calibrations Gigahertz-Optik is regularly asked for on-site service measurements and qualification. Our engineers are specialists in several applications within the thematic ***Measurement of Light*** and ***Measurement with Light***.
On this page a short overview of our capabilities is provided.
If you are interested in our measurement and qualification service please contact the factory to discuss your requirements.

AM-001 UV-VIS Spectral Irradiance Measurements

Gigahertz-Optik has been active in spectral irradiance measurements since 1986.
Based on a mobile double monochromator spectral radiometer, spectral irradiance measurements in the UV-VISIBLE wavelength range from 250 nm up to 780 nm are offered.
Measurement strategy, actual calibration and documentation are set-up and performed by Toni Gugg-Helminger, technical director of Gigahertz-Optik. He is well known in the field of UV radiometry through his activities in the “Thematic Network for Ultraviolet Measurements” a committee for safe use of optical radiation. Since 2001 he is also publicity appointed expert for Ultraviolet radiation measurements.

AM-003 Laser Classification with TÜV Certificate

Lasers, especially those that cannot be totally shielded from view in the application, need to be classified according to the European standard EN60825-1: 1994 + A11: 1996 + A2: 2001.
Gigahertz-Optik offers laser classification service in cooperation with the TUEV Bayern for low intensity lasers in the range from 350 to 1070 nm.
The certificate includes a description of the measurement procedure as well as the laser classification.

AM-004 UV-VISIBLE-NIR Transmission Measurements on XXL Samples

Commercially available photometers are designed for measurement of small sample sizes only. Spectral transmittance measurements on large size samples are not possible without cutting the sample into small pieces that can be accepted by the photometer.
Based on a double monochromator and a tunable light source from 250 to 780 nm used to irradiate the sample with a collimated light beam, Gigahertz-Optik’s calibration set-up allows transmission measurement of any size sample.
The detector is built with a 100 mm diameter integrating sphere made out of OP.DI.MA. (see chapters OP.DI.MA. and Integrating Spheres) allowing measurements in the deep ultraviolet spectral range.
The very low stray-light level of the double monochromator and the use of very sensitive photo multiplier detectors enables optical density measurements down to OD4 at wavelength of 250 nm.
The certificate includes the description of the measurement procedure, spectral transmittance data and comments about the measurement uncertainty.

Table of Contents

Introduction, Properties and Concepts of Light and Color

I. Introduction

Light, or the visible part of the electromagnetic radiation spectrum, is the medium through which human beings receive a major portion of environmental information. Evolution has optimized the human eye into a highly sophisticated sensor for electromagnetic radiation. Joint performance between the human eye and visual cortex, a large part of the human brain, dwarfs recent technical and scientific developments in image processing and pattern recognition. In fact a major part of the information flow from external stimuli to our brain is transferred visually. Photometry deals with the measurement of this visible light energy.

However, optical radiant energy not only encompasses visible 'light' but radiation invisible to the human eye as well. The term optical is used because this radiation follows the laws of geometrical optics.

Radiometry deals with the measurement of all optical radiation inclusive of the visible portion of this radiant energy.

This tutorial is an introduction to the basic nature of light and color, radiometric, photometric, colorimetric, reflection and transmission principles, quantities, symbols and units. Sections covering a sampling of current applications, detectors, electronics and calibration are included. A list of reference sources is provided for future study.

SI (Système International) units are used throughout these tutorials. Many international organizations including the CIE (Commission Internationale de l'Eclairage) have adopted this system of units exclusively. The terminology used follows that of the CIE *International Lighting Vocabulary*.

II. Properties and Concepts of Light and Color

Thorough knowledge of the physical nature of light and light perception provides the foundation for a comprehensive understanding of optical measurement techniques. Yet, from a practical point of view there is little necessity to fully understand formation and propagation of light as an electromagnetic wave as long as the reader accepts wavelength as the most important parameter describing the quality of light. The human eye perceives light with different wavelengths as different colors (figure II.1.), as long as the variation of wavelength is limited to the range between 400 nm and 800 nm (1 nm = 1 nanometer = 10^{-9} m). In the optical range of the electromagnetic spectrum, wavelength is sometimes also given in Ångstrøm (Å= 10^{-10} m). Outside this range, our eye is insensitive to electromagnetic radiation and thus we have no perception of ultraviolet (UV, below 400 nm) and infrared (IR, above 800 nm) radiation.

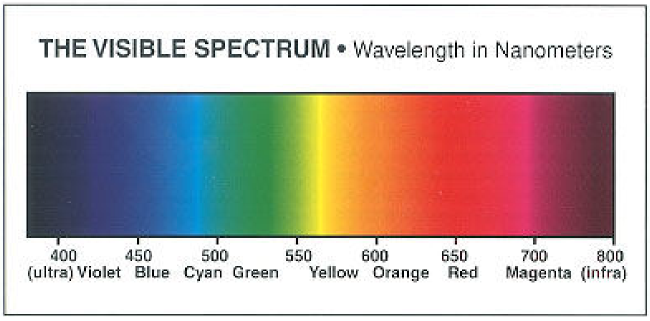


Fig. II.1. Monochromatic electromagnetic radiation of different wavelengths between 400 nm and 800 nm causes the impression of different colors. Outside this wavelength range, the human eye is insensitive.

II.1. The wavelength range of optical radiation

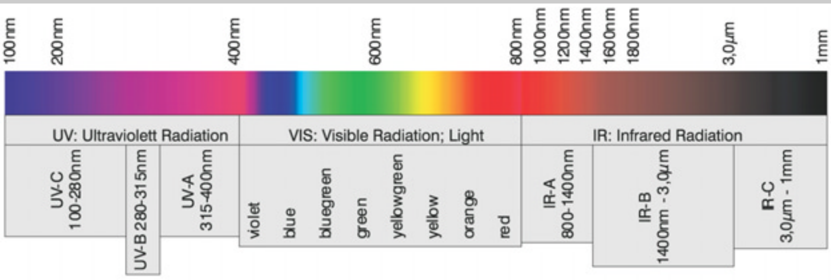
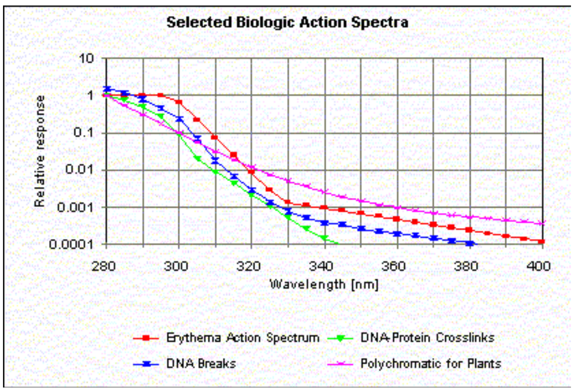


Fig. II.2. Wavelength ranges of electromagnetic radiation.

According to DIN 5031, the term „**optical radiation**“ refers to electromagnetic radiation in the wavelength range between 100 nm and 1 mm. The terms „**light**“ and „**visible radiation**“ (VIS) refer to the wavelength range between 400 nm and 800 nm, which can be perceived by the human eye. Optical radiation with wavelengths shorter than 400 nm is called **ultraviolet (UV) radiation** and is further subdivided in UV-A, UV-B and UV-C ranges. Similarly, **infrared (IR) radiation** covers the wavelength range above 800 nm and is subdivided in IR-A, IR-B and IR-C ranges (DIN 5031, part 7).

It must be emphasized that this classification of electromagnetic radiation is a matter of convention and is not based on qualitative properties of the electromagnetic wave itself. Instead, it is largely motivated by the effects of the electromagnetic wave on matter. For instance, the UV-B range covers the wavelengths in the solar spectrum which is particularly responsible for DNA damage and thus causes melanoma and other types of skin cancer. As the strength of radiation effects on matter does not change abruptly with wavelength, different authors define UVA and UVB ranges slightly different. As an example, the US Food and Drug Administration (FDA) and the US Environmental Protection Agency (EPA) define the UV-A range between 320 nm and 400 nm. However, two of the main standardization authorities, the CIE and the DIN, agree with their definition of the UVA range between 315 nm and 400 nm.

Spectral sensitivity functions, such as the CIE photopic response, have also been defined in other biological effects of optical radiation, such as DNA damage, formation of erythema (sunburn) and of non-melanoma skin cancer, tanning of the human skin and the photosynthesis process in green plants, have been studied and quantified by spectral sensitivity functions (Fig.). Especially when related to certain biological reactions, the term “action spectrum” is often used instead of “spectral sensitivity”.



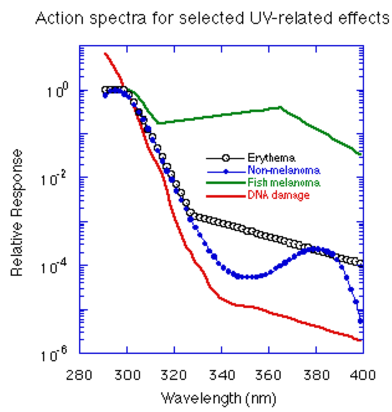
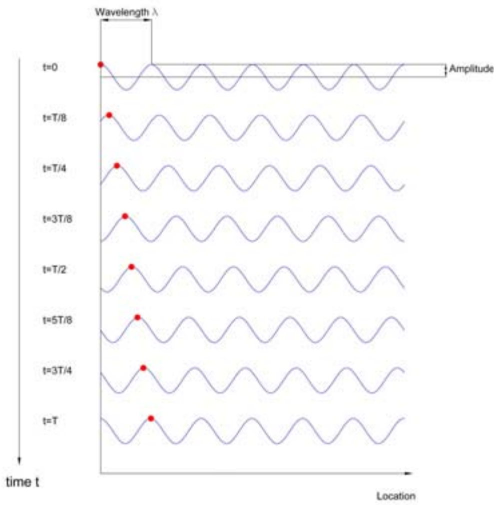


Fig. II.3. Action spectra for various biological reactions to UV radiation

II.2. Velocity, amplitude, wavelength, and frequency - the measures of a wave

Like all other waves (waves in a string, water waves, sound, earthquake waves ...), light and electromagnetic radiation in general can be described as a vibration (more general: a periodical change of a certain physical quantity) that propagates into space (Fig. II.4.a). The propagation is caused by the fact that the vibration at a certain location influences the region next to this location. For example in the case of sound, the alternating rarefaction and compression of air molecules at a certain location results in periodic changes in the local pressure, which in turn causes the movement of adjacent air molecules towards or away from this location (Fig. II.4.b).



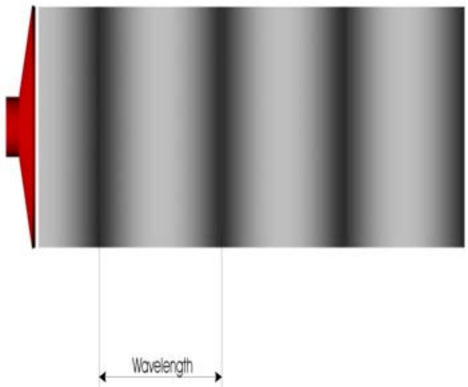


Fig. II.4 (a) Formation and propagation of a wave in a string. (b) Formation and propagation of a compression wave in air, a phenomenon colloquially called sound

In the case of an electromagnetic wave, the mechanism of propagation involves mutual generation of periodically varying electric and magnetic fields and is far more difficult to understand than sound. Yet, the result still can be described as a periodic change of a physical quantity (the strength of the electric and the magnetic field) propagating into space. The velocity of this propagation is generally abbreviated with the letter c (unit: meters per second, m/s) and depends on the nature of the wave and on the medium (see Table II.Ibelow).

In order to describe the basic properties of a wave, the following quantities have been defined for all kinds of waves:

- The **amplitude** is the maximum disturbance of the medium from its equilibrium. In the case of a wave in a horizontal string (Fig. II.4.a), this value is identical with half of the vertical distance between the wave's crest and its trough. In the case of a pressure wave in air („sound", Fig. II.4.b), the amplitude is half of the pressure difference between rarefaction and compression.
- The **wavelength** $\boldsymbol{\lambda}$ is the distance between two adjacent crests (or troughs) and is given in meters.
- The **period T** of a wave is the time that elapses between the arrival of two consecutive crests (or troughs) at a certain location X. This definition is identical with the statement that the period is the time the vibration at X takes to complete a full cycle from crest to trough to crest. The period of a wave is given in seconds.
- The **frequency** $\boldsymbol{\nu}$ of a wave is the number of vibration cycles per second at a certain location X. The unit of frequency is Hertz (Hz) and 1 Hz is the reciprocal of 1 second. As an example, a wave with a period T = 0.25 s takes ¼ of a second to complete a full vibration cycle (crest - trough - crest) at a certain location and thus performs four vibrations per second. Hence its frequency is f = 4 Hz. From this example it is obvious that the period of a wave completely defines its frequency and vice versa. The relation between these quantities is given by

$$\nu = 1 / T$$

If we look at a wave as a process that is periodical in space and in time, we can regard the wavelength λ as the distance between two repetitions of the process in space and the period T as the „distance" between two repetitions of the process in time.

A basic relation between wavelength, frequency and velocity results from the following consideration:

During the time span a crest needs to travel the distance of one wavelength λ from location X to location Y (Fig. II.4.a), the next crest arrives at location X. Thus, this time span is identical with the wave's period T. But when a crest needs the time span T to travel the distance λ, its velocity c amounts to

$$c = \lambda / T = \lambda \,.\, \nu \qquad \text{Equ. II.1}$$

When a wave passes from one medium to another, its frequency remains the same. If the velocities of the wave in the two media differ, the wavelengths in the two media also differ as a consequence of equation II.1..

As the frequency of a wave does not depend on the medium the wave is passing, it is more convenient to use frequency instead of wavelength to characterize the wave. In acoustics, this is common practice – in most cases the pitch of sound is characterized by its frequency instead of its wavelength in a certain medium (for example air). In optics, the situation is different: In most cases wavelength is used instead of frequency, although this leads to a certain complication: For example, green light has a wavelength of 520 nm in vacuum, but in water its velocity is smaller by a factor of 1.33 and thus, in water the same green light has a wavelength of only 520 / 1.33 = 391.0 nm. Hence, if we want to characterize a wave by its wavelength, we also have to state for which medium the actual wavelength value is given. According to CIE regulations, which are also applied throughout this tutorial, the term "wavelength" refers to "wavelength in air" unless otherwise stated. However, when applying the given wavelength figures to light passing through a medium other than vacuum, one should keep in mind that the light's wavelength changes according to the relation

$$\lambda_{Medium} = \lambda_{Vacuum} / n_{Medium} = \lambda_{Air} \cdot n_{Air} / n_{Medium}$$

with

$$n_{Air} = c_{Vacuum} / c_{Air} \text{ and } n_{Medium} = c_{Vacuum} / c_{Medium}$$

n_{Medium} is called the medium's index of refraction and is more commonly used to specify the optical properties of a material than c_{Medium}.

	Sound	Optical (electromagnetic) radiation		
		at λ= 434 nm	at λ= 589 nm	at λ= 656 nm
in vacuum	-	299792 km/s (n = 1)		
in air	340 m/s	299708 km/s (n = 1.000280)	299709 km/s (n = 1.000277	299710 km/s (n = 1.000275)
in water	1500 m/s	299708 km/s (n = 1.340)	224900 km/s (n = 1.333)	225238 km/s (n = 1.331)

Table II.I Velocities of sound and light in air and in water. For optical radiation, the respective index of refraction is given in parenthesis

II.3. Spectra of various light sources

A spectrum generally describes the variation of a certain physical quantity as a function of wavelength. The term “spectrum” without any further specifications refers to the quantification of the monochromatic intensity as a function of wavelength (the term “spectrum” is also used for other (physical) quantities apart of intensity, but is then always used with a specific prefix. As an example, the strength of a biological reaction (for example erythema – see § VI.1) to light with different wavelengths is described by an “action spectrum”). As an example, the next figure shows spectra of an incandescent bulb, natural sunlight and two types of discharge lamps.

When examining spectral intensity distributions of various light sources, it is possible to distinguish four significant types. These are:

- Monochromatic radiation
- Near monochromatic radiation
- Continuous spectra
- Band spectra

Typical sources of monochromatic radiation are lasers and the output signal from monochromators with narrow bandwidths. Typical sources of near monochromatic radiation are light emitting diodes and band pass filtered sources.

If a mixture of radiation covers a relatively large range of wavelengths without gaps, this radiation has a continuous spectrum. Typical examples of continuous radiation spectra are direct and diffuse sunlight and light emitted by incandescent bulbs. On the other hand, in a band spectrum there are gaps separating individual regions of radiation. If a spectrum has a number of lines of monochromatic intensity, it is called a line spectrum. Typical sources emitting a line spectrum are gaseous discharge lamps, such as helium or xenon lamps, and metal vapor lamps, such as the mercury vapor lamp. Multi-vapor discharge lamps are used to achieve a more uniform spectral distribution (see Fig. II.5.).

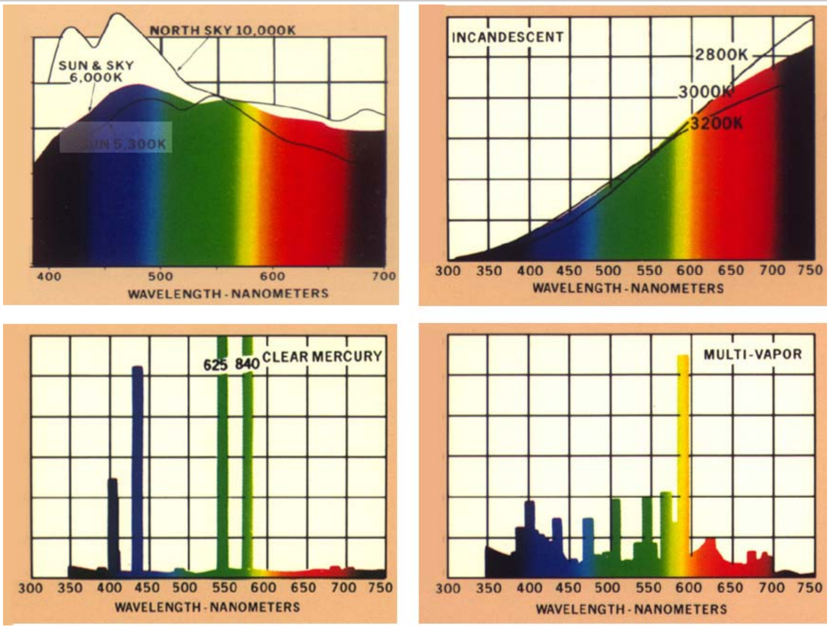


Fig. II.5. Emission spectra of natural light from the sun and the sky and of artificial light from incandescent bulbs at different temperatures, from a mercury vapor lamp and from a multi-vapor lamp.

II.4. Basic radiometric quantities

The whole discipline of optical measurement techniques can be roughly subdivided into the two areas of **photometry** and **radiometry**. Whereas the central problem of photometry is the determination of optical quantities closely related to the sensitivity of the human eye (see § II.6.), radiometry deals with the measurement of energy per time (= power, given in watts) emitted by light sources or impinging on a particular surface. Thus, the units of all radiometric quantities are based on **watts (W)**. According to CIE regulations, symbols for radiometric quantities are denoted with the subscript “e” for “energy”. Similarly, radiometric quantities given as a function of wavelength are labeled with the prefix “spectral” and the subscript “λ” (for example spectral radiant power Φ_λ).

Remark: The definitions of radiometric quantities cannot be understood without a basic comprehension of differential quantities. For an intuitive understanding of these quantities, which is the main purpose of this paragraph, the differential quantities $d\lambda$, dA and $d\Omega$ can be regarded as tiny intervals or elements $\Delta\lambda$, ΔA and $\Delta\Omega$ of the respective quantity. As a consequence of the fact that these intervals or elements are very small, radiometric quantities can be considered constant over the range defined by $d\lambda$, dA and/or $d\Omega$. Similarly, $d\Phi_e$, dI_e, dL_e and dE_e can be regarded as small portions which add up to the total value of the respective quantity. In paragraph II.5., the concept of differential quantities and integral calculus is briefly explained for spectral radiometric quantities.

II.4.a. Definition of solid angle

The geometric quantity of a **solid angle Ω** quantifies a part of an observer’s visual field. If we imagine an observer located at point P, his full visual field can be described by a sphere of arbitrary radius r (see Fig.II.). Then, a certain part of this full visual field defines an area A on the sphere’s surface and the solid angle Ω is defined by

$$\Omega = A / r^2 \qquad \text{Equ. II.2}$$

As the area A is proportional to r², this fraction is independent of the actual choice of r.

If we want to calculate the solid angle determined by a cone, as shown in Fig.II.area A is the area of a spherical calotte. However, as the solid angle is not only defined for conical parts of the full visual field, area A can be any arbitrary shape on the sphere’s surface.

Although Ω is dimensionless, it is common to use the unit **steradian** (**sr**). The observer’s total visual field is described by the whole surface of the sphere, which is given by 4πr², and thus covers the solid angle

$$\Omega_{total} = 4\pi r^2 / r^2 = 4\pi \text{ sr} = 12.57 \text{ sr}$$

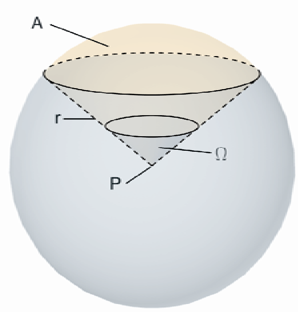


Fig.II.6. The solid angle Ω quantifies a certain part of the visual field, seen by an observer located at P

II.4.b. Radiant power or radiant flux Φ_e

Radiant power Φ_e is defined by the total power of radiation emitted by a source (lamp, light emitting diode, etc.), transmitted through a surface or impinging upon a surface. Radiant power is measured in watts (W). The definitions of all other radiometric quantities are based on radiant power. If a light source emits uniformly in all directions, it is called an isotropic light source.

Radiant power characterizes the output of a source of electromagnetic radiation only by a single number and does not contain any information on the spectral distribution or the directional distribution of the lamp output.

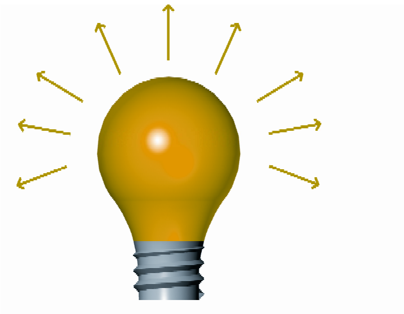


Fig. II.7. The radiant power of Φ_e of a light source is given by its total emitted radiation.

II.4.c. Radiant intensity I_e

Radiant intensity I_e describes the radiant power of a source emitted in a certain direction. The source's (differential) radiant power $d\Phi_e$ emitted in the direction of the (differential) solid angle element $d\Omega$ is given by

$$d\Phi_e = I_e\, d\Omega$$

and thus

$$\Phi_e = \int_{4\pi} I_e\, d\Omega$$

In general, radiant intensity depends on spatial direction. The unit of radiant intensity is **W / sr**.

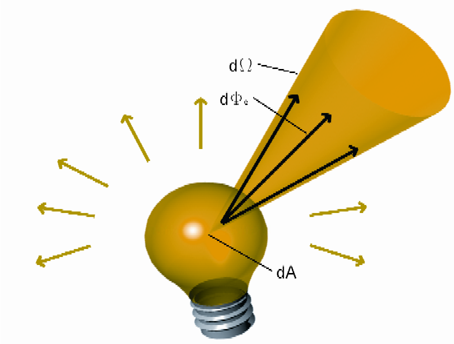


Fig. II.8. Typical directional distribution of radiant intensity for an incandescent bulb.

II.4.d. Radiance L_e

Radiance L_e describes the intensity of optical radiation emitted or reflected from a certain location on an emitting or reflecting surface in a particular direction (the CIE definition of radiance is more general. Within the frame of this tutorial, the most relevant application of radiance describing the spatial emission characteristics of a source is discussed). The radiant power $d\Phi_e$ emitted by a (differential) surface element dA in the direction of the (differential) solid angle element $d\Omega$ is given by

$$d\Phi_e = L_e \cos(\vartheta)\, dA\, d\Omega$$

Equ.II3

In this relation, ϑ is the angle between the direction of the solid angle element $d\Omega$ and the normal of the emitting or reflecting surface element dA.

From the definition of radiant intensity I_e it follows that the differential radiant intensity emitted by the differential area element dA in a certain direction is given by

$$dI_e = L_e \cos(\vartheta)\, dA$$

Thus,

$$I_e = \int_{\substack{emitting\\surface}} L_e \cdot \cos(\vartheta) dA$$

Equ.II.4

whereby ϑ is the angle between the emitting surface element dA and the direction for which I_e is calculated.

The unit of radiance is **W/(m²·sr).**

II.4.e. Irradiance E_e

Irradiance E_e describes the amount of radiant power impinging upon a surface per unit area. In detail, the (differential) radiant power $d\Phi_e$ upon the (differential) surface element dA is given by

$$d\Phi_e = E_e\, dA$$

Generally, the surface element can be oriented at any angle towards the direction of the beam. However, irradiance is maximised when the surface element is perpendicular to the beam:

$$d\Phi_e = E_{e,normal}\, dA_{normal}$$

Note that the corresponding area element dA_{normal}, which is oriented perpendicular to the incident beam, is given by

$$dA_{normal} = \cos(\vartheta)\, dA$$

with ϑ denoting the angle between the beam and the normal of dA, we get

$$E_e = E_{e,normal} \cos(\vartheta) \qquad \text{Equ.II.5}$$

The unit of irradiance is **W/m²**.

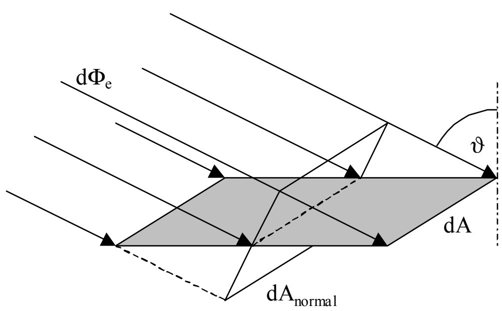


Fig. II.9 – Irradiance is defined as incident radiant power $d\Phi_e$ per surface area element dA.at P

II.4.f. Radiant exitance M_e

Radiant exitance M_e quantifies the radiant power per area, emitted or reflected from a certain location on a surface. In detail, the (differential) radiant power $d\Phi_e$ emitted or reflected by the surface element dA is given by

$$d\Phi_e = M_e\, dA$$

From the definition of radiance follows that the (differential) amount radiant exitance dM_e emitted or reflected by a certain location on a surface in the direction of the (differential) solid angle element dΩ is given by

$$dM_e = L_e \cos(\vartheta)\, d\Omega$$

and consequently

$$M_e = \int_{2\pi\, sr} L_e \cos(\vartheta)\, d\Omega \qquad \text{Equ.II6}$$

The integration is performed over the solid angle of 2π steradian corresponding to the directions on one side of the surface and ϑ denotes the angle between the respective direction and the surface's normal.
The unit of radiant exitance is **W/m²**. In some particular cases, $M_e = E_e$ (see § II.8.a).

II.4.g. Spectral radiant power $\Phi_\lambda(\lambda)$, spectral radiant intensity $I_\lambda(\lambda)$, spectral radiance $L_\lambda(\lambda)$, spectral irradiance $E_\lambda(\lambda)$, and spectral radiant exitance $M_\lambda(\lambda)$

The radiometric quantities discussed above are defined without any regard to the wavelength(s) of the quantified optical radiation. In order to quantify not only the absolute amount of these quantities but also the contribution of light from different wavelengths, the respective **spectral** quantities are defined.
Spectral radiant power is defined as a source's radiant power per wavelength interval as a function of wavelength. In detail, the source's (differential) radiant power $d\Phi_e$ emitted in the (differential) wavelength interval between λ and λ+dλ is given by

$$d\Phi_e = \Phi_\lambda(\lambda)\, d\lambda$$

This equation can be visualised geometrically (see Fig. II.10.). As dλ is infinitesimally small, spectral radiant power $\Phi_\lambda(\lambda)$ is approximately constant in the interval between λ and λ+dλ. Thus, the product $\Phi_\lambda(\lambda)\, d\lambda$ equals the area under the graph of $\Phi_\lambda(\lambda)$ in the interval between λ and λ+dλ. This area describes the contribution of this very wavelength interval to the total value of radiant power Φ_e, which is graphically represented by the total area under the graph of spectral radiant power $\Phi_\lambda(\lambda)$.
Mathematically, this can be expressed by the integral

$$\Phi_e = \int_0^\infty \Phi_\lambda(\lambda)\, d\lambda$$

The unit of spectral radiant power is **W/nm** or **W/Å**
The other spectral quantities are defined correspondingly and their units are given by the unit of the respective quantity, divided by nm or Å (see Table VII.IV and Table VII.V).
Generally, a radiant quantity can be calculated from the respective spectral quantity by integration over wavelength from λ=0 to λ=∞. However, this integration is often restricted to a certain wavelength range, which is indicated by the respective prefix. For instance, UVA irradiance is defined as

$$E_{e,UVA} = \int_{315\,nm}^{400\,nm} E_\lambda(\lambda)\, d\lambda$$

as the UVA range is defined from λ= 315 nm to λ = 400 nm.

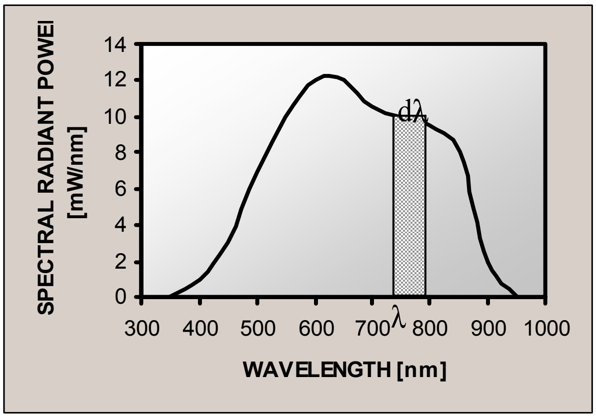


Fig.II.10. Relation between spectral radiant power $\Phi_\lambda(\lambda)$ and radiant power Φ_e visualized at a hypothetical example. Radiant power emitted in the wavelength interval between λ and λ+dλ is given by the area of the shaded rectangle, which amounts to $\Phi_\lambda(\lambda)\, d\lambda$. The total amount of radiant power Φ_e emitted over the whole spectrum is given by the area under the curve describing $\Phi_\lambda(\lambda)$, which is mathematically expressed by an integral.

II.5. Calculation of radiometric quantities - Examples

A small source emits light equally in all directions (spherical symmetry). Its radiant power equals $\Phi_{e,source}$=10 W.
If we are interested in the characteristics of this source in a distance r that is much larger than the geometric dimensions of the source itself, we can neglect the actual size of the source and assume that the light is emitted from a point. As a rule of thumb, this approximation is justified if distance r is at least 10 times larger than the dimensions of the light source.

a/ As the source emits light symmetrical in all directions, its radiant intensity is equal for all directions and amounts to $I_e = \Phi_{e,source} / 4\pi$ sr = 10 W / 4π sr = <u>0.796 W / sr</u>.

b/ An infinitesimal surface element dA at distance r and perpendicular to the beam occupies the solid angle

$$d\Omega = dA / r^2$$

and thus the infinitesimal radiant power $d\Phi_{e,imp}$ impinging onto dA can be calculated by

$d\Phi_{e,imp} = I\, d\Omega = \Phi_{e,source} / 4\pi\ sr \cdot dA / r^2 = \Phi_{e,source} / 4\pi r^2 \cdot dA$

Thus, the irradiance at distance r amounts to

$E_e = \Phi_{e,source} / 4\pi r^2$

This result can also be obtained by the following argument:
At distance r, all the radiant power $\Phi_{e,source}$ emitted by the source passes through the surface of a sphere with radius r, which is given by $4r^2\pi$. As the light source emits light symmetrically in all directions, the irradiance has the same value at every point of this sphere. Thus, irradiance E of a surface at a certain distance r and oriented perpendicular to the beam can be calculated from its definition:

E_e = radiant power impinging upon a surface / area of this surface = $\Phi_{e,source} / 4\pi r^2$

which is identical with the result above.

Remark: The fact that E is proportional to r⁻² is generally known under the name "*inverse square law*". However, it only holds true for distances much larger than the geometric dimensions of the source, which allows the assumption of a point source. In other cases, a source with considerable geometric dimensions might possibly be replaced by a "virtual" point source, and then the "inverse square law" still holds true when distance r is measured from this virtual point source (see Example 2). However, when the source cannot be assumed point like and every point of the source emits light in more than a single direction , the "inverse square law" no longer holds true. As an example, this is the case for fluorescent tubes.

II.5.a. Example 1: Isotropic point source

II.5.b. Example 2: Spot source

In a simple flashlight, a concave mirror reflects light from a small bulb (radiant power Φ = 200 mW) into a divergent cone (see figure below). Assuming that the mirror reflects without any losses and uniform distribution of power over the cone,

Note that the flashlight does not emit light symmetrically in all directions, therefore the equations derived in Example 1 cannot be used.

a/ In a distance of 25 cm from the flashlight's front window, the whole radiant power of 200 mW (= 0.2 W) impinges on a circle with a radius of 0.05 m. If we assume that irradiance is constant all over this circle and we neglect the fact that the surface is not everywhere strictly perpendicular to the beam, we can calculate the irradiance at a distance of 25 cm from the flashlight's front window:

E = radiant power impinging upon a surface / area of this surface
== 0.2 / 0.05² π W / m²
E ≈ <u>25 W / m²</u>

b/ In order to determine the flashlight's radiant intensity, we have to determine the solid angle determined by the cone. Following the definition of solid angle and approximating the area of the spherical calotte by the area of a circle with a radius of 5 cm (= 0.05 m), we get

$$\Omega = A_{Circle} / r^2$$

with r describing the distance of the circle form the cone's vertex.

From Fig. II.11, we get

$$r = x + 0.25 \text{ m}$$

and

$$x / x+0.25 = 0.03 / 0.10$$

from which we calculate

$$x = 0.107 \text{ m}$$

and

$$r = 0.357 \text{ m}$$

Thus, the cone defines a solid angle given by

$$\Omega = A_{Circle} / r^2 = 0.05^2\,\pi / 0.357^2 = 0.0616 \text{ sr}$$

and the flashlight's radiant intensity amounts to

$$I = \Phi / \Omega = 0.2 / 0.0616 \text{ W / sr} = \underline{3.25 \text{ W / sr}}.$$

Remark: As a virtual point source located at the cone's vertex produces the same spatial radiation distribution as the flashlight's bulb together with its concave mirror, the "inverse square law" holds true for this configuration. However, the distance r which the law relates to has to be measured from the position of the virtual point source.

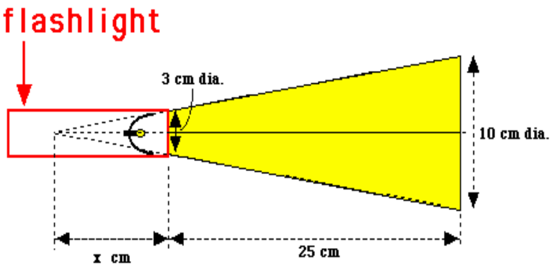


Fig. II.11 - Calculating the irradiance caused by a flashlight.

II.5.c. Example 3: The Lambertian surface

By definition, a **Lambertian surface** either emits or reflects radiation into all directions of a hemisphere with constant radiance L_e (Fig.II.12). From Equ.II.4 in paragraph II.4.d. follows that the directional distribution of radiant intensity is given by

$$I_e(\vartheta) = I_{e,0} \cdot \cos(\vartheta)$$

with

$$I_{e,0} = \int_{\substack{emitting\\surface}} L_e \cos(0)\, dA = \int_{\substack{emitting\\surface}} L_e\, dA$$

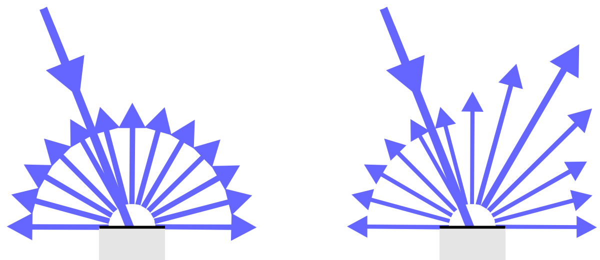
whereby $I_{e,0}$ denotes radiant intensity emitted in the direction perpendicular to the surface and $I_e(\vartheta)$ denotes radiant intensity emitted in a direction enclosing the angle ϑ with the surface's normal. Calculating the surface's exitance M_e from Equ.II.6 in paragraph II.4.f. by use of the relation $d\Omega = \sin(\vartheta)\, d\vartheta\, d\varphi$, we get

$$M_e = \int_{2\pi\, sr} L_e \cos(\vartheta)\, d\Omega = L_e \int_0^{2\pi}\int_0^{\frac{\pi}{2}} \cos(\vartheta)\sin(\vartheta)\, d\vartheta\, d\varphi = L_e \cdot \pi$$

Equ.II7

The respective relations for photometric quantities (see § II.6.) characterizing a Lambertian surface can be derived by replacing the index "e" by the index "v".

Reflecting Lambertian surfaces are widely used in light measurement for well defined, perfectly diffuse scattering fully independent of the direction of the incoming beams. Thus, the radiance reflected from a certain location on the surface in a certain direction is proportional to the total radiant power impinging onto the reflecting surface. This allows the realization of detector geometries for radiant power, exitance and irradiance (or luminous flux, luminous exitance and illuminance), which have to be determined by an integration over all directions of a solid angle of 4π or 2π. Lambertian reflection is especially desired for the coating of integrating spheres, which are widely used for detector input optics or for output optics of radiance or luminance standards.



Ideal diffuse reflection (lambertian surface) — Diffuse reflection with directional components

Fig.II.12. Constant spatial distribution of radiance L_e after ideal diffuse reflection at a Lambertian surface

II.6. Spectral sensitivity of the human eye

The sensitivity of the human eye to light of a certain intensity varies strongly over the wavelength range between 380 and 800 nm. Under daylight conditions, the average normal sighted human eye is most sensitive at a wavelength of 555 nm, resulting in the fact that green light at this wavelength produces the impression of highest "brightness" when compared to light at other wavelengths. The spectral sensitivity function of the average human eye under daylight conditions (photopic vision) is defined by the **CIE spectral luminous efficiency function V(λ)**.

Only in very rare cases, the spectral sensitivity of the human eye under dark adapted conditions (scotopic vision), defined by the spectral luminous efficiency function V'(λ), becomes technically relevant. By convention, these sensitivity functions are normalized to a value of 1 in their maximum.

As an example, the photopic sensitivity of the human eye to monochromatic light at 490 nm amounts to 20% of its sensitivity at 555 nm. As a consequence, when a source of monochromatic light at 490 nm emits five times as much power (expressed in watts) than an otherwise identical source of monochromatic light at 555 nm, both sources produce the impression of same "brightness" to the human eye.

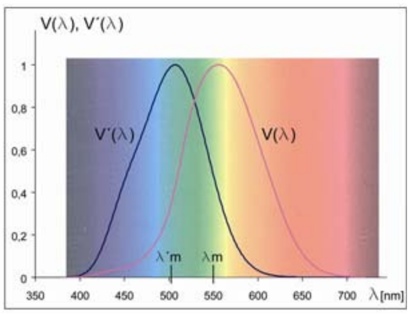


Fig. II.13. Spectral luminous efficiency functions V (λ) for photopic vision and V'(λ) for scotopic vision, as defined by the CIE.

Properties and Concepts of Light and Color

II.7. Basic photometric quantities

One of the central problems of optical measurements is the quantification of light sources and lightning conditions in numbers directly related to the perception of the human eye. This discipline is called "Photometry", and its significance leads to the use of separate physical quantities, which differ from the respective radiometric quantities only in one respect: Whereas radiometric quantities simply represent a total sum of radiation power at various wavelengths and do not account for the fact that the human eye's sensitivity to optical radiation depends on wavelength, the photometric quantities represent a weighted sum with the weighting factor being defined by either the photopic or the scotopic spectral luminous efficiency function (see § II.6). Thus, the numerical value of photometric quantities directly relates to the impression of "brightness". Photometric quantities are distinguished from radiometric quantities by the index "v" for "visual", and photometric quantities relating to scotopic vision are denoted by an additional prime, for example Φ_v'. The following explanations are given for the case of photopic vision, which describes the eye's sensitivity under daylight conditions, thus being relevant for the vast majority of lighting situations (photopic vision takes place when the eye is adapted to luminance levels of at least several candelas per square meters, scotopic vision takes place when the eye is adapted to luminance levels below some hundredths of a candela per square meter. For mesopic vision, which takes place in the range in between, no spectral luminous efficiency function has been defined yet). However, the respective relations for scotopic vision can be easily derived when replacing V(λ) by V'(λ) and replacing K_m (= 683 lm / W) by K'_m (= 1700 lm / W) (see definition in § VII.2).
As the definition of photometric quantities closely follows the corresponding definitions of radiometric quantities, the corresponding equations hold true – the index "e" just has to be replaced by the index "v". Thus, not all relations are repeated. Instead, a more general formulation of all relevant relations is given in the Appendix.

II.7.a. Luminous flux Φ_v

Luminous flux Φ_v is the basic photometric quantity and describes the total amount of electromagnetic radiation emitted by a source, spectrally weighted with the human eye's spectral luminous efficiency function V(λ). Luminous flux is the photometric counterpart to radiant power. The unit of luminous flux is lumen (lm), and at 555 nm, where the human eye has its maximum sensitivity, a radiant power of 1 W corresponds to a luminous flux of 683 lm. In other words, a monochromatic source emitting 1 W at 555 nm has a luminous flux of exactly 683 lm. The value of 683 lm / W is abbreviated by the symbol K_m (the value of K_m = 683 lm/W is given for photopic vision. For scotopic vision, K_m'=1700 lm/W has to be used). However, a monochromatic light source emitting the same radiant power at 650 nm, where the human eye is far less sensitive and V(λ) = 0.107, has a luminous flux of 0.107*683 lm = 73.1 lm. For a more detailed explanation of the conversion of radiometric to photometric quantities, see paragraph II.7.f.

II.7.b. Luminous intensity I_v

Luminous intensity I_v quantifies the luminous flux emitted by a source in a certain direction. It is therefore the photometric counterpart of the radiometric quantity "radiant intensity" I_e. In detail, the source's (differential) luminous flux $d\Phi_v$ emitted in the direction of the (differential) solid angle element $d\Omega$ is given by

$$d\Phi_v = I_v \cdot d\Omega$$

and thus

$$\Phi_v = \int_{4\pi} I_v d\Omega$$

The unit of luminous intensity is lumen per steradian (lm / sr), which is abbreviated with the expression "candela" (**cd**):

$$1 \text{ cd} = 1 \text{ lm / sr}$$

II.7.c. Luminance L_v

Luminance L_v describes the measurable photometric brightness of a certain location on a reflecting or emitting surface when viewed from a certain direction. It describes the luminous flux emitted or reflected from a certain location on an emitting or reflecting surface in a particular direction (the CIE definition of luminance is more general. Within the frame of this tutorial, the most relevant application of luminance describing the spatial emission characteristics of a source is discussed).

In detail, the (differential) luminous flux $d\Phi_v$ emitted by a (differential) surface element dA in the direction of the (differential) solid angle element $d\Omega$ is given by

$$d\Phi_v = L_v \cos(\theta) \cdot dA \cdot d\Omega$$

with θ denoting the angle between the direction of the solid angle element $d\Omega$ and the normal of the emitting or reflecting surface element dA.
The unit of luminance is

$$1 \text{ lm m}^{-2} \text{ sr}^{-1} = 1 \textbf{ cd m}^{\mathbf{-2}}$$

II.7.d. Illuminance E_v

Illuminance E_v describes the luminous flux per area impinging upon a certain location of an irradiated surface. In detail, the (differential) luminous flux $d\Phi_v$ upon the (differential) surface element dA is given by

$$d\Phi_v = E_v \cdot dA$$

Generally, the surface element can be oriented at any angle towards the direction of the beam. Similar to the respective relation for irradiance, illuminance E_v upon a surface with arbitrary orientation is related to illuminance $E_{v,normal}$ upon a surface perpendicular to the beam by

$$E_v = E_{v,normal} \cos(\vartheta)$$

with ϑ denoting the angle between the beam and the surface's normal.
The unit of illuminance is **lux (lx)**, and

II.7.e. Luminous exitance M_v

Luminous exitance M_v quantifies the luminous flux per area, emitted or reflected from a certain location on a surface. In detail, the (differential) luminous flux $d\Phi_v$ emitted or reflected by the surface element dA is given by

$$d\Phi_v = M_v \cdot dA$$

The unit of luminous exitance is 1 lm m^{-2}, which is the same as the unit for illuminance. However, the abbreviation lux is **not** used for luminous exitance.

II.7.f. Conversion between radiometric and photometric quantities

Monochromatic radiation: In the case of monochromatic radiation at a certain wavelength λ, a radiometric quantity X_e is simply transformed to its photometric counterpart X_v by multiplication with the respective spectral luminous efficiency V(λ) and by the factor K_m = 683 lm / W. Thus,

$$X_v = X_e * V(\lambda) * 683 \text{ lm / W}$$

with X denoting one of the quantities Φ, I, L, or E.

Example: An LED (light emitting diode) emits nearly monochromatic radiation at λ = 670 nm, where V (λ) = 0.032. Its radiant power amounts to 5 mW. Thus, its luminous flux equals

$$\Phi_v = \Phi_e * V(\lambda) * 683 \text{ lm / W} = 0.109 \text{ lm} = 109 \text{ mlm}$$

As V(λ) changes very rapidly in this spectral region (by a factor of 2 within a wavelength interval of 10 nm), for accurate results the LED's light output should not be considered monochromatic. However, using the relations for monochromatic sources still results in an approximate value for the LED's luminous flux which might be

Polychromatic radiation: If a source emits polychromatic light described by the spectral radiant power $\Phi_\lambda(\lambda)$, its luminous flux can be calculated by spectral weighting of $\Phi_\lambda(\lambda)$ with the human eye's spectral luminous efficiency function V(λ), integration over wavelength and multiplication with with K_m = 683 lm / W, so

$$\Phi_v = K_m \int_\lambda \Phi_\lambda(\lambda) \cdot V(\lambda)\, d\lambda$$

In general, a photometric quantity X_v is calculated from its spectral radiometric counterpart $X_\lambda(\lambda)$ by the relation

$$X_v = K_m \int_\lambda X_\lambda(\lambda) \cdot V(\lambda)\, d\lambda$$

with X denoting one of the quantities Φ, I, L, or E.

II.8. Reflection, Transmission, and Absorption

Reflection is the process by which electromagnetic radiation is returned either at the boundary between two media (surface reflection) or at the interior of a medium (volume reflection), whereas **transmission** is the passage of electromagnetic radiation through a medium. Both processes can be accompanied by **diffusion** (also called **scattering**), which is the process of deflecting a unidirectional beam into many directions. In this case, we speak about **diffuse reflection** and **diffuse transmission** (Fig. II.14). When no diffusion occurs, reflection or transmission of an unidirectional beam results in an unidirectional beam according to the laws of geometrical optics (Fig. II.15). In this case, we speak about **regular reflection** (or **specular reflection**) and **regular transmission** (or **direct transmission**). Reflection, transmission and scattering leave the frequency of the radiation unchanged. Exception: The Doppler effect causes a change in frequency when the reflecting material or surface is in motion.

Absorption is the transformation of radiant power to another type of energy, usually heat, by interaction with matter.

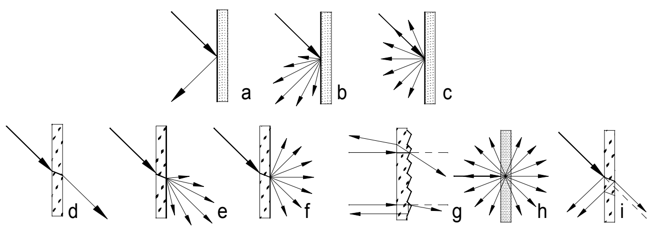


Fig. II.14 - a-c: Direct, mixed and diffuse reflection d-f: direct, mixed and diffuse transmission

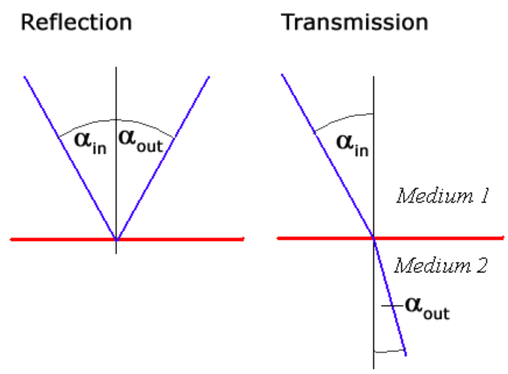


Fig. II.15 - When directly reflected or directly transmitted, an unidirectional beam follows the laws of geometrical optics: direct reflection (left): $\alpha_{in} = \alpha_{out}$, direct transmission (right): $n_1 \cdot \sin(\alpha_{in}) = n_2 \cdot \sin(\alpha_{out})$ with n_1 and n_2 denoting the respective medium's index of refraction

II.8.a. Reflectance ρ, Transmittance τ, and Absorptance α

In general, reflection, transmission and absorption depend on the wavelength of the affected radiation. Thus, these three processes can either be quantified for monochromatic radiation (in this case, the adjective "spectral" is added to the respective quantity) or for a certain kind of polychromatic radiation. For the latter, the spectral distribution of the incident radiation has to be specified. In addition, reflectance, transmittance and absorptance might also depend on polarization and geometric distribution of the incident radiation, which therefore also have to be specified.

The **reflectance ρ** is defined by the ratio of reflected radiant power to incident radiant power. For a certain area element dA of the reflecting surface, the (differential) incident radiant power is given by the surface's irradiance E_e, multiplied with the size of the surface element, thus

$$d\Phi_{e,\text{incident}} = E_e\, dA$$

and the (differential) reflected radiant power is given by the exitance M_e, multiplied with the size of the surface element:

$$d\Phi_{e,\text{reflected}} = M_e\, dA$$

Thus,

$$\rho = \frac{d\Phi_{e,\text{reflected}}}{d\Phi_{e,\text{incident}}} = \frac{M_e \cdot dA}{E_e \cdot dA} = \frac{M_e}{E_e}$$

or $$M_e = \rho\, E_e$$

Total reflectance is further subdivided in **regular reflectance ρ_r** and **diffuse reflectance ρ_d**, which are given by the ratios of regularly (or specularly) reflected radiant power and diffusely reflected radiant power to incident radiant power. From this definition, it is obvious that

$$\rho = \rho_r + \rho_d$$

The **transmittance τ** of a medium is defined by the ratio of transmitted radiant power to incident radiant power. Total transmittance is further subdivided in **regular transmittance τ_r** and **diffuse transmittance τ_d**, which are given by the ratios of regularly (or directly) transmitted radiant power and diffusely transmitted radiant power to incident radiant power. Again,

$$\tau = \tau_r + \tau_d$$

The **absorptance α** of a medium is defined by the ratio of absorbed radiant power to incident radiant power.
Being defined as ratios of radiant power values, reflectance, transmittance and absorptance are dimensionless.

Gigahertz-Optik

Properties and Concepts of Light and Color

Quantities such as reflectance and transmittance are used to describe the optical properties of materials. The quantities can apply to either complex radiation or to monochromatic radiation.
The optical properties of materials are not a constant since they are dependent on many parameters such as:

- thickness of the sample
- surface conditions
- angle of incidence
- temperature
- the spectral composition of the radiation (CIE standard illuminants A, B, C, D65 and other illuminants D)
- polarization effects

The measurement of optical properties of materials using integrating spheres is described in DIN 5036-3 and CIE 130-1998.
Descriptions of the principle measurements are presented in paragraph III.1.f below.

II.8.b. Radiance coefficient q_e, Bidirectional reflectance distribution function (BRDF)

The **radiance coefficient q_e** characterizes the directional distribution of diffusely reflected radiation. In detail, the radiance coefficient depends on the direction of the reflected beam and is defined by the ratio of the radiance reflected in this direction to the total incident irradiance. In general, the reflected radiance is not independent from the directional distribution of the incident radiation, which thus has to be specified.
In the USA, the concept of **Bidirectional reflectance distribution function BRDF** is similar to the radiance coefficient. The only difference is that the BRDF is a function of the directions of the incident **and** the reflected beam (Fig.). In detail, the (differential) irradiance dE_e impinging from a certain direction causes the reflected radiance dL_e in another direction, which is given by

$$dL_e = BRDF \cdot dE_e$$

This BRDF depends on more arguments than the radiance coefficient. However, its advantage is the simultaneous description of the material's reflection properties for all possible directional distributions of incident radiation, whereas the radiance coefficient generally is valid for just one specific directional distribution of incident radiation.
The unit of radiance coefficient and BRDF is 1/steradian. The BRDF is often abbreviated by the Greek letter ρ, which bears the danger of mixing the BRDF up with reflectance (see foregoing paragraph).

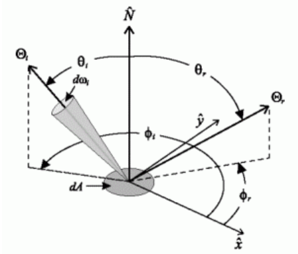


*Fig. II.16 - Geometry used for the definition of the bidirectional reflectance distribution function (BRDF). The BRDF depends on the directions of incident **and** reflected radiation, which are given by the angles ϑ_i and ϑ_r, which are measured relative to the reflecting surface's normal, and the azimuth angles φ_i and φ_r, which are measured in the plane of the reflecting surface.*

II.9. The perception of color

Color sensations are human sensory perceptions, and color measurement technology must express them in descriptive and comprehensible quantities. DIN 5033, Part 1, defines color as follows:

"Color is the visual sensation, associated with a part of the field of view that appears to the eye to be without structure, through which this part can be distinguished from another unstructured neighbouring area when observed with a single, unmoving eye".

This rather complicated but unambiguous definition of color allows the visual sensation of "color" to be distinguished from all the other impressions received when seeing. The insertion of the term "unstructured" into this definition also separates the texture of observed objects from the sensation of color.
Thus the texture of a textile, for instance, is not included in the color.
The definition also calls for observation with a "single" eye which is "unmoving", conditionally excluding other factors such as spatial sensation, the perception of the location of objects, their direction, and even their relative movement from the perception of color. Since single-eyed observation of an unmoving object with an unmoving eye does not allow for the perception of gloss, the evaluation of gloss is excluded from the perception of color.
In general, unlike mass, volume or temperature, color is not merely a physical property of an object. It is, rather, a sensation triggered by radiation of sufficient intensity. This can be the radiation of a self-emitting light source, or it can be reflected from a surface. This radiation enters the eye, where receptive cells convert it into nervous stimulation, which is in turn transmitted to the appropriate part of the brain, where it is experienced as color. The sensation of color depends not only on physical laws, but also on the physiological processing of the radiation in the sense organs. Visual conditions, luminance (brightness) and the state of the eye's adaptation are amongst the contributory factors.
Color manifests itself in the form of light from self-emitting light sources, surface colors (of non-self emitting light sources) and in the intermediate form of the luminescent colors of dyestuffs such as optical brightening agents and dayglow paints that absorb photons from a short wavelength part of the spectrum and emit the energy in a part of the spectrum with longer wavelengths.

II.9.a. Physiological background

From the fact that spectral decomposition of white light produces the perception of different colors, it can be deduced that color perception is closely connected to the wavelength of light (Fig. II.17.). As an example, light with a wavelength of 650 nm wavelength is perceived as „red" and light with a wavelength of 550 nm is perceived as „green". However, there are colors, such as purple, which cannot be directly related to a certain wavelength and therefore do not occur in the spectral decomposition of white light.
The perception of color is formed in our brain by the superposition of the neural signals from three different kinds of photoreceptors which are distributed over the human eye's retina. These photoreceptors are called cones and are responsible for photopic vision under daylight conditions. Scotopic (night) vision is caused by photoreceptors called rods, which are much more sensitive than cones. As there is only one kind of rods, night vision is colorless.
The three different kinds of cones differ in their spectral sensitivity to electromagnetic radiation, which is shown in Fig. for the average normal sighted human eye. If monochromatic radiation irradiates the eye, as it is the case with spectral decomposition of white light, the wavelength determines which types of cones are excited. For instance, monochromatic light at 680 nm exclusively excites one type of cones, whereas the two other types are insensitive at this wavelength. The brain interprets signals from only this type of cones - in the absence of a signal from the other cones - as the color „red". Therefore, these cones are called „red cones". Similarly, the two other types of cones are called „blue cones" and "green cones".

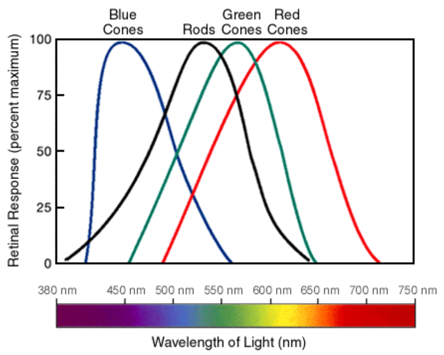


Fig. II.17 - Relative spectral sensitivity of all four types of the human eyes retinal light receptors. The three types of cones are responsible for photopic vision, whereas the rods are responsible for scotopic (night) vision

II.9.b. Color addition

As discussed above, monochromatic light of a certain wavelength might predominately excite a single type of cones, thus producing the color perception of “blue”, “green” or “red”. Depending on the actual wavelength, monochromatic light might also excite two types of cones simultaneously, thus producing the perception of another color. Red and green cones, for instance, are both excited by monochromatic light of 580 nm, and a signal from these two types of cones – with the simultaneous absence of a signal from blue cones – produces the color perception of “yellow”.
However, our visual system cannot discriminate between monochromatic and broadband radiation as long as the excitation of the three types of cones remains the same. Thus, the perception of “yellow” can also be produced by a broadband spectrum between 550 nm and 700 nm as long as green and yellow cones are comparably stimulated and blue cones are not stimulated at all. Similarly, the perception of “cyan” is produced by simultaneous stimulation of blue and green cones, whereas the perception of “magenta” (or purple) is caused by simultaneous stimulation of blue and red cones (Fig. II.17). Simultaneous stimulation of all three types of cones results in the perception of “white”.
This fact has an important consequence: Consider a light source consisting of three single sources with the colors red, green and blue. If it is possible to vary the intensities of the three single sources individually, all possible colors can be produced. This is the main idea of color cathode ray tubes commonly used in TV and computer monitors - every pixel (a point on the monitor) consists of three smaller individual spots in the colors red, green and blue (Figure II.18). As these individual spots are so close together, the human eye cannot resolve them. Instead, they produce the perception of a certain color by superposition of their respective intensities. For instance, the pixel appears yellow when only the red and the green spot are emitting light, and the pixel appears white when all three spots are emitting light. The entirety of colors produced by color addition forms the **RGB color space**, as they are based on the three (additive) primary colors red, green and blue.

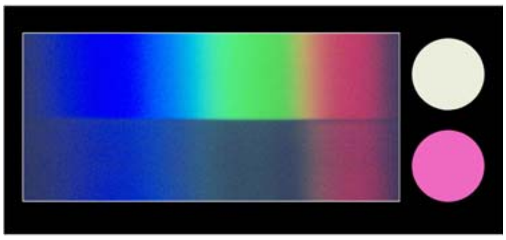


Fig. II.18 - The effect of color addition demonstrated with white light from an overhead projector before (top) and after (bottom) passing through a magenta filter. To the left, the respective spectral decomposition is shown, whereas the circle to the right shows the resulting color impressions. It can be clearly seen that the filter strongly absorbs light from the green part of the visual spectrum, whereas blue and red light pass the filter with low attenuation. The impression of magenta is produced by simultaneous presence of light from the blue and red regions of the visible spectrum, whereas light from the green region is missing.

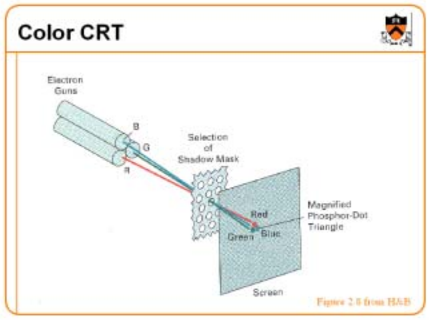


Fig. II.19 - An RGB monitor consists of tiny red, green and blue spots. Variation of their brightness produces the impression of different colorsby color addition.

II.9.c. Color subtraction

Whereas color addition describes the perception of different colors caused by a superposition of red, green and blue light sources, the concept of color subtraction is based on the absorption of white light by filters or pigments. As an example, a yellow filter absorbs wavelengths below about 500 nm, corresponding to blue light, but transmits longer wavelengths corresponding to green and red light. Thus, when irradiated with white light the filter transmits only wavelengths which stimulate the green and red cones, whereas the blue cones are not stimulated. As discussed above, this results in the perception of the color “yellow”. Similarly, a surface (better: pigments on a surface) absorbing wavelengths below about 500 nm and reflecting wavelengths above appears yellow when irradiated with white light. So, when irradiated with white light filters (or pigments) absorbing blue light appear yellow, filters (or pigments) absorbing green light appear magenta and filters (or pigments) absorbing red light appear cyan. As the effect of filters on transmitted light is the same as the effect of pigments on reflected light, the following conclusions derived for pigments are also valid for filters.
What happens if two pigments are combined ? The combination of a yellow pigment, which absorbs short (blue) wavelengths with a cyan pigment, which absorbs long (red) wavelengths, leaves only medium (green) wavelengths to be reflected when irradiated with white light. So, the combination of yellow and cyan pigments results in green reflected light. Similarly, the combination of yellow and magenta pigments results in red and the combination of cyan and magenta results in green reflected light. In next figure, the effect of color subtraction is demonstrated for filters.
Ideally, a combination of yellow, cyan and magenta pigments should result in total absorption of the whole visible wavelength range and thus in the perception of a black surface.
However, in reality the absorption properties of these pigments are never ideal, thus four-color-printing uses a black pigment in addition. Colors produced by a combination of **c**yan, **y**ellow, **m**agenta and blac**k** form the so called **CYMK color space**.

Fig. II-20 - Overlapping arrangement of yellow, cyan and magenta color filters on an overhead projector. In the overlapping regions, color subtraction results in green, red and blue light.

II.10. Colorimetry

The basic problem of colorimetry is the quantification of the physiological color perception caused by a certain **spectral color stimulus function $\boldsymbol{\varphi_\lambda(\lambda)}$**. When the color of a primary light source has to be characterised, $\varphi_\lambda(\lambda)$ equals the source’s spectral radiant power $\Phi_\lambda(\lambda)$ (or another spectral radiometric quantity, such as radiant intensity or radiance). When the color of a reflecting or transmitting object (for example a filter) has to be characterised, $\varphi_\lambda(\lambda)$ equals the incident spectral irradiance impinging upon the object’s surface, multiplied by the object’s spectral reflectance, its spectral radiance coefficient or its spectral transmittance. As colors of reflecting or transmitting objects depend on the object’s illumination, the CIE has defined colorimetric standard illuminants. The CIE Standard Illuminant A is defined by a Planckian blackbody radiator at a temperature of 2856 K, and the CIE Standard Illuminant D_{56} is representative of average daylight with a correlated color temperature of 6500 K (for the definition of color temperature, see below).

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II.10.a. RGB and XYZ color matching functions

According to the tristimulus theory, every color which can be perceived by the normal sighted human eye can be described by three numbers which quantify the stimulation of red, green and blue cones. If two color stimuli result in the same values for these three numbers, they produce the same color perception even when their spectral distributions are different. Around 1930, Wright and Guild performed experiments during which observers had to combine light at 435.8 nm, 546.1 nm and 700 nm in such a way that the resulting color perception matched the color perception produced by monochromatic light at a certain wavelength of the visible spectrum. Evaluation of these experiments resulted in the definition of the standardised **RGB color matching functions** $\bar{r}(\lambda)$ $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$ which have been transformed into the CIE 1931 **XYZ color matching functions** $\bar{x}(\lambda)$ $\bar{y}(\lambda)\bar{z}(\lambda)$ These colour matching functions define the **CIE 1931 standard colorimetric observer** and are valid for an observer's field of view of 2°. Practically, this observer can be used for any field of view smaller than 4°. For a field of view of 10°, the CIE specifies another set of colour matching $\bar{x}_{10}(\lambda)$ $\bar{y}_{10}(\lambda)$ $\bar{z}_{10}(\lambda)$ functions

This set defines the **CIE 1964 supplementary standard colorimetric observer**, which has to be used for fields of view larger than 4°.

Although RGB and XYZ color matching functions can be equally used to define three parameters which numbers uniquely describe a certain color perception, the XYZ color matching functions are preferred as $\bar{y}(\lambda)$ they have positive values for all wavelengths (Fig. II.21). In addition, is equal to the CIE spectral luminous efficiency function V(λ) for photopic vision.

The XYZ tristimulus values of a certain spectral color stimulus function $\varphi_\lambda(\lambda)$ are calculated by

$$X = k \int_\lambda \varphi_\lambda(\lambda) \cdot \bar{x}(\lambda) d\lambda$$

$$Y = k \int_\lambda \varphi_\lambda(\lambda) \cdot \bar{y}(\lambda) d\lambda$$

$$Z = k \int_\lambda \varphi_\lambda(\lambda) \cdot \bar{z}(\lambda) d\lambda$$

The choice of the normalisation constant k depends on the colorimetric task:

$$k = \frac{100}{\int_\lambda E_\lambda(\lambda)\, \bar{y}(\lambda)\, d\lambda}$$

When the spectral color stimulus $\varphi_\lambda(\lambda)$ describes a spectral radiometric quantity of a primary light source, k = 683 lm/W and consequently Y yields the

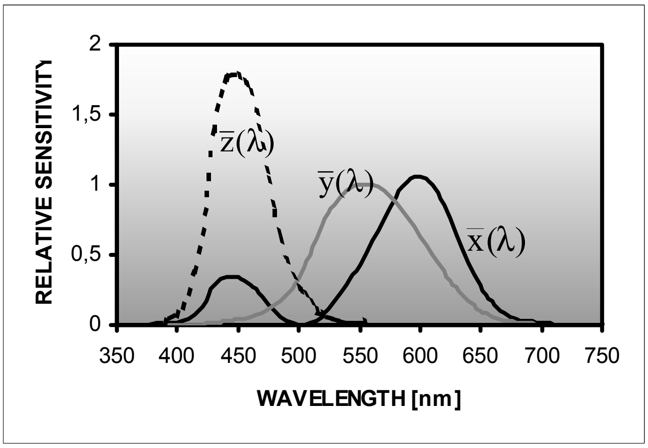


Fig. II.21 - XYZ color matching functions as defined by the CIE 1931 standard colorimetric observer. $\bar{x}(\lambda)$ (solid black line) consists of a short- and a long-wavelength $\bar{y}(\lambda)$ part, and (solid gray line) is identical with the CIE spectral luminous efficiency function V(λ).

II.10.b. The (x,y)- and (u',v')-chromaticity diagrams

Although the XYZ tristimulus values define a three-dimensional color space representing all possible color perceptions, for most applications the representation of color in a two-dimensional plane is sufficient. One possibility for a two-dimensional representation is the **CIE 1931 (x, y) chromaticity diagram** with its coordinates x and y calculated from a projection of the X, Y and Z values:

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

Although widely used, the (x, y) chromaticity diagram has a major disadvantage of non-uniformity as geometric distances in the (x, y) chromaticity diagram do not correspond to perceived color differences. Thus, in 1976 the CIE defined the **uniform (u', v') chromaticity scale (UCS) diagram**, with its coordinates defined by

$$u' = \frac{4X}{X+15Y+3Z} \qquad v' = \frac{9Y}{X+15Y+3Z}$$

Although this definition of the coordinates u' and v' does not provide a strict correspondence between geometric distances and perceived color differences, there are far less discrepancies than in the CIE (x, y) chromaticity diagram.

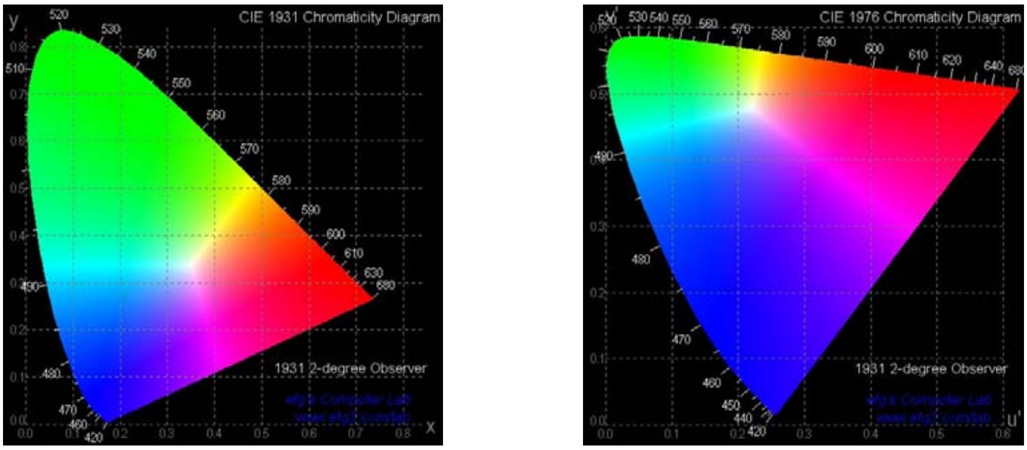


Fig. II.22 - The CIE 1931 (x,y) chromaticity diagram and the CIE 1976 (u', v') chromaticity diagram.

II.10.c. Correlated color temperature

The **correlated color temperature** is used to characterize the spectral distribution of optical radiation emitted by a light source. This characterisation corresponds to the projection of a two-dimensional chromaticity diagram onto a one-dimensional scale and thus is very coarse. In detail, the correlated color temperature is given in Kelvin (K) and is the temperature of the blackbody (Planckian) radiator whose received color most closely resembles to that of a given color stimulus.

As a (simplified) rule of thumb, spectral distributions dominated by long (reddish) wavelengths correspond to a low correlated color temperature whereas spectral distributions with dominated by short (bluish) wavelengths correspond to a high correlated color temperature.

As an example, the warm color of incandescent lamps has a correlated color temperature of about 2800 K, average daylight has a correlated color temperature of about 6500 K and the bluish white from a Cathode Ray Tube (CRT) has a correlated color temperature of about 9000 K.

III. Measurement of light with integral detectors

Spectroradiometry – the measurement of radiation intensity as a function of wavelength – is the only way to provide full spectral information about optical radiation emitted by a light source or impinging upon a surface. Obtaining this information has its price: Spectroradiometers are highly sophisticated optical measurement devices and in general, their proper calibration, operation and maintenance is rather time consuming. However, for the vast majority of applications, integral detectors (the term „integral" describes the fact that the output signal of an integral detector is proportional to the wavelength integral over the measured quantity's spectral distribution, multiplied with the detector's spectral sensitivity (see § III.2)) offer an economical and user friendly alternative: In most cases, it is not necessary to determine the exact spectral distribution of the measured quantity, and it is sufficient to use a detector especially designed to match a certain predefined spectral sensitivity function. As an example, the spectral sensitivity of photometric detectors is matched to the CIE spectral luminous sensitivity function V(λ), and detectors for solar UV irradiance potentially harmful to the human skin are matched to the CIE erythema action spectrum.

As integral detectors provide just a single output signal (usually voltage or photocurrent), they are much easier to characterise than spectroradiometers. The main parameters determining the usability and the quality of an integral detector are

- The detector's input optics, which determines its directional sensitivity
- The detector's spectral sensitivity
- The dynamic range, over which the detector's output is proportional to the input signal's intensity
- The detector's time behaviour

Refer to § III.5. for more info about calibration laboratory. More information is also available about our calibration services and calibration standards as well as Uniform Light Sources.

III.1. The detector's input optics and its directional sensitivity

Basically, the design of a detector's input optics is determined by its desired directional sensitivity, which in turn depends on the radiometric or photometric quantity to be measured:

- The determination of a light source's radiant and luminous flux requires constant directional sensitivity over the solid angle of 4π steradian or over the hemispherical solid angle of 2π steradian. This is achieved by an integrating sphere with the light source placed either inside the sphere or directly at the sphere's entrance port. Refer also to § III.1.b.
- The determination of irradiance and illuminance requires a detector's directional sensitivity proportional to the cosine of the angle of incidence, which can be achieved either by a flat field detector or by the entrance port of an integrating sphere. Refer also to § III.1.c.
- Radiant and luminous intensity, radiance and luminance are quantities which are defined as a function of solid angle, and therefore the detector's field of view has to be limited to a small angle. This can be achieved by baffles and/or lenses arranged in a tube.

Refer also to § III.1.d and III.1.e.

III.1.a. Integrating spheres used with integral detectors

In an ideal case, the inner surface of an integrating is a perfect diffuse Lambertian reflector (see § II.4.c). Thus, the directional distribution of reflected radiation is independent from the directional distribution of incident radiation, and no specular reflection occurs.

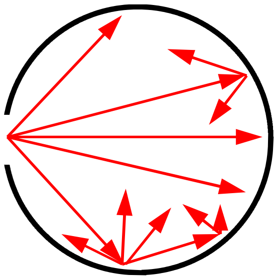


Fig. III.1. Ideal multiple Lambertian reflections inside an integrating sphere

Due to its geometry, an ideal integrating sphere is characterised by constant irradiance (or illuminance)) at all locations of it's inner surface. Furthermore, the level of this irradiance (illuminance solely depends on the total amount of radiant power (luminous flux) entering the sphere and is independent from its directional distribution.

However, real surfaces do not show perfect Lambertian reflection properties. Although minimised by the properties of the respective material, a certain amount of specular reflection still occurs. Baffles, placed at specific locations inside the sphere, are used to prevent major measurement errors by specular reflection. Moreover, at the input and exit ports, where the coating material is missing, radiation is far from being ideally reflected. For these reasons, the quality of measurements performed with integrating spheres strongly depends on the sphere's coating material, on the exact position of baffles and on the size of the ports in relation to the sphere's diameter. As a general rule of thumb, the total area of entrance and exit ports should not exceed 5% of the sphere's internal surface. Numerous standard setups are used for the determination of radiometric and photometric quantities, defining the arrangement of the sphere's entrance and exit ports and internal baffles (see § III.1.b. to III.1.f).

Apart from their directional sensitivity, integrating spheres offer additional advantages:

- The high number of internal reflections generally eliminates a detector's sensitivity to the polarisation of incident radiation.
- For the characterisation of powerful light sources, an integrating sphere can be used for attenuation in order to prevent saturation effects of the detector. As this attenuation results in an increase of internal temperature, the light source's maximum power is limited by the sphere's temperature range of operation.
- In general, geometric alignment of source and integrating sphere is not very critical, which simplifies calibration and measurement procedures.

For more detailed information about the theory and application of integrating spheres, see chapter V.

III.1.b. Measurement of radiant power and luminous flux

Radiant power and luminous flux of lasers and spot sources

Lasers, LEDs, spot lamps, endoscopes, optical fibres and other sources emit radiation with various directional distributions. As long the emission is limited to a hemispherical (2π steradian) solid angle, the source can be attached to the entrance window of an integrating sphere and does thus not interfere with the sphere's internal reflections.

The entrance port has to be large enough to ensure that all radiation from the source enters the sphere. A baffle is necessary to shield the detector from direct irradiation by the source.

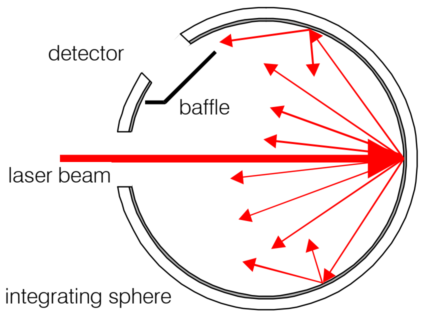


Fig. III.2. Integrating sphere used for laser power measurements

Measurement of Light

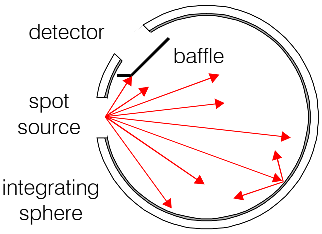


Fig. III.2. Integrating sphere used for radiant power and luminous flux

As an alternative, radiant power and luminous flux of collimated (parallel) beams can be directly measured by flat field detectors as long as the detector's active area exceeds the beam's cross section. Despite the simple measurement setup, this method has significant disadvantages in comparison to the use of an integrating sphere:

- The detector might be possibly sensitive to the beam's polarisation.
- The detector's active area might be possibly inhomogeneous in its sensitivity. In this case, it is important to ensure equal illumination during calibration and measurement.
- Alignment of the detector relative to the beam is critical.

<u>Radiant power and luminous flux of lamps</u>

Lamps emit radiation in all directions of the full (4π steradian) solid angle. Therefore, a lamp has to be placed inside an integrating sphere in order to determine its total radiant power or luminous flux. As a consequence, the lamp itself and its accessories interfere with the sphere's internally reflected radiation and thus causes a source of measurement error, which can be accounted for by use of an auxiliary lamp (see below).

Integrating spheres used to measure the radiant power or luminous flux of lamps must be well suited for the lamp under test to reduce measurement uncertainty. One important design parameter is that the diameter of the hollow sphere should be about ten times (twice for tube lamps) the maximum dimension of the lamp. For example, an integrating sphere set-up to measure the luminous flux of fluorescent lamps with 120 cm (47 in) length should be at least 2 m (79 in) in diameter. Furthermore, the diameter of the sphere limits the maximum power of the lamp.

In actual measurements, the lamp must be placed in the centre of the hollow sphere. This is typically accomplished using a tube holder, which carries the power and measurement leads into the sphere. A socket at the end of the tube holds and connects the lamp. To get the lamp in the centre position, hinged integrating spheres that open and have large diameters of more than 50 cm (20 in) are used. Spheres with smaller diameters may offer a large diameter port to mount the lamp in the centre of the sphere. The port is normally closed with a cap during the measurement. The port cap's inside surface should be coated with the same diffuse coating as the hollow sphere surface. The detector is placed at a port on the integrating sphere. It must be baffled against direct irradiation by the lamp.

For precise measurements, the lamp must be aged before testing. The burn-in time depends on the lamp type. The burn-in time for tungsten lamps should be 2-5 hours (IEC 64) and for arc lamps about 100 hours (IEC 81) is recommended.

In precise luminous flux measurement applications an auxiliary lamp with baffle(s) is recommended. The diffuse illumination generated by the auxiliary lamp can be used to reduce the negative effects of the lamp under test and its accessories according to the relation

$$\Phi_X = \Phi_N \cdot \frac{Y_X}{Y_N} \cdot \frac{Y_{HN}}{Y_{HX}}$$

- Φ_X : luminous flux of the test lamp
- Φ_N : luminous flux of the calibration lamp
- Y_X : measurement signal of the test lamp (with auxiliary lamp switched off)
- Y_N : measurement signal of the calibration lamp (with auxiliary lamp switched off)
- Y_{HN} : measurement signal of the auxiliary lamp (with calibration lamp switched off)
- Y_{HX} : measurement signal of the auxiliary lamp (with test lamp switched off)

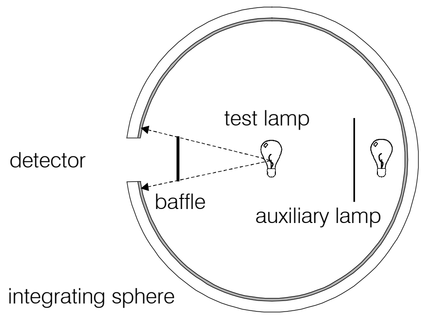


Fig. III.3. Experimental setup for radiant power and luminous flux measurements of a lamp. The auxiliary lamp is used to reduce measurement uncertainties caused by the interference of the lamp under test and its accessories with the sphere's internally reflected radiation.

III.1.c. Measurement of irradiance and illuminance

According to Equ.II.5 in paragraph II.4.e., a detector for irradiance or illuminance of a surface has to weight the incident radiation according to the cosine of its angle of incidence. This can be either achieved by

- an integrating sphere especially designed for irradiance (or illuminance) measurements (see figure below) or
- a cosine diffuser, an optical element which shows purely diffuse transmission regardless of the directional distribution of incident radiation (Fig. III.5).

In both cases, the ideal directional cosine response can only be approximately achieved. Deviations of a real detector's directional response from the ideal cosine response are quantified by the detector's **cosine error function**, which is given by

Light Source	Approximate Average Illuminance (lx)
overcast night	0,0001
full moon	0,1
office light	500
clear bright sky	70000 - 85000

Table III.1 – Some avarage illuminance values

$$\text{cos ineerror}(\vartheta) = \frac{\frac{S(\vartheta)}{S(0)} - \cos(\vartheta)}{\cos(\vartheta)} = \frac{S(\vartheta) - S(0)\cos(\vartheta)}{S(0)\cos(\vartheta)}$$

In this equation, S(θ) denotes the detector's signal caused by a ray of light impinging upon the detector's entrance optics at an angle θ, measured relative to the normal (see Fig. II.9). S(0) denotes the detector's signal caused by the same ray of light impinging vertically upon the detector's entrance optics.

Fig. III.5 - Irradiance detector heads with cosine diffuser and waterproof version for underwater and outdoor use

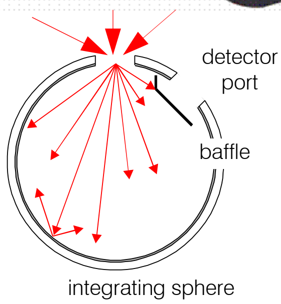


Fig. III.4. Integrating sphere design for measurement of irradiance or illuminance of a horizontal surface. The baffle prevents direct illumination of the detector, and the knife edges at the sphere's entrance port prevent shading by the sphere's wall, which would distort the detector's cosine response.sources.

III.1.d. Measurement of radiant and luminous intensity

Radiant and luminous intensity describe the directional distribution of a source's emitted radiation. For determination of this directional distribution, the relative position between source and detector has to be varied. The **goniophotometer** is a mechanical setup allowing the variation of the source's orientation and/or the detector's position, whereby the distance between source and detector is kept constant. As the source's directional characteristics often depends on its internal temperature distribution and thus on its position relative to the vertical, for accurate measurements of radiant and luminous intensity it is not recommended to rotate the source around a horizontal axis.

As radiant and luminous intensity are defined by the surface integral of radiance and luminance (see Equ. II.4), the emitting source has to be completely in the detector's field of view. Ideally, both quantities have to be determined with a setup that allows the source to be considered point like. As a crude rule of thumb, the distance between detector and source should be at least ten times the largest geometric dimension of the source.
For precise measurements, special care has to be taken to minimize reflections at the lamp's surrounding (walls, ceiling, the goniophotometer itself) in the direction of the detector. Blackening of the surrounding, the use of additional baffles and the reduction of the detector's field of view are proper precautions.

III.1.e. Measurement of radiance and luminance

Radiance and luminance describe the directional distribution of the radiance emitted or reflected by a certain area element. Similar to radiant and luminous intensity, radiance and luminance can be determined with a goniophotometer, but the detector is placed much closer to the emitting or reflecting surface and the detector's field of view is limited to a few degrees. Thus, only radiation from a small part of the source's surface enters the detector (Fig. III.6).

Light Source	Approximate Average Luminance (cd/m²)
self-luminous paints	$0{,}02\ 10^{-3}$
Candle flame	1
computer screen	100
overcast daytime sky	1000
clear bright sky	5000-6000

Table III.2 – Some average luminance values

III.1.f. Measurement of reflection and transmission properties

Reflectance ρ (for incident radiation of given spectral composition, polarization and geometrical distribution) is used to describe the optical properties of materials (see § II.8).
Ratio of the reflected radiant or luminous flux to the incident flux in the given conditions.
The measurement of reflectance is made in comparison to a reflection standard (reflectance ρ_N) with a collimated or conical radiation beam.
The signals of the detector will be calculated as follow:

$$\rho = \frac{I(X)-I(stray)}{I(N)-I(stray)}\,\rho_N$$

I(X): signal with sample irradiation
I(N): signal with standard irradiation

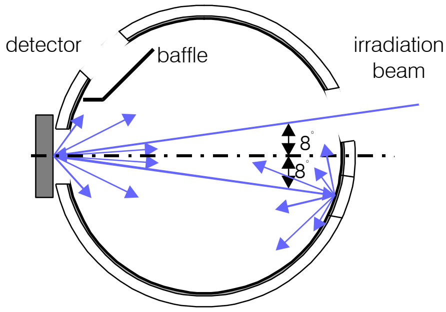


Fig. III.7. Integrating Sphere Total Reflection Measurement Set-up

Diffuse Reflectance r_d is used to describe the optical properties of materials (see § II.8).
Ratio of the diffusely reflected part of the (whole) reflected flux, to the incident flux.
The measurement of diffuse reflectance is made in comparison to a reflection standard (reflectance r_N) with a collimated or conical radiation beam.
The signals of the detector will be calculated as follow:

$$\rho_d = \frac{I(X) - I(stray) - \rho[I(mi) - I(stray)]}{I(N) - I(stray) - \rho_N[I(mi) - I(stray)]}\,\rho_N$$

I(X): signal with sample irradiation
I(N): signal with standard irradiation
I(stray): signal with open measurement port
I(mi): signal with irradiance of a mirror

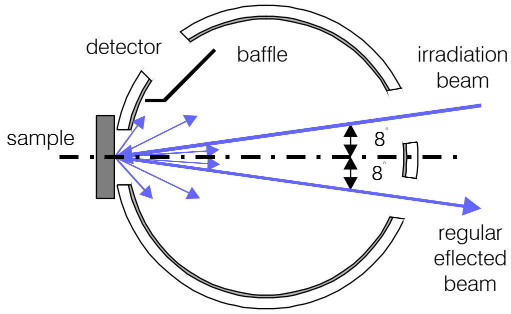


Fig. III.8. Integrating Sphere Diffuse Reflectance Measurement Set-up

Transmittance τ (for incident radiation of given spectral composition, polarization and geometrical distribution) is used to describe the optical properties of materials (see § II.8).

Ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions.

The measurement of transmittance is made with a collimated or conical radiation beam. The signals of the detector will be calculated as follow:

$\tau = I(X) / I(open)$

I(X): signal with sample irradiation
I(open): signal with open measurement port

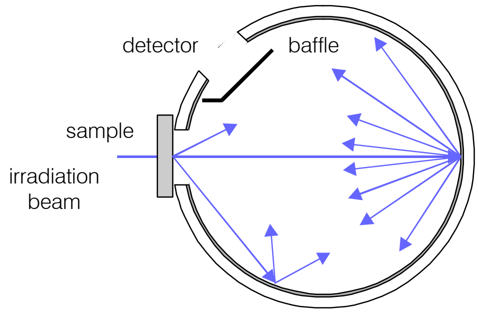


Fig. III.9. Integrating Sphere Total Transmittance Measurement Set-up

Measurement of Light

Diffuse Transmittance τ_d is used to describe the optical properties of materials (see § II.8).

Ratio of the diffusely transmitted part of the (whole) transmitted flux, to the incident flux.

The measurement of transmittance is made with a collimated or conical radiation beam. The signals of the detector will be calculated as follow:

$$\tau_d = \frac{I(X) - t.I(stray)}{I(open) - I(stray)}$$

I(X): signal with sample irradiation
I(open): signal with open measurement port and close output port
I(stray): signal with open measurement port and open output port

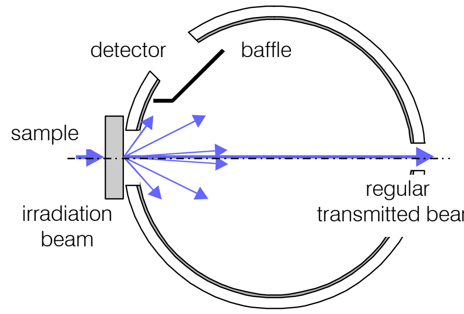


Fig. III.10. Integrating Sphere Diffuse Transmittance Measurement Set-up

III.2. Spectral sensitivity of an integral detector

Within the normal range of operation of an integral detector, the relation between the input signal (the spectral radiometric quantity to be measured) $X_\lambda(\lambda)$ entering the detector and its corresponding output signal Y has to fulfil the following condition of **linearity**:

Let Y_1 be the detector's response to the input signal $X_{\lambda 1}(\lambda)$ and Y_2 the detector's response to the input signal $X_{\lambda 2}(\lambda)$. Then, the detector's response to the superimposed input signal $X_{\lambda 1}(\lambda)+X_{\lambda 2}(\lambda)$ is given by Y_1+Y_2. Moreover, the detector's response is proportional to the input signal and therefore, the response to the input signal $a \cdot X_{\lambda 1}(\lambda)$ is given by $a \cdot Y_1$ (whereby a denotes an arbitrary positive number). A detector might possibly show a certain ***dark signal*** *Y_0 (usually dark current or dark voltage), which is a nonzero output signal even when the detector is not exposed to any radiation at all. In this case, Y, Y_1 and Y_2 have to be replaced by $Y-Y_0$, Y_1-Y_0 and Y_2-Y_0.*
Deviations from this behaviour are called **nonlinearities** and cause measurement errors. However, it is possible to experimentally determine a detector's nonlinearities and to correct for them. An example of a nonlinearity effect is the saturation of a detector's output signal at high radiation levels, which poses the upper limit of a detector's range of operation.
When nonlinearity effects can be neglected, the detector's output signal under arbitrary polychromatic radiation can be regarded as a superposition of the detector's output signals under monochromatic radiation. This leads to the concept of spectral sensitivity.

In detail, the CIE defines a detector's **spectral sensitivity** (also: **spectral responsivity**) **s(λ)** by

$$s(\lambda) = \frac{1}{X_\lambda(\lambda)} \frac{dY}{d\lambda}$$

whereby $X_\lambda(\lambda)$ denotes the spectral radiometric quantity defining the detector's input signal and dY denotes the (differential) increase of the output signal caused by the input radiation in the (differential) wavelength interval between λ and λ+dλ. When linear behavior of the detector can be assumed, the detector's signal Y is given by

$$Y = \int_\lambda X_\lambda(\lambda) \cdot s(\lambda)\, d\lambda$$

Often, the spectral sensitivity function s(λ) is described by the product of a reference value s_m and the **relative spectral sensitivity** $s_r(\lambda)$:

$$s_r(\lambda) = s_m \cdot s_r(\lambda)$$

In many cases, s_m is given by the maximum of s(λ), thus $s_r(\lambda)$ is normalised to a value of 1 in its maximum. Another possibility is the normalisation of $s_r(\lambda)$ to a total wavelength integral value 1, which is achieved by the definition of

$$s_m = \int_\lambda s(\lambda)\, d\lambda$$

In terms of relative spectral sensitivity the detector's output signal Y is given by

$$Y = s_m \int_\lambda X_\lambda(\lambda) \cdot s_r(\lambda)\, d\lambda$$

This integral relation is equivalent to the definition of photopic quantities, whereby the detector's relative spectral sensitivity $s_r(\lambda)$ corresponds to the CIE spectral luminous efficiency function V(λ) and s_m corresponds to K_m = 683 lm/W (see § II.7.f). Similarly, the calculation of effective radiation doses relevant for certain biological reactions is based on a corresponding relation containing the respective biological action spectrum. For instance, the erythemal action spectrum is used for definition of **Sunburn Unit**, which is used for quantification of erythemally active solar UV irradiance (see § VI.1).
This correspondence allows the direct determination of photopic quantities or biologically active radiation by an especially designed integral detector. In particular, the detector's relative spectral sensitivity $s_r(\lambda)$ has to be matched closely to the CIE spectral luminous efficiency function V(λ) or to the respective action spectrum. For the determination of chromaticity coordinates or correlated color temperature, it is necessary to simultaneously use three detectors with their spectral sensitivities especially adapted to the color matching functions defined by the CIE 1931 standard colorimetric observer (see § II.10.a).

Gigahertz Optik uses different combinations of photodiodes and filters to achieve proper spectral sensitivities for detectors used in photometry, radiometry and colorimetry.

III.2.a. Monochromatic radiometry

For radiometric characterisation of monochromatic or near monochromatic radiation of a known wavelength, a detector's spectral sensitivity does not necessarily have to match a certain predefined shape. Thus, a photodiode can be used without any spectral correction filters as long it is sensitive at the respective wavelength.
Typical tasks of monochromatic radiometry are the laser power measurements, characterisation of LEDs with near monochromatic light output and power measurements in fibre optical telecommunication. Gigahertz Optik offers

- laser power meters equipped with a flat field detector (for lasers with collimated beams) or with an integrating sphere (for lasers with non-collimating beams and LEDs),
- integrating spheres equipped small area photodiodes, whose low capacitance results in a detector time constant in the order of nanoseconds. Thus, these detectors are perfectly suitable for laser pulse analysis with high time resolution.
- detectors equipped with integrating spheres with unique baffle design for measurements in fibre optics telecommunication. Additional adapters for standard fibre optic connectors are available.

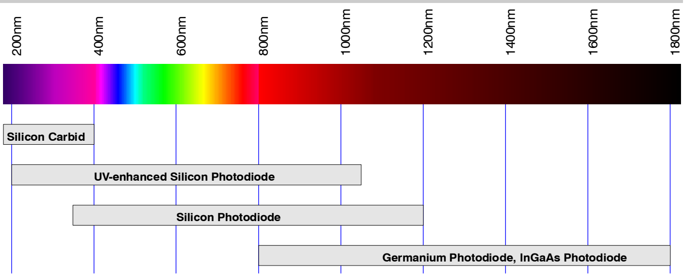


Fig. III.11. Sensitivity ranges of various types of photodiodes

III.2.b. Polychromatic radiometry

The determination of total radiation power over a certain spectral range requires the detector's spectral sensitivity function to closely match a rectangular shape.
Gigahertz Optik offers absolutely calibrated irradiance and radiant power meters equipped with a cosine diffuser or an integrating sphere, whose spectral sensitivity is optimised for UVA, UVB, UVC, visible (VIS) and near infrared (NIR) ranges.

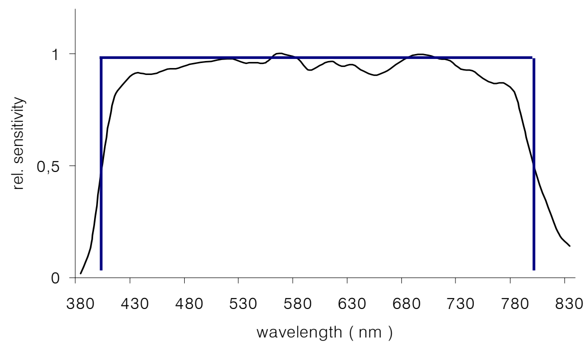


Fig. III.12. Spectral sensitivity of Gigahertz Optik's RW-3703 VISIBLE$_{400\text{-}800\ nm}$ Irradiance detector closely matches the ideal rectangular shape.

III.2.c. Photometry

For photometric measurements, the detector's relative spectral sensitivity $s_r(\lambda)$ has to match the CIE spectral luminous efficiency function V (λ) as close as possible. In order to quantify a detector's inevitable spectral mismatch, the CIE recommends the evaluation index f_1', which is defined by

$$f_1' = \frac{\int_\lambda |s_r^*(\lambda) - V(\lambda)|\, d\lambda}{\int_\lambda V(\lambda)\, d\lambda}$$

where $s^*_r(\lambda)$ is given by

$$s_r^*(\lambda) = \frac{\int_\lambda S_A(\lambda)\, V(\lambda)\, d\lambda}{\int_\lambda S_A(\lambda)\, s_r(\lambda)\, d\lambda} \cdot s_r(\lambda)$$

where $S_A(\lambda)$ is the spectral distribution of the CIE standard Illuminant A (see § II.10.), which is the recommended photometric calibration source. High quality photometric detectors show a value for f_1' below 3%, whereas a value of f_1' above 8% is considered as poor quality. The DIN 5032, part 7 requires a spectral mismatch of f_1' ≤ 3% for "Class A" instruments and f_1' ≤ 6% for "Class B" instruments. Gigahertz Optik offers high quality illuminance, luminance and luminous flux detectors meeting Class A level (f_1' = 3%) and, as an economical alternative, detectors meeting class B level (f_1' = 5%).

III.2.d. Colorimetry

For the determination of a color stimulus X, Y and Z values as defined by the CIE 1931 standard colorimetric observer, the same stimulus has to be measured by three different detectors, whose spectral sensitivity functions have to be adapted to the CIE 1931 XYZ color matching functions (see § II.10.a). However, as the x(λ) color matching function consists of two separated regions of sensitivity, the X value is often determined by two detectors. In this case, altogether four detectors are needed for the determination of a stimulus' X, Y and Z values. As the color matching function y(λ) is identical with the CIE spectral luminous efficiency function V(λ), the respective detector can be absolutely calibrated for simultaneous photometric measurements.

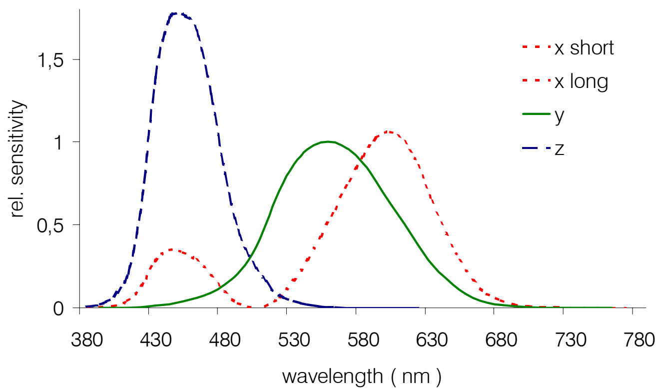


Fig. III.13. Spectral sensitivity functions used for colorimetric measurements with Gigahertz Optik's CT-3701 High Precision

III.3.The detector's time behaviour

A detector's time resolution is limited by its response to an instantaneous change of the input signal. Due to electrical capacities of the light sensitive element and the electronics, the output signal does not change instantaneously as well but gradually increases or decreases until it reaches its final value. The detector's **rise time** is defined by the time span required for the output signal to rise from a certain low percentage (usually 10%) to a certain high percentage (usually 90%) level of the maximum value when a steady input is instantaneously applied. Accordingly, **fall time** is defined by the time span required for the output signal to drop from a certain high percentage (usually 90%) to a certain low percentage (usually 10%) of the maximum value when a steady input is instantaneously removed.
Typically, the detector's response to an instantaneous change of the input signal exponentially approaches the final value. In that case, the detector's time behaviour is best described by the **time constant** τ, which is the time span required for the output signal to vary from its initial value by 63% of its final change (the value of 63% is derived from 1 – 1/e, which equals 0.63). The temporal change of the output signal Y(t) from its initial value Y_0 to its final value Y_f is then given by

$$Y(t) = Y_0 + (Y_f - Y_0) \cdot e^{-\frac{t}{\tau}}$$

Gigahertz Optik's integral detectors use photodiodes, which are typically characterised by time constants of **µ**s. As most variable light sources change their intensity levels in significantly longer time scales, the detector's time constant is not really an issue for most applications. However, especially lasers are often pulsed with a frequency in the order of 10^9 Hz (for example in telecommunication), which corresponds to signals periods in the order of 1 ns. In that case, the relatively slow response of normal photodiodes prevents the accurate characterisation of the laser signal's time characteristics. For this application, Gigahertz Optik offers the LPPA-9901 detector, which uses a photodiode with an especially small capacity. This allows to reduce the LPPA-9901's time constant to a value of 5 ns.

III.4. The detector's dynamic range

In general, a detector fulfils the condition of linearity (see § III.2.) only for a limited range of the input signal level. There are two effects which define the boundaries of this **dynamic range**:

- At very low levels of the input signal, the detector's output is largely dominated by noise. **Noise** is a random temporal fluctuation of the output signal which occurs even when the input signal is constant. The absolute level and the frequency distribution of these variations depends on the physical properties of the detector and the subsequent electronics. For many detectors, noise is largely independent from the absolute level of the input signal and can be neglected for input signals above a certain minimum level. However, for very low input signals, the output signal is dominated by noise and does no longer quantify the physical quantity which should be determined. The lower limit of the measurement range, which is posed by noise, is quantified by the **noise equivalent input**. The CIE defines the noise equivalent input as the value of the respective physical quantity (radiant power or luminous flux, irradiance or illuminance, ...) that produces an output signal equal to the root mean square noise output. As the shape of the noise signal depends on the temporal resolution that can be achieved of the recording electronics (often characterised by the electronics' time constant), the noise equivalent input is defined for a stated frequency and bandwidth. Unless otherwise stated, a 1 Hz bandwidth is usually considered. Depending on the detector's characteristics, its noise level can be reduced by longer detector integration times or by averaging subsequent measurements of the same input signal.
- At high levels of the input signal, the detector's output signal no longer increases proportional to its input signal, and thus the detector no longer fulfils the condition of linearity (see § III.2.). Instead, physical limits of the light sensitive element and / or the electronics cause **saturation** of the output signal, which increases less than proportional to the input signal and finally reaches a constant level. To a certain extent, subsequent correction of the detector's output signal can account for the effects of saturation and thus extend the detector's dynamic range. This correction has to be based on a thorough laboratory investigation of the detector's dynamic behaviour and still leads to higher measurement uncertainties at high levels of the input signal.

The detector dynamic range depends on the photodiode type The overall measurement system dynamic range will depend on both the detector and electronic meter's range capabilities. For example, a typical silicon photodiode is capable of measuring more than 2 mA of current before saturating, however the upper current measurement range of the meter may be limited to 200 µA.
This range covers extremely low intensity levels, for instance the quantification of erythemally active UV radiation, or very high intensity levels, which are used for industrial UV curing processes.

III. 5. Calibration of integral Detectors

Calibration is the determination of the correlation between an input and an output quantity. All measurement instruments, such as voltmeters, manometers, vernier calipers, etc., must be calibrated to determine the variation in reading from the absolute quantity. In radiometry, the input quantity is provided by standard lamps and optical radiation detector standards. Because of the many different measurement quantities involved, calibration standards for each quantity are required if an optical radiation calibration laboratory hopes to cover the whole range of possible calibrations. A 'traceable' lab calibration standard should show an unbroken chain of links to national (better international) standards. But this in itself does not guarantee accuracy or the ability of the lab to meet its calibration uncertainty claims. Since calibration standards are subject to change with age and use, a means to periodically check the calibration of the standards themselves must be in place. Occasionally the standards must be replaced in order to maintain the quality of calibration and traceability. The end user of the calibrated product may be required to audit the calibration facility to ensure its competency and traceability. In Germany, the Deutsche Kalibrierdienst – DKD (the German accreditation institution) and the Physikalisch-Technische Bundesanstalt (the German national standard laboratory) offer an accreditation service for industrial calibration laboratories where the lab's calibration standards, calibration procedures and the stated re-calibration intervals are subject to audit. This accreditation ensures that the traceability of the calibration is on an absolute level. The DKD also ensures the international acceptance of its accredited calibration laboratories. Refer to Appendix VI.6 for more information on national calibration organizations.

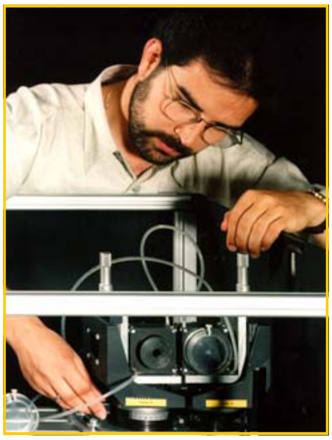


Fig. III.14.
GO Calibration Engineer

III.5.a Traceability: an Unbroken Chain of Transfer Comparisons

Calibration is the most important prerequisite for accuracy in measurement instrumentation. It is the foundation upon which subsequent measurements are based upon. Optical radiation calibration is typically done by the transfer method where the relationship between the value indicated by a measuring instrument and the value represented by a calibration standard is compared with the former reading adjusted as needed, recorded and certified.

Since the reading of a meter-under-test is directly compared against that of the transfer standard, the qualification of this standard is of the highest importance.

A qualified standard should display an unbroken chain of transfer comparisons originating at a national standards laboratory. For example, the transfer standard of the national laboratory, primary standard (A) is used to calibrate the reference standard (B) at an accredited calibration laboratory. This reference standard is used to calibrate the laboratory work standard (C) to be used daily by the cal lab. This work standard is then used to calibrate the final product (D) or device under test. Accordingly, the calibration path is A-B-C-D. This path is called the chain of traceability.

Each transfer device in the chain should be subjected to periodic examination to ensure its long-term stability. The lab performing the calibration typically sets the time span between examinations and is self audited.

III.2.b. Polychromatic radiometry

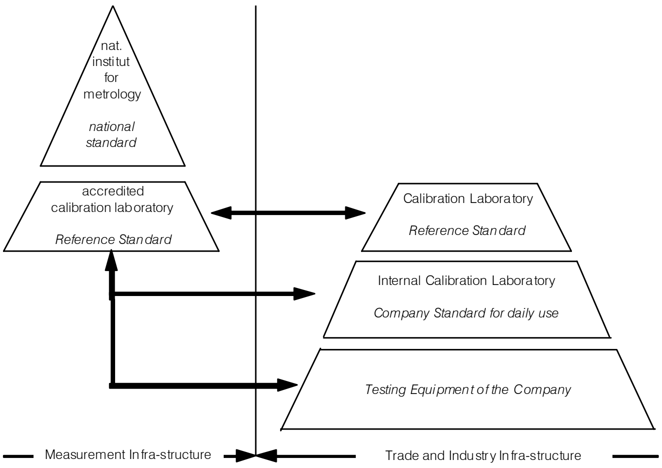


Fig. III.15
Calibration Hierarchy from Primary Standard to Test Equipment

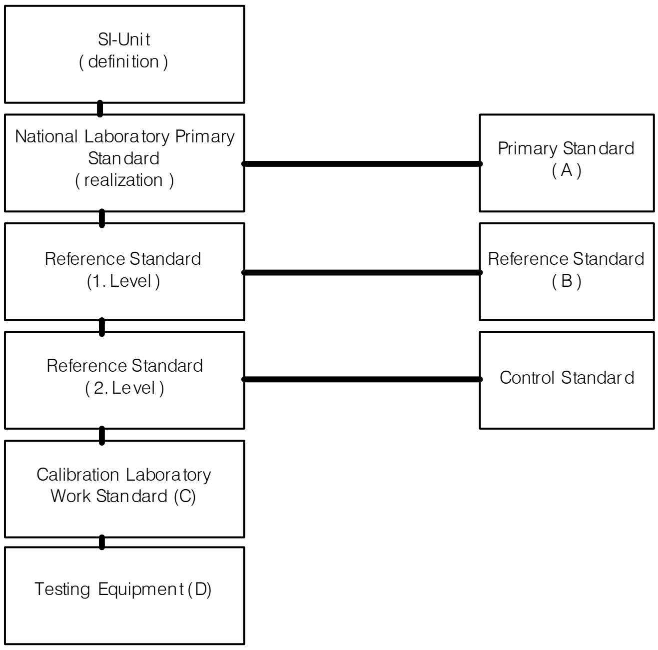


Fig. III.16 - Hierarchy of Standards

Accredited calibration laboratories guarantee recalibration cycle times for their standards plus a review of their calibration procedures since they are subject to review by an official accreditation authority.

III.5.b. ISO/IEC/EN 17025 (formerly ISO Guide 25 and EN45001)

The aims of the General Requirements for the Competence of Calibration and Testing Laboratories are to provide a basis for use by accreditation bodies in assessing competence of laboratories; establish general requirements for demonstrating laboratory compliance to carry out specific calibrations or test; and assist in the development and implementation of a laboratory's quality system. * Without exception, DKD accredited calibration laboratories fulfill the requirements of the European standard EN 45001 (general criteria to operate a testing laboratory, May 1990). Outside of Europe this standard is not compulsory. Instead of this the ISO/IEC Guide 25 (General requirements on the competence of testing and calibration laboratories, December 1990) is recognized. In content, EN 45001 and ISO/IEC Guide 25, known as ANSI/NCSL Z540-1 in the United States, is identical. This is the basis for the mutual appreciation between the European cooperation for Accreditation (EA) and its extra-European partners. In 1999 ISO/IEC 17025 took the place of EN 45001 and ISO/IEC Guide 25 which eliminated any formal differences.

ISO/IEC/EN 17025 is compatible with A2LA and NVLAP requirements.

*ISO 17025 web page : http://www.fasor.com/iso25

III.5.c Calibration Quantities

Spectral Irradiance
W cm^{-2} nm^{-1}

Irradiance (W/m^2) measured as a function of wavelength (nm), is known as spectral irradiance. This type of source calibration is performed with a spectral measurement device or spectroradiometer as compared to a reference standard. The spectral range of calibration depends on the source and spectral zone of interest. A typical QH lamp may be spectrally scanned from 200 to 2500 nm using a fixed wavelength increment or variable bandwidth depending on the required resolution.

Spectral Radiance
W cm^{-2} sr^{-1} nm^{-1}

Radiance (W/cm^2·sr) measured as function of wavelength is called spectral radiance. Radiance in a given direction, at a given point of a real or imaginary surface is the optical unit used to calibrate optical radiation sources. Calibration is normally performed with a spectral measurement system or spectroradiometer equipped with a radiance lens assembly that has been calibrated with an integrating sphere based radiance standard. The spectral range of calibration will depend on the source and the spectral range of interest. A full spectral scan may cover from 350 to 2500 nm.

Spectral Responsivity

Optical radiation detectors, photodetectors, photodiodes, exhibit changes in sensitivity at different wavelengths. This spectral responsivity can be measured as relative responsivity in percent (%) versus wavelength (nm) across the active wavelength bandpass of the photodevice. For example a silicon device scan could cover the wavelength range from 250 to 1100 nm at a set increment. Or a GaAsP photodiode from 250 to 700 nm. The increment setting could span from 1 to 50 nm depending on the required resolution. Also, single point response at a particular wavelength may be all that's required for some applications. Calibrations are performed by transfer comparison and certified against qualified reference standards.

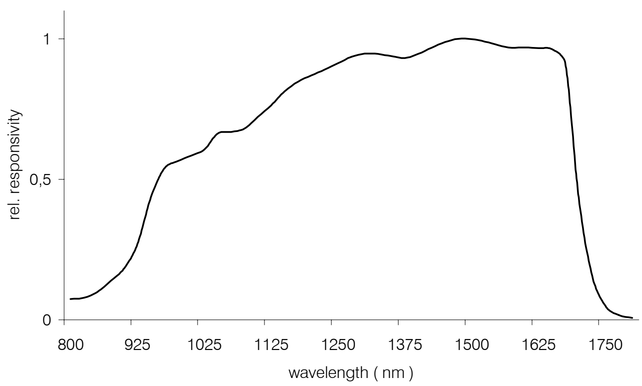


Fig. III.18. InGaAs Detector with sphere. Relative Spectral Response Plot

Measurement of Light

Illuminance Sensitivity
lux / foot-candles
Calibration of the illuminance response of photopic detectors is normally performed as a transfer comparison from a photopic reference standard. The photometric responsivity of the reference standard can be qualified through radiometric measurement using red, blue and green filtered photodetectors. However this is a complicated procedure left to advance radiometry labs. Illuminance sensitivity calibrations allow direct reading of the photopically corrected detector in lux or foot-candles. Very often a tungsten source is used for illuminance calibrations. If the photopic detector spectral response does not match the CIE photopic curve too a high degree, measurement errors will occur when measuring different type sources.

Luminance Sensitivity
cd/m^2 & fL
Luminance responsivity of photopic detectors equipped with field limiting input optics is accomplished by comparison to a luminance reference standard detector. A uniform field of luminance is produced as the calibration source using an integrating sphere or a source with an optically diffuse material in front of it. Luminance detector's field of view is confined to a narrow angle so that the detection area is overfilled with a sample of the uniform luminance field. Luminance detectors are calibrated to measure in the optical units of candela per square meter and foot-lamberts.

Color Sensitivity
Broadband colorimetric detectors are calibrated by comparison to reference standards based on CIE tristimulus values using a light source of known color temperature. Color temperature, luminance and illuminance calibrations may be included depending on the color meters capability. The color meter is calibrated to display the color chromaticity coordinates x,y and /or u', v' of the light source under test.

Irradiance Sensitivity
W/m^2 & W/cm^2
Broadband irradiance detector calibrations are performed by transfer comparison to reference standards with consideration to the spectral characteristics of the detector to be tested. Reference detectors are calibrated against spectral irradiance measurements using a double monochromator spectroradiometer, itself calibrated using traceable spectral irradiance standards. Irradiance detectors are calibrated to read out in the optical units of watts per square meter or watts per square centimeter over a specific wavelength range.

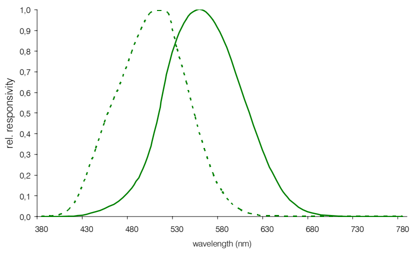


Fig. III.19. CIE Scotopic and Photopic Function

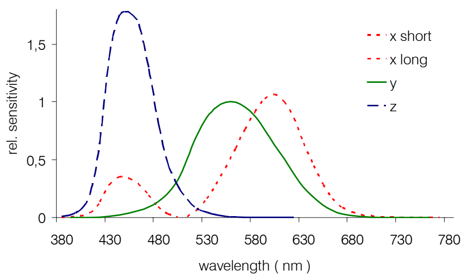


Fig. III.20. Color Detector Tristimulus Functions

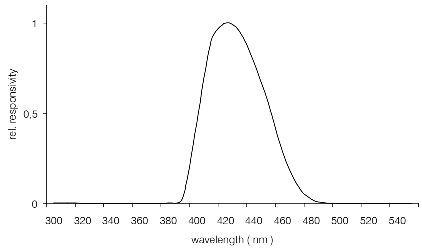


Fig. III.21. BLUE Spectral Response Irradiance Detector

Spectral Reflectance
Calibration of the spectral reflectance of materials is accomplished by comparison to reference reflectance standards which themselves are used to set-up calibration of the spectrophotometric instrument which actually performs the measurement. Single or double beam spectrophotometers can spectrally range from 250 to 2500 nm, with adjustable wavelength increments. When coupled to an integrating sphere; total hemispherical, diffuse and specular reflectance can be separately measured with the spectrophotometer. Without the sphere the in-line set-up of the spectrophotometer measures the normal specular reflectance component only.

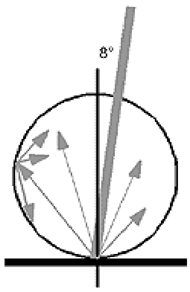


Fig. III.22. 8 Degree Reflectance Measurement Set-up

Spectral Transmittance
Calibration of the spectral transmittance of materials is accomplished by comparison to reference transmission standards which themselves are used to set-up calibration of the spectrophotometric instrument which actually performs the measurement. Single or double beam spectrophotometers can spectrally range from 250 to 2500 nm, with adjustable wavelength increments. When coupled to an integrating sphere; total hemispherical, diffuse and regular (specular) transmittance can be separately measured with the spectrophotometer. Without the sphere the in-line set-up of the spectrophotometer measures the regular reflectance component only. Calibration is performed as percent transmission versus wavelength.

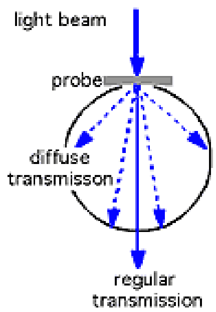


Fig. III.23. Transmission Measurement Set-up

III.5.d Calibration Standards

Calibration standards are employed to generate an input quantity for the equipment used in the calibration. Since the calibration standard supplies a signal of known quantity, the difference of the output signal of the equipment to the signal of the calibration standard can be evaluated. From these differences calibration correction factors can be calculated allowing absolute readings when the output signal is corrected by these values. For photometric and radiometric measurement quantities different calibration standards are needed:

Photometric – Radiometric Quantity:
Luminous Flux – Radiant Power
Luminous Intensity – Radiant Intensity
Luminance – Radiance
Illuminance – Irradiance

Equivalent photometric and radiometric quantities exist where the measurement and therefore calibration geometry is the same. The only difference is the radiometric or photometric responsivity of the detection system. This means most calibration reference standards can be used for both, photometric and radiometric calibration, if the calibration data is available. For very precise or close tolerance calibrations specially selected calibration standards are needed. Typically calibration standards are used as transfer standards, meaning they transfer the values of the primary standard to a lab standard for subsequent transfer to a device under test. For traceable calibrations an unbroken chain of transfer comparisons back to the national primary standard is certified. Calibration uncertainty is of course dependent on the calibration hierarchy of the standard. Since the calibration transfer is a real hardware transfer of the standard itself, careful handling and operation of the calibration standard is extremely important. In imaging applications the uniformity of response or transmittance is critical. So light sources with a uniform luminous area are needed to determine the non-uniformity of a lens system or visual imaging detection system

Source Based Standards

Every optical radiation detection or measurement system needs to be calibrated in reference to an optical radiation source. There are two possible ways to handle the calibration:

- The source may be calibrated in the required quantity and the difference between the input signal, generated by the source, and the output signal of the detection system can be determined using the calibration data of the source
- The uncalibrated source may be operated under stable conditions and the calibration done by comparing the reading of the detection system with a calibrated detection system (reference standard). The reference standard must have the same measurement geometry and the same spectral response as the unit to be calibrated.

The most common optical radiation source used for calibration standards is the tungsten halogen lamp since its emission spectrum is close to a Planckian radiator (blackbody source). Other sources where optical radiation is produced by means of an element heated to incandescence by electrical current are also in use. Filament position and stability of the tungsten halogen lamp is critical plus it has a limited lifetime. Therefore the lamp should only be operated in the position specified in the calibration certificate. Comparing the lamp output against other in-house reference standard sources or against suitable reference detection systems must be periodically done to check stated lamp calibration uncertainty.
In radiometric applications, where the spectral characteristic of the source is used, the source should be operated in current controlled mode, to ensure the stability of the spectral characteristic. The minimum specification for current stability should be held at 10^{-4} A.
In photometric applications or radiometric applications with broadband detectors, intensity controllable standards can be used if changes in the spectral emission characteristics are not critical.
If the tungsten halogen lamp is used as a spot source the exact location on the filament used during the calibration of the source, must be subsequently used.
In luminance, radiance and imaging uniformity calibrations, tungsten halogen lamps must be fitted with a diffuse screen or placed within an integrating sphere. Sphere based luminance and radiance standards offer higher uniformity and a better diffuse function.
For calibrating luminance and radiance meters with a limited field-of-view, a diffuse transmitting screen can be used at the sphere output. In imaging applications the uniformity and the diffuse function of currently available screen materials are not precise enough so the open output port of the sphere is typically used.
If the intensity of the tungsten halogen lamp is not high enough, which happens especially in the UV range, arc lamps such as xenon lamps may be used. But the increase in intensity can affect calibration uncertainty.

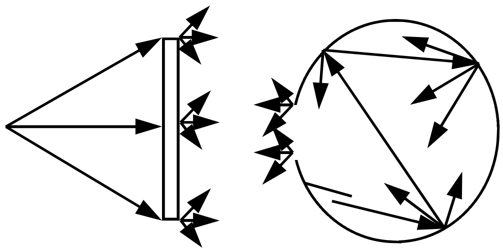


Fig. III.24. Diffuse Screen & Integrating Sphere

Detector Based Standards

Due to the high levels of maintenance and care required to operate optical radiation source based calibration standards, detector based standards are very attractive alternatives. The detector has the advantage of long-term absolute and mechanical stability, especially true of semiconductor detectors.
The use of detector-based standards is very common in monochromatic radiometric applications such as the calibration of laser power meters for telecommunication testing. But because of surface reflections, polarization effects, beam misalignment and beam 'bounce-back' errors, the use of detector based calibration standards must be carefully considered.
The use of spectrally broadband detectors as calibration standards is mostly limited to photometric applications where detectors with a precise filter corrected photometric spectral response are available. Calibration is performed by comparison of the output signal of the reference detector to that of the device to be calibrated. The same stable source of optical radiation is used during the calibration procedure. For monochromatic calibrations a monochromatic radiation source is needed. If a detector's spectral responsivity is to be measured over its entire active bandpass, a tungsten halogen lamp with a monchromator attached to it can be used to create monochromatic radiation at all of the different required wavelengths.

Spectral Irradiance Standards

Tungsten Halogen lamps are the 'workhorse' of spectral irradiance standards.
FEL type lamps with a filament support arm are recommended for high intensity BLUE light and UV applications.
Sylvania calibration grade lamps are recommended for visible and near IR applications where the best long term stability is required.
In order to qualify for calibration as a standard, each lamp must undergo a minimum 15-hour burn-in procedure and must display a satisfactory burn-in data trend during this period. The calibrated tungsten reference source provides spectral irradiance data from 250 to 2500 nm covering many typical UV-Vis-IR radiometric and photometric applications.
The lamp is normally provided in a housing and socket made from ceramic or other material which ensures long-term stability and protection. Filament targeting aids may be provided for best measurement accuracy in the calibration laboratory.
Since lifetime is somewhat limited, lamp power supplies with on/off ramping functions are recommended for use with these sources.

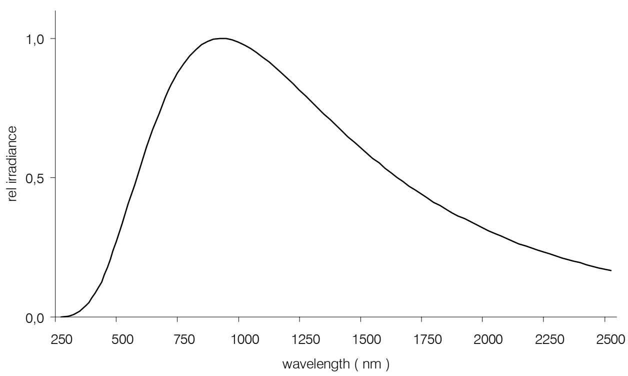


Fig. III.26. Lamp Spectral Distribution

Fig. III.25. FEL Calibration Standard Lamp

Measurement of Light

Luminance Standards

Reference sources of luminance are used to calibrate the uniformity of imaging systems and the luminance output of luminance meters, spot exposure meters and other photometric equipment.
The standard is constructed around the integrating sphere of various diameters which provide the highly uniform diffuse luminance at the exit port required for these types of calibrations. The spheres may be coated with barium sulfate or machined from optically diffuse plastics. Seasoned tungsten halogen sources are typically used with lamp power supplies and temperature stabilized photometric reference detectors to form the complete system. Control feedback loop techniques control the luminance output intensity and help prolong the useable lifetime of the system. Any change in ambient and sphere body temperature affecting the output signal is eliminated through the temperature stabilized reference detector. This also reduces system warm-up time.
An optimally designed sphere layout is capable of less than ± 0.7% non-uniformity over 90% the port opening which can be as large as 100 mm in diameter. Angular uniformity of less than ± 5% within ±40° enables luminance output calibration of detection systems with wide acceptance angles. Luminance outputs can range from 0.5 to 35000 cd/m2. Some standards may offer a variable luminance output requiring more sophisticated electronics, multiple lamps and exhaust fans.
In order to qualify as a calibration standard the system itself must be calibrated by a competent calibration facility. Luminance output, uniformity and angular uniformity must be measured and certified.

Fig. III.27. Luminance Standard

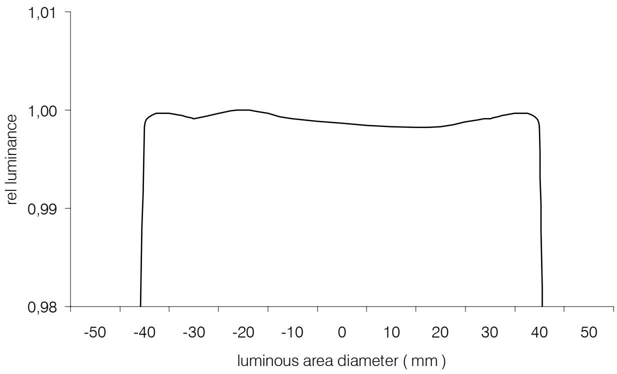


Fig. III.28. Typical Luminance Uniformity Response Plot

Spectral Radiance Standards

Reference sources of radiance are used to calibrate radiance detectors and other radiometric equipment. The standard is constructed around the integrating sphere of various diameters which provide the highly uniform diffuse radiance at the exit port required for these types of calibrations.
The spheres may be coated with barium sulfate or machined from optically diffuse plastics. Seasoned tungsten halogen sources are typically used with lamp power supplies and temperature stabilized photometric reference detectors to form the complete system. Control feedback loop techniques control the luminance output intensity and help prolong the useable lifetime of the system. Any change in ambient and sphere body temperature affecting the output signal is eliminated through the temperature stabilized reference detector. This also reduces system warm-up time.
An optimally designed sphere layout is capable of less than ± 0.7% non-uniformity over 90% the port opening which can be as large as 100 mm in diameter. Angular uniformity of less than ± 5% within ±40° enables luminance output calibration of detection systems with wide acceptance angles. Some standards may offer a variable radiance output requiring more sophisticated electronics, multiple lamps and exhaust fans.
In order to qualify as a calibration standard the system itself must be calibrated by a competent calibration facility. Radiance output, uniformity and angular uniformity must be measured and certified.

Fig. III.29. Variable Radiance Standard

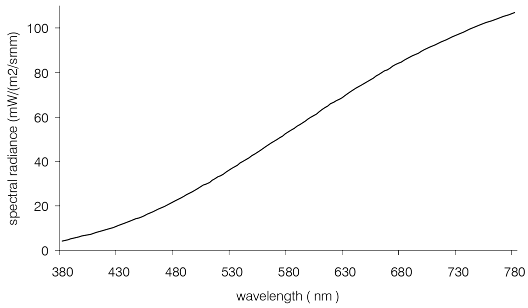


Fig. III.30. Typical Spectral Radiance Plot

Spectral Responsivity Standards

Due to their long term stability and broad spectral coverage, silicon photodiodes are used as reference spectral standards by national and private calibration laboratories worldwide.
These photodiodes with active areas as large as 100 mm^2, are mounted into machined housings to protect and precisely fix the detector in a calibration set-up in concert with targeting aids. Some housings may include an integral temperature sensor to monitor thermal characteristics during test sessions. Or to ensure best measurement uncertainty, temperature stabilization using cooling jackets that maintain the device temperature to within ± 0.5°C are employed. UV enhanced Si devices offer spectral coverage from 250 to >1100 nm. Calibration with certification from an accredited traceable calibration facility is required to qualify the device for use as a reference standard.

Fig. III.31. Detector Calibration Standard

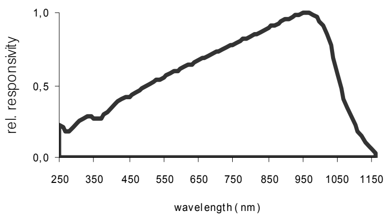


Fig.

Reflectance Standards

White optically diffuse reflectance standards traceably calibrated for spectral reflectance over a spectral range from 250 to 2500 nm are used in the calibration of reflectance meters, optical distance measurement systems, densitometers, spectrophotometers and other optical and imaging systems. Qualifications of a reflectance standard include light and temperature stability and durability, near Lambertian diffuse reflectance and up to 98% spectrally neutral reflectance over the spectral range of interest. Processed PTFE machined and cut into various shapes and thicknesses is currently used for reflectance standards. High reflectance white, black and gray shades at varying reflectance values are available.
To maintain the quality of a calibrated standard it is normally mounted into a protective housing with a removable lid to keep the material clean and covered when not in use.

IV. Detector Signal Measurement

A typical light detector or photoactive device converts impinging photons into a current or voltage proportional to the incoming signal.
The detector connects to an electronic meter for amplification, possible conversion from an analog to digital signal (ADC), calibration and display of the measurement result. Together, the meter, photodetector and accessory components form an optometer, radiometer, photometer, color, laser or optical power meter and reflection/transmission measurement systems. A radiometer consists of a voltage or current meter coupled with a radiometric type detector. Photometers employ the same meters used with photometric type detectors. Multi-channel color meters are used with colorimetric detectors to display multiple quantities. The optometer is a term used to indicate that the meter can be used with either radiometric or photometric type detector heads. Microprocessor controlled units capable of measuring currents down to tenths of picoamperes up to a few milliamperes are available. This allows full utilization of the sensitivity range of most photosensitive devices. Measurement methodology might employ 16-bit signal digitization by means of an analog to digital converter (A/D) with sampling rates in the microseconds. Selectable averaging calculation of the sampled results from microseconds to seconds provides more measurement flexibility for fast events or low-level signals. Operation of the device can be accomplished through a logical menu structure with user input via front-panel keyboard or through computer control via RS232 or IEEE computer interface.
The quantity or optical unit measured will depend on the detector type, how it's configured in the way of filtering and input optic, and its calibration. Radiometers are available in hand-held mobile or bench-top models for laboratory use. Self-contained cordless models are used for remote dynamic monitoring where a standard detector that connects to the meter via a cable might foul. Capabilities such as dynamic measurement range, operating modes (example: CW, dose, pulse energy) and features (example: auto-ranging, backlit display, digital interface, datalogging) separate the different models. Usually the application determines what specific capabilities are important to have in the radiometer system. For example, in a UV curing production process where multiple stations must be monitored, a multi-channel radiometer with settable min/max reading feature, RS232 or IEEE interface and remote multiplexed detectors would be desirable.
The following is a list of various features, modes of operation and specifications offered in current light meters. Note that available features and functions will vary depending on the type of meter and manufacturer.

Operating Modes & Features:

CW: Continuous wave is a run of continuous type measurements. The measurement frequency depends on the *integrating time* and the max. *sample rate*. of the meter.
CW Min/Max: CW measurement where the min. or max. value that occurred during the measurement run will be displayed. The min. or max. value can be reset with the RESET switch.
CW Level Check: CW measurement where the measurement values are compared against min.-max. threshold values. The threshold values are entered into the meter by the user.
CW Level Minimium / Maximum: Menu to adjust the threshold values for CW Level Check.
Run/Hold: To freeze a measurement value on the display and stop the continuous measurement.
Relative Ratio (%): Measurement value as the relative ratio of a reference value (stored in the optometer) or a reference measurement value (2-channel optometer required).
Relative Ratio Factor: Measurement value as the relative ratio factor of a reference value (stored in the optometer) or a reference measurement value (2-channel optometer required).
Attenuation (dB or dBm): Measurement value as the logarithmic ratio factor (attenuation) of a reference value e.g. dBm (stored in the optometer) or a reference measurement value e.g. dB (2-channel optometer required).
Dose: CW measurement values integrated over the dose measurement time. A preset dose measurement time or a max. dose value will stop the measurement.
Data Logger: Each measurement value of a CW measurement will be stored individually in the optometer's memory. Each measurement may be manually or automatically initiated by a preset measurement cycle time. Measurement data can be outputted through computer interface.
Color: Chromaticity coordinates x,y and u',v' and the correlated color temperature are calculated from the ratio of the detector's signals.
Peak Maximum: Each CW measurement interval consists of a certain number of samples (number depends on integration time and sampling rate). Peak Maximum is the most positive sample of one measurement interval. A new Peak Maximum is calculated and displayed for each measurement interval.
Peak Minimum: Each CW measurement interval consists of a certain number of samples (number depends on integration time and sampling rate). Peak Minimum is the most negative sample of one measurement interval. A new Peak Minimum is calculated and displayed for each measurement interval.
Peak to Peak: Each CW measurement interval consists of a certain number of samples (number depends on integration time and sampling rate). Peak to Peak is the difference of the most positive to the most negative sample of one measurement interval. A new Peak to Peak value is calculated and displayed for each measurement interval.
I-Effective: Measures and calculates the energy of light pulses based on the Schmidt-Clausen formula. The input signal is sampled with the max. sampling rate for one measurement interval (Pulse Measurement Time). First the pulse-energy is calculated by integrating the samples. I-Effective is calculated by using the pulse-energy and the peak-value of the measurement interval using the following formula:
I-effective = peak-value * pulse-energy / (peak-value * C + pulse-energy)
C = IF-Time Constant (between 0.1s and 0.2s, depending on application)
IF Time Constant: Factor C for calculation of I-Effective (Schmidt-Clausen).
Pulse Energy: Measures and calculates the energy of light pulses. The input signal is sampled with the max. sampling rate for one measurement

Measurement of Light

interval (Pulse Measurement Time). The energy is calculated by integrating these samples.
Pulse Measurement-Time: Measurement interval for I-Effective and Pulse Energy measurements.
Remote RS232: enables RS232 interface of the device. RS232 is a standard for Asynchronous Transfer between computer equipment and accessories. Data is transmitted bit by bit in a serial fashion. The RS232 standard defines the function and use of all 25 pins of a DB-25 type connector. Minimally configured, 3 pins (of a DB-9 type connector) are used, namely: Ground, Transmit Data and Receive Data. On PCs, the RS-232 ports labeled as "serial" or "asynch" and are either 9 or 25 pin male type.
Remote IEEE488: Interface IEEE488 of the device enabled. IEEE488 is a standard for Parallel Transfer between computer equipment and measurement instruments. Data is transmitted in parallel fashion (max. speed 1MByte/s). Up to 31 devices (with different addresses) can be connected to one computer system.
USB: a communication standard that supports serial data transfers between a USB host computer and USB-capable peripherals. USB specifications define a signaling rate of 12 Mbs for full-speed mode. Theoretically 127 USB-capable peripherals are allowed to be connected to one USB host computer. The connected devices may be powered by the host computer.
Auto Range: when activated, the measurement range is switched by the device automatically to the optimal value (depending on the input signal).
Manual Range: with autorange disabled, the measurement range can be manually fixed to a certain value. The device is not allowed to switch measurement ranges automatically. Manual range adjustment can be useful in cases where input signals are changing rapidly.
Calibration Factor: Optical sensors transform optical signals into current. This current is measured by the device. The calibration factor determines the relationship between the measured current and the calculated and displayed measurement result (optical signal).
Offset: The Offset value is subtracted from the measured signal to calculate the result. Offset can be set to zero or to the measured CW-value. Offset is useful to compensate for the influence of ambient light or if the measurement value is very small relative to the adjusted measurement range.
Integration Time: Time period for which the input signal is sampled and the average value of the sampled values is calculated (>CW). Integration time should be selected carefully. For example, if multiples of 20 ms (50 Hz) are selected as the integration interval, errors produced by the influence of a 50Hz AC power line can be minimized.
Sampling Rate: The rate which specifies how often the input signal is measured (sampled). The CW-value is calculated using the average value of all samples of one measurement interval (integration time). A sampling rate of 100ms means that 10000 samples per second are taken. If the measurement interval (integration time) is 0.5 s, there are 5000 samples used to get the CW value.

Specifications:

Slew-rate: how fast a signal changes. For example, a rate of 5 Volt/ms means that the signal changes with a value of 5 Volts every ms.
Rise-time: Time needed for a signal to change from 10% to 90% of its final value.
Fall-time: Time needed for a signal to change from 90% to 10% of its start value.
Input Ranges / Measurement Range: To achieve a dynamic measurement capability greater than six decades, different levels of measurement ranges (Gains) for the "current to voltage input amplifier" are necessary. Gains can span from 1V/10pA to 1V/1mA (depending on the device).
Linearity: The linearity of an optometer can be described as follows: Reading a value of 10nA, with a max. gain error of 1%, the possible error is +/-0.1nA. Together with an additional offset error of 0.05nA, the total measurement uncertainty would be 10nA +/-0.15nA or 1.5%.
At a reading of only 1nA in the same gain range, the gain error would be 1% of 1nA or 0.01nA. The offset error would still be 0.05%. The total measurement uncertainty would be 1nA +/-0.06nA or 6%. The offset error is minimal with our optometers since these meters offer an internal offset compensation or allow an offset zero setting from the menu. Here the only offset error is from the display resolution or the nonlinearity of the analog-digital converter (ADC).
Measurement Accuracy / Linearity: The max. possible error of a measurement result can be calculated as follows:
Total Error: Gain Error + Offset Error
Gain Error: Displayed (or readout) result X (Gain Error (in percent) / 100)
Offset Error: Constant value depending on measurement range
The Offset Error can be nearly eliminated be using offset compensation.
Some errors cannot be compensated because they are produced by the nonlinearity of the ADC (Analog Digital Converter) and the display resolution.
Maximum Detector Capacitance: The input current-to-voltage ampflifier is sensitive to input capacitance. If the input capacitance is too large, the amplifier may oscillate. The maximum detector capacitance is the largest value of capacitance for which the amplifier will remain out of oscillation.
Measurement Range: The measurement range is typically specified by the resolution and the max. reading value. But the user should note that for a measurement with a max. measurement uncertainty of 1%, the min. measurement value should be a factor of 100X higher than the resolution. On the other hand, the max. value may be limited by the detector specifications such as max. irradiation density, max. operation temperature, detector saturation limits, etc., and therefore the manufacturer's recommended measurement values should be adhered to.

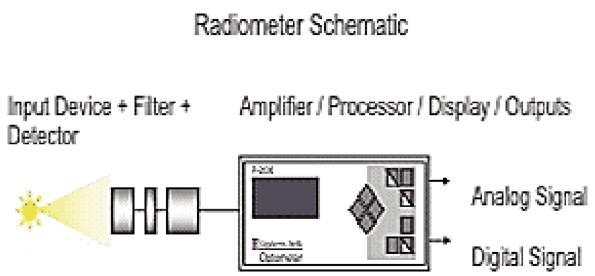


Fig. IV.1. Radiometer Schematic

V. Theory and applications of integrating spheres

Integrating spheres are very versatile optical elements, which are designed to achieve homogenous distribution of optical radiation by means of multiple Lambertian reflections at the sphere's inner surface. The primary radiation source can be located either inside the sphere or in front of the source's entrance port. In the latter case, only the optical radiation entering the sphere is relevant for the sphere's internal radiation distribution.
As long as we restrict ourselves to those regions which are shielded from direct irradiation by the primary source and are thus only illuminated by reflections at other of the inner surface, the theory of the ideal integrating sphere leads to two important conclusions:

- Irradiance of the sphere's inner surface is proportional to the total radiant power either emitted by a source inside the sphere or entering the sphere through its entrance port. Geometrical and directional distribution of the primary source's radiation do not influence irradiance levels as long as direct illumination of the respective location is prevented. This property becomes especially important when an integrating sphere is used as the input optical element of a detector for radiant power (see § III.1.b).

- Radiance reflected by a region of the sphere's inner surface shielded from direct illumination is constant in its directional distribution and independent from the specific location where the reflection occurs. Thus, the sphere's exit port can be used as an ideal Lambertian source as optical radiation leaving the sphere is characterised by homogenous radiance and exitance distributions. This property becomes especially important when a sphere is used as a standard calibration source.

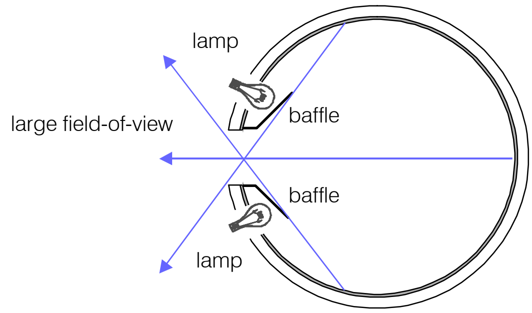


Fig. V.1. Integrating sphere used as a standard source for optical radiation. Multiple Lambertian reflections inside the sphere result in a homogenous radiance and exitance distributions at the sphere's exit port.

V.1. Theory of the ideal integrating sphere

The ideal integrating sphere, a theoretical construction which allows the explanation of the sphere's basic principle of operation, is characterised by the following properties:

- Its entrance and exit ports are infinitesimally small.
- All objects inside the sphere, light sources and baffles, are also infinitesimally small and their influence on optical radiation after its first reflection at the sphere's inner surface can be neglected.
- Its inner surface is a perfectly homogenous Lambertian reflector, and its reflectance ρ is independent from wavelength. For a more detailed discussion of reflective materials largely fulfilling these properties, see § II.5.c. and III.1.a.

During the following considerations, the symbol index describes the order of reflection. So, E_0 denotes the irradiance caused directly by the light source, whereas E_1, E_2, ... denote the irradiance caused by light from the source after one, two, ... reflections. Total irradiance is then given by the infinite sum

$$E_{total} = E_0 + E_1 + E_2 + ...$$

For convenience, the index „e", denoting radiometric quantities, is omitted. However, if the reflectance ρ of the sphere's coating material is independent from wavelength, the derived relations also hold true for photometric quantities, which would be denoted by the index „v".
Lets consider an ideal integrating sphere of radius R, consisting of a hollow perfect Lambertian reflector with infinitesimally small entrance and exit ports. An inhomogeneous radiation source produces direct irradiance levels E_0 (the term „direct irradiance" refers to the fact that E_0 is directly caused by the source without any reflections) which depend on the respective location at the sphere's inner surface (Fig.V.2). As a first step, we want to calculate the irradiance E_1 of the sphere's inner surface, produced by the radiance L_1 after the first reflection. Due to the Lambertian reflection property of the sphere's material, the radiation reflected by a certain area element dA is characterised by a constant directional radiance distribution L. According to Equ. II.7 in paragraph II.5.c, the area element's exitance M_1 is related to the reflected radiance L_1 by

$$M_1 = L_1 \pi$$

and is further related to the element's direct irradiance E_0 by

$$M_1 = \rho E_0$$

whereby ρ denotes the total reflectance of the sphere's inner surface.

As a consequence,

$$L = \frac{\rho E_0}{\pi} \qquad \text{Equ.V.1}$$

Although L does not depend on the direction relative to the surface element dA, it still depends on the location at the sphere's inside, which is a consequence of the generally irregular direct illumination by the light source.
If we want to calculate the radiant power emitted by the area element dA and impinging upon another area element dA', we have to calculate the solid angle of dA', as seen from dA (Fig.V.2). As dA' is tilted by an angle ε relative to the line of sight between the two area elements, dA' occupies the solid angle dΩ', as seens from dA:

$$d\Omega' = \frac{\cos(\varepsilon)\, dA'}{d^2}$$

with d denoting the distance between dA and dA'.

According to Equ.II.3 in paragraph II.4.d., the radiant power emitted by dA into the solid angle dΩ' and thus impinging upon dA' is given by

$$L \cos(\varepsilon)\, dA\, d\Omega' = L\, dA \frac{\cos^2(\varepsilon)\, dA'}{d^2}$$

and dividing this expression results in the (infinitesimal) irradiance dE_1 of the sphere's inner surface at the location of dA' which is caused by a single reflection of direct radiation from the source at the area element dA:

$$dE_1 = L \frac{\cos^2(\varepsilon)}{d^2} dA = \frac{E_0 \rho}{\pi} \frac{1}{4R^2} dA$$

using Equ. V.1 and the relation d = 2 R cos(ε), which can be easily seen from Fig.V.2

In order to obtain the irradiance E_1 at the location of dA', caused by a single reflection of the source's radiation at the whole inner surface of the sphere, the above expression for dE_1 has to be integrated over the sphere's inner surface:

Formula A

whereby Φ_0 denotes the total radiant power emitted by the source and impinging upon the sphere's inner surface.
Note that the irradiance of the inner surface after the first reflection is independent from the actual location on the sphere, which holds true despite the inhomogeneous direct irradiance caused by direct illumination from the source. Deriving the irradiance E_2 caused by the source's radiation after two reflec-

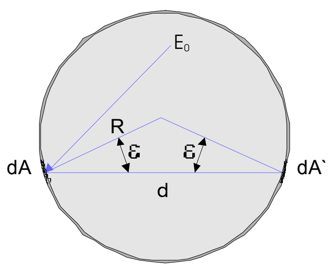


Fig.V.2. Geometry of an ideal integrating sphere of radius R.

A: $$E_1 = \int_{\text{inner surface}} \frac{E_0 \rho}{\pi} \frac{1}{4R^2} dA = \frac{\rho}{4\pi R^2} \int_{\text{inner surface}} E_0\, dA = \frac{\rho \Phi_0}{4\pi R^2}$$

B: $$E_2 = \int_{\text{inner surface}} \frac{E_1 \rho}{\pi} \frac{1}{4R^2} dA = \frac{\rho}{4\pi R^2} \int_{\text{inner surface}} E_1\, dA = \frac{\rho}{4\pi R^2} E_1 \cdot 4\pi R^2 = \rho E_1 = \frac{\rho^2 \Phi_0}{4\pi R^2}$$

Integrating Spheres

tions in the same way, we get

Formula B

Generally, the irradiance of the sphere's inner surface caused by the source's radiation after k reflections is given by

$$E_k = \frac{\rho^k \, \Phi_0}{4 \, \pi \, R^2}$$

and the total irradiance is thus given by Formula C

In this expression, only E_0 actually depends on the respective location on the sphere's inner surface. As a consequence, E_{total} is independent from the actual location of the sphere's inner surface as long as we assure that $E_0 = 0$ at this location. This means that no direct radiation from the source reaches the location, which can be obtained by baffles. In this case, total irradiance is proportional to the total amount of radiant power Φ_0 reaching the sphere's inner surface directly from the source:

$$E_{total} = \frac{\Phi_0}{A_{sphere}} \cdot \frac{\rho}{1-\rho} = \frac{\Phi_0}{A_{sphere}} \cdot K$$

As the constant K describes the enhancement of irradiance relative to the average irradiance of a non-reflecting sphere, it is called „sphere multiplier" and, for an ideal sphere, solely depends on the coating material's reflectance ρ.

Formula C:

$$E_{total} = E_0 + E_1 + E_2 + \ldots = E_0 + \sum_{k=0}^{\infty} \frac{\rho^k \, \Phi_0}{4 \, \pi \, R^2} = E_0 + \frac{\Phi_0}{A_{sphere}} \sum_{k=0}^{\infty} \rho^k = E_0 + \frac{\Phi_0}{A_{sphere}} \cdot \frac{\rho}{1-\rho}$$

V.2. Real integrating spheres

Due to the simplifications assumed for an ideal integrating sphere, the relations derived in paragraph IV.1 cannot be directly used in practical applications. Instead, they have to be altered for the following reasons:

- The reflectance ρ might depend on wavelength. This results in a wavelength dependent sphere multiplier K and thus in a spectral distortion of the primary source's output. Thus, the relations for the ideal sphere, which have been formulated for radiometric quantities, can no longer directly be applied. Instead, the sphere's behaviour for monochromatic radiation has to be determined by the respective relations for spectral radiometric quantities. If desired, radiometric quantities describing the sphere's radiation output can be determined by subsequent wavelength integration of the respective spectral radiometric quantities.
- Intensity considerations pose a lower limit for the size of the entrance and exit ports, as the radiant power entering or exiting a sphere is proportional to the area of the respective port. As a result, these ports might considerably reduce the amount of light reflected at the sphere's inner surface, which can be accounted for by a modified sphere multiplier:

$$E_{total} = \frac{\Phi_0}{A_{sphere}} \cdot \frac{\rho}{\left[1-\rho\,(1-a)\right]} = \frac{\Phi_0}{A_{sphere}} \cdot K$$

with

$$K = \frac{\rho}{\left[1-\rho\,(1-a)\right]}$$

In these relations, a denotes the relative share of the area of all ports and other non-reflecting areas on the sphere's total inner surface:

$$a = \frac{\text{sum of all non-reflecting areas}}{A_{sphere}}$$

below shows the dependence of the sphere multiplier on reflectance ρ for different values of a. It can be clearly seen that even a small variation of reflectance might cause significant change in the sphere multiplier.

For this reason, a slight wavelength dependency of ρ may result in a strong wavelength dependency of the sphere multiplier.

- Objects inside the sphere, for example the light source itself, cannot generally be neglected in their influence on the reflected optical radiation. A possible solution is the determination of the light source's influence by means of an auxiliary lamp (see paragraph III.1.b).
- Baffles inside the sphere and deviations of the coating material's reflectance properties from perfect Lambertian reflection cause further deviations of the sphere's behaviour from the relations derived in chapter 0. Their influence can only be simulated by numerical Monte Carlo simulations, which basically use ray tracing techniques to follow the paths of a large number of individual photons.

Apart from these factors, integrating spheres are also subject to temporal variations of their optical properties, which are primarily caused by degradation of their coating material. Especially the traditional coating material Barium sulphate ($BaSO_4$) ages significantly when exposed to UV radiation.

Optically diffuse material (OP.DI.MA) is an optical grade plastic especially designed to work as a volume reflector. It has been designed to replace barium sulfate as a coating for integrating spheres in UV and high temperature applications. Its reflective properties depend on its thickness, generally specified at 10 mm, which is the recommended minimum thickness for lighting engineering.

Apart from its temporal stability, OP.DI.MA offers additional advantages. Using different additives, its reflection factor can be adjusted to any value between 3% (deep black) and 99% (brilliant white), whereby uniform reflectance over a wide spectral range and over large geometrical areas can be achieved. Like other plastics, it can be processed by turning, drilling, sawing and milling and is available in raw blocks, plates and foils in various sizes for this purpose.

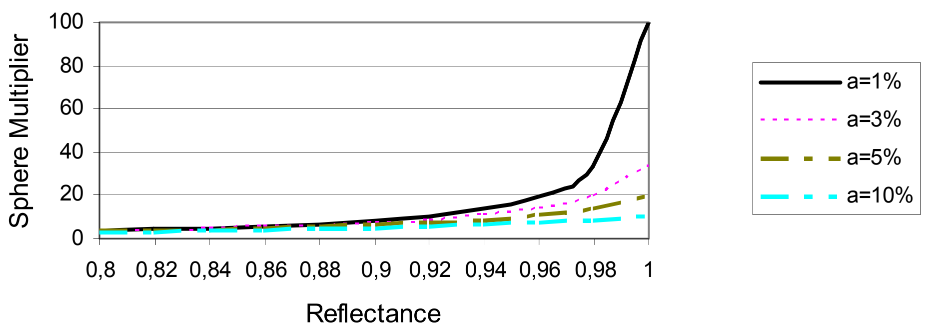


Fig. V.3. Dependence of the sphere multiplier K on reflectance ρ for different values of the share of non-reflecting areas on the sphere's total inner surface.

VI. Applications for Light Measurement in Medicine, Technology, Industry and Environmental Science

For most technical applications of light, authorities like the International Commission on Illumination (CIE) or the Deutsche Industrienormen (DIN) have developed well-defined standards regarding its measurement. In virtually all areas connected with light, there is a strong demand for high quality measurement instruments. Many of these instruments must be specially designed and manufactured for the specific application. Moreover, these instruments must be calibrated against national standardization authorities, such as the National Institute of Standards and Technology (NIST) in the United States or the Physikalisch-Technische Bundesanstalt (PTB) in Germany.
Gigahertz Optik not only offers a wide variety of absolutely calibrated light detectors, but also offers its experience in light measurement technology for the development of specialized solutions based on customer requirements. Gigahertz Optik's accredited calibration facility provides accurate, state of the art absolute calibration of instruments and secondary standard light sources (see § III.5).

VI.1. Phototherapy and Radiation Protection

85% of all sensory perceptions are optical in origin but optical radiation is not only involved in the process of human vision, it has many other biological effects as well.

The photobiological effects of optical radiation, especially in the ultraviolet and blue (400 to 500nm) spectral regions, can be therapeutic. For example, it is used in phototherapy to treat a variety of skin diseases and in postnatal treatment of Hyperbilirubinemia. For proper dosimetry, irradiance (W/m^2) and irradiance dose (J/m^2) delivered by UV sources in phototherapy processes need to be monitored and controlled through accurate measurements. These measurements are typically performed with a spectrally and spatially qualified UV-A, UV-B and UV-B$_{311}$ radiometer.
However, optical radiation also poses a potential health hazard for both human skin and eyes. For example, overexposure to ultraviolet and blue 'light' can cause common sunburn, photokeratitis (welder's eye) and burning of the retina or cornea.
Because of the dramatic increase in global UV radiation and the cumulative nature of the harmful effects, the additional risk of UV exposure by artificial sources is a concern.
The efficiency of protective devices like sun creams, UV blocking fabrics and sunglasses are the subjects of study.
Photobiologists, industrial hygienists, health and safety officers measure UV irradiance (W/m^2) and irradiance dose (J/m^2) of solar and artificial light sources in the lab, field and in the work place in order to study both the harmful and helpful effects of light and establish safe guidelines for its use. It is important to note that UV levels and subject exposure times typically vary so datalogging over some time period is commonly employed.
Because Gigahertz-Optik is actively involved in the „Thematic Network for Ultraviolet Measurements" funded by the Standards, Measurements and Testing program of the Commission of the European Communities, the detector and instrument designs are at the highest available level. The CIE, Commission Internationale de l'Eclairage, is reviewing many of the concepts put forth by the European Commission in an effort to internationally standardize the evaluation of UV radiometric measurement instrumentation much like the way photometric instruments are characterized now.

Incoherent Optical Radiation Protection

Even though there are many wide ranging and highly positive effects of light there are also negative effects to consider. Naturally occurring optical radiation, especially in the UV range of the solar spectrum, poses a potential health risk to outdoor workers and others who spend a significant amount of time outdoors. The most serious long-term consequence of UV exposure is the formation of malignant melanoma of the skin, a dangerous type of cancer. In the US, skin cancer is the most frequently contracted type of cancer, and since the 1970s, the incidence rates of malignant melanoma have more then doubled. As a similar development can be found for other countries, national and supranational networks of solar UV detectors have been established recently to monitor solar UV levels and the World Meteorological Organization is currently preparing guidelines for their characterization, calibration and maintenance.

In simple terms, incoherent optical radiation is optical radiation in the range of wavelengths between 100 nm and 1 mm, other than that emitted by lasers. The effect of incoherent optical radiation on the skin and the eye is being afforded increasing attention. The reasons for this are to be found in the rising exposure to radiation from sunlight, particularly in the UV range, and the growing use of high powered lamps in radiation therapy, radiation cosmetics, UV radiation curing, UV sterilization, vehicle headlamps, lighting equipment, etc. The high proportions of UV and blue light in the emission spectra of these lamps can, in addition to their desired effects, also result in radiation damage through both direct and indirect contact if the maximum permitted exposure levels are exceeded.
The shallow depth of penetration of optical radiation restricts the health hazards primarily to the eye and skin.

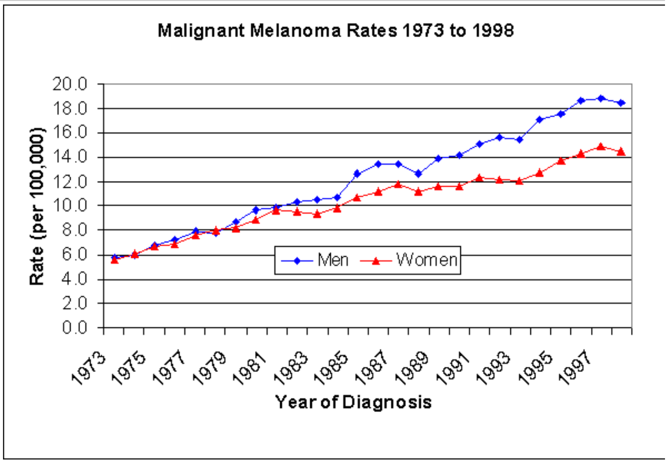


Fig.VI.1. Incidence rates of malignant melanoma in the US since 1973.

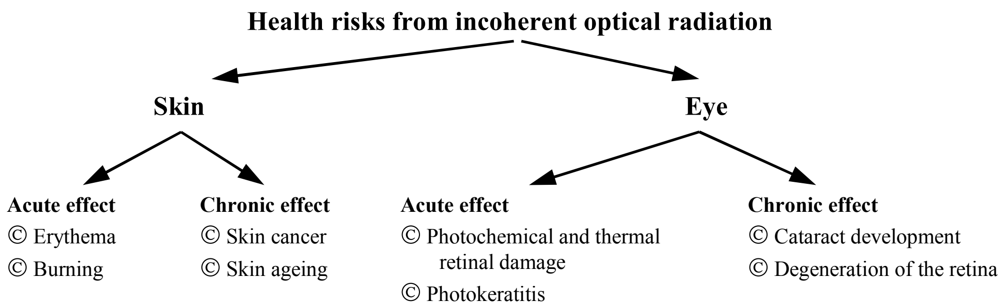


Fig.VI.2. Optical Radiation Health Risks

Relevant Radiation Quantities

When evaluating the harm that might be caused by incoherent optical radiation, it is the effective radiance (or the time integral of the radiance) that is critical for the retina, whereas for the skin, cornea and lens of the eye the critical quantity is the effective irradiance (or the exposure, also known as the dose) that can, for instance, arise at a workplace or in some other location where time is spent.

Photobiologically effective radiance (W/(m² sr))

$$L_{biol} = \int_0^\infty L_{e\lambda}(\lambda) * s(\lambda)_{biol,rel} * d\lambda$$

with $L_{e\lambda}(\lambda)$: spectral radiance of the radiation sources

Photobiologically effective irradiance (W/m²)

$$E_{biol} = \int_0^\infty E_{e\lambda}(\lambda) * s(\lambda)_{biol,rel} * d\lambda$$

with $E_{e\lambda}(\lambda)$: spectral irradiance of the radiation sources

Photobiologically effective exposure (dose, J/m²)

$$H_{biol} = \int_0^{t1} E_{biol} * dt$$

with $s(\lambda)_{biol,rel}$ stands for the relevant spectral response functions of the skin and eye.

If exposure limits are given in guidelines as effective radiance, Limit, or as effective irradiance, E_{limit}, then the following conditions should be maintained:

$$E_{biol} \le E_{limit} \text{ or } L_{biol} \le L_{limit}$$

If the exposure vaues are given as the time integral of the radiance Li or as the exposure (dose), H, then the maximum permissible exposure duration, t, can be calculated:

$$t = L_i / L_{biol} \text{ or } t = H / E_{biol}$$

ACGIH / ICNIRP Spectral Weighting Functions for Assessing UV Radiation Hazards

The spectral weighting function for the acutely harmful effects of UV radiation, was developed by the *American Conference of Governmental Industrial Hygienists (ACGIH) and* the *International Commission on Non-Ionising Radiation Protection (ICNIRP)*
If one examines the spectral curve describing this function, it is seen that the spectral effectiveness in the UV-C and UV-B ranges is very high, and that it falls drastically in the UV-A range. The reason for this is that the function is derived from the functions relating the radiation to erythema (skin reddening) and photokeratoconjunctivitis (corneal inflammation). The range of wavelengths from 315 to 400 nm (UV-A) corresponds to a rectangle function representing total UV-A. Threshold Limit Values given for the maximum permissible exposure of the skin define the range of wavelengths as 200 (180) to 400 nm in reference to the ACGIH-ICNIRP function. The limits of maximum permissible exposure for the eye in the range 200 (180) to 400 nm and 315 to 400 nm (UV-A) are defined separately. By definition ACGIH-ICNIRP UV-C/B is measured in effective irradiance according to the spectrally weighted function and the UV-A level is assessed by measurement of the total UV-A irradiance (no spectral weighting function) for UV-A rich sources.

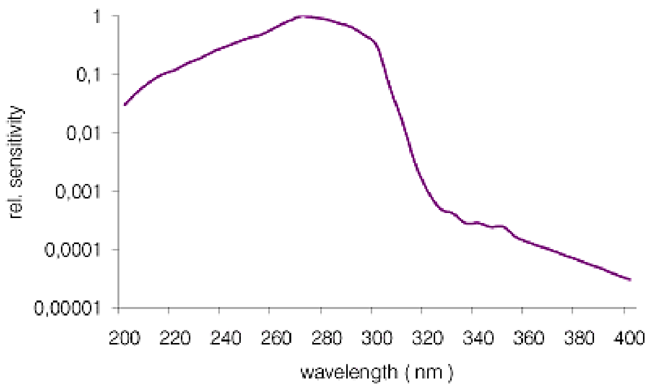


Fig. VI.3. ACGIH Spectral Function

Blue-Light Hazard Photochemical Risks to the Retina

If optical radiation with wavelengths between 380 and 1400 nm of sufficient intensity reaches the retina it can cause photochemical and thermal injury. Radiation in the "blue" part of the spectrum from 380 to 700 nm (effectively 380 to 550 nm) triggers photochemical reactions, if the photon energy in the radiation is high enough, converting chemically unstable molecules into one or more other molecule types. The spectral curve of the blue light hazard response function is shown in the following diagram. ICNIRP 1997 gives the following limits for the effective radiance of the BLH function:
$L_{BLH} * t \le 100$ J*cm^{-2} * sr^{-1} for $t \le$ 10.000s
$L_{BLH} \le 10$ mW * cm^{-2} * sr^{-1} for $t >$ 10.000s
L_{BLH} = effective radiance
t =duration of exposure

The blue light hazard function generally applies to exposure periods of more than 10 s. For shorter exposure times, the thermal retinal injury function applies.

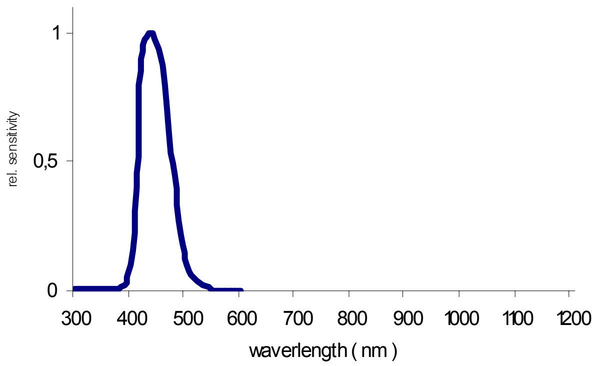


Fig. VI.4. Blue Light Hazard Spectral Function

Thermal Injury to the Eye -(RTH - Retina Thermal Hazard)

If the retina is exposed during short periods to high radiation intensities, a temperature rise to 45°C leads to hyperthermia, to 60°C causes coagulation, and to over 100°C results in vaporization. Removing the heat depends for the most part on the capacity of the irradiated zone to transfer heat, and thus on the size of the image of the radiation source on the retina. The diagram above illustrates the spectral response function for thermal damage to the retina according to ICNIRP.
In the spectral range between 380 and 500 nm, the effect of the RTH function is larger than the BLH function by a factor of 10. Whereas the latter rapidly falls to zero above 500 nm, the thermal function continues on to 1400 nm. Since no industrially useable radiation sensors with spectral sensitivity from 380 to 1400 nm exist, an acceptable simulated match using silicon photodiodes is in use. In this context it is quite adequate to measure the range up to 1200 nm, since various light sources exhibit no more than 4% difference in the integrated totals to 1200 nm and to 1400 nm. This statement is also confirmed by ICNIRP in their working paper /1/.

For radiation sources whose emissions lie primarily in the near infrared range (IR-A) between 780 and 1400 nm, and that generate a visual luminance of less than 10 cd/m^2, the visual stimulus is so weak that the aversion reflex is not activated. In such applications the measurement of radiance must, according to ICNIRP, take place exclusively in the IR-A region.
L(λ): spectral radiance of the radiation source being measured, RTH (λ) : Retina Thermal Hazard Function, α = apparent radiation source.

Limits are also prescribed for the RTH function. Thus, for the case where

$$10\mu \leq t \leq 10s$$

$L_{haz} \leq 50/(\alpha * t^{0,25})$ (kW*m^{-2}*sr^{-1})
L_{haz} = effective radiance for the RTH function,
a = size of the light source expressed in radians
For t < 10 µs the limit must not be any greater than L_{haz} for t= 10 µs. For t > 10 µs the limit must not be any greater than L_{haz} for t= 10 s.
Metrological Considerations

Radiance is the quantity relevant to the evaluation of BLH and RTH hazards. The latest draft standards (IEC 825-1, November 1998), and ICNIRP (printed in Health Physics 1999) express views as to the angle of the measurement field of radiance meters. The applicable figures related to exposure durations are:

t<10s an α of 1.7mrad [1)];
t=10s...100s an α of 11mrad [2)]
t= 100s...10000s an α of 1.1*t^{0,5} [2)];
t> 10000s an α of 100mrad [2)]

[1)] Dominance of thermal damage to the retina
[2)] Dominance of blue light hazard

For RTH IR-A evaluation ANSI/ IESNA RP-27.1-96 recommends a field of view of 11 mrad, and of 100 mrad for very large radiation sources.
/1/ ICNIRP: Guidelines of limits of exposure to broad-band incoherent optical Radiation (0,38µm to 3 µm) (September 1997)(0,38µm to 3 µm) (September 1997)

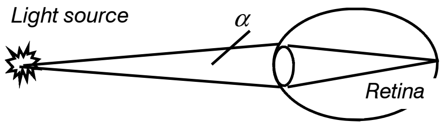


Fig. VI.5. Light Source - Subtended Angle – Retina

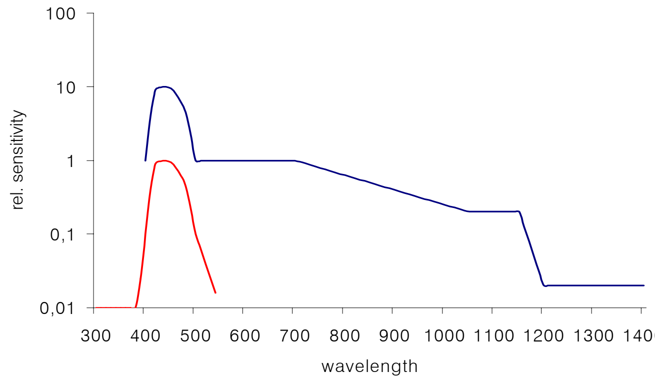


Fig. VI.6. Retinal Thermal & Blue Light Hazard Spectral Functions

UV-Erythema

The typical symptom of UV erythema is acute skin inflammation caused by UV radiation (sunburn). It used to be thought that erythema was only caused by radiation components in the UV-B range of wavelengths. Present opinion is that UV-A plays a part in causing erythema because there is so much more of it present. Medical investigations have shown that intensive exposure to UV in leisure time and at work increases the risk of skin cancer. Children in particular should be protected from strong UV radiation, as the skin stores the information about the UV dose received in the first years of life, and this can be an important factor in the development of skin tumors in later years.
Sunburn occurs in fair-skinned people (skin type 2) with a UV dose of as little as 250 J/m². Our table (following F. Greiter: Sonne und Gesundheit, (Sun and Health), published by Gustav Fischer Verlag 1984) lists the various exposure duration's for minimal skin reddening for different skin types.

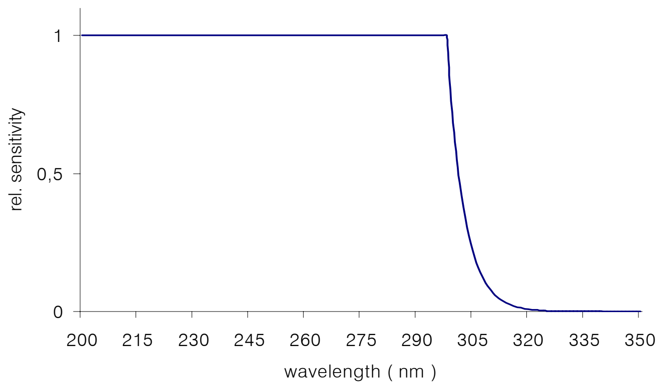


Fig. VI.7. Erythemal Spectral Function

Skin type	Description	Identification	Reaction to the sun Sunburn	Tanning	Exposure duration (min)
I	Skin: noticeably light; Freckles: strong; Hair: reddish; Eyes: blue, rarely brown; Nipples: very pale	Celtic type(2 percent)	Only very painful	No reddeningwhite after 1 to two days, skin peels	5 to 10
II	Skin: somewhat darker than I Freckles: rarely; Hair: blonde to brown; Eyes: blue, green and grey; Nipples: light	Light skinned European (12 percent)	Only very painful	HardlySkin peels	10 to 20
III	Skin: light to light brown, fresh Freckles: none; Hair: dark blonde, brown; Eyes: grey, brown; Nipples: darker	Dark skinned European (78 percent)	Moderate	Average	20 to 30
IV	Skin: light brown, olive; Freckles: none; Hair: dark brown; Eyes: dark; Nipples: dark	Mediterranean type (8 per-cent)	Hardly	Fast and deep	40

Table VI.1. Skin Type Categories

Phototherapy; UV-A, UV-B and UV-B$_{311}$ Phototherapy

UV is widely used by dermatologists in the treatment of certain skin diseases like Psoriasis and Vitiligo. Whole body exposure booths and hand and foot units employing light sources which emit broadband UV-A, UV-B, narrowband 311nm UVB and combinations of UV-A and UV-B are used to irradiate the patient.

In PUVA phototherapy, also called photochemotherapy, UV-A is applied in combination with a photosensitizing agent which is taken in pill form or applied topically to the skin. This medication called psoralen, giving rise to the acronym PUVA, makes the skin more sensitive and responsive to the UV-A (315-400nm) wavelengths.

Due to the risks of premature skin ageing and skin cancer from prolonged exposures, also with consideration to skin type, PUVA is only recommended for moderate to severe cases of Psoriasis. As a side note, psoralen is also being used as a photosensitizer in UV sterilization of blood.

UV-B broadband treatment is normally administered without a photosensitizing agent. It is considered safer than UV-A for wavelengths between approx. 290 to 315 nm, since it does not penetrate as deeply into the skin and is more energetic allowing shorter overall exposure times. However, it is generally accepted that wavelengths below 290 nm produce more erythema which can actually inhibit the therapeutic effects of the longer wavelengths.

As a result, narrowband UV-B sources emitting at predominantly 311-312 nm, have been developed. They emit right in the wavelength zone of most effectiveness while producing less erythemal interference than broadband UV-B sources.

This is generally known as a TL-01 source. A TL-12 UV-B source with a slightly wider band of emittance between 280-350 nm, peaking at about 305 nm is also in use. For more information contact the National Psoriasis Foundation and the American and European Academies of Dermatology.

Dose, used here as irradiance accumulated over time, is normally measured in phototherapy applications.

joules/cm² = watts/cm² x seconds

(dose/energy) = irradiance x time

In the research & development stage or field service, direct irradiance may be monitored to discern any variation in output through lamp or delivery system degradation but most of today's phototherapy equipment is equipped with sensors and electronics which allow delivery of pre-selected doses of UV.

Third party checks of these internal dosimeters by qualified UV radiometers is recommended to ensure proper dosimetry and safety.

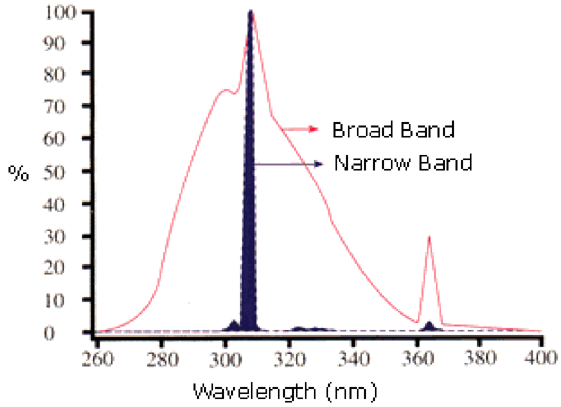


Fig. VI.8. Narrowband 311nm & Broadband UV-B Source Spectra

Bilirubin Phototherapy

Newborn jaundice or neonatal hyperbilirubinaemia, a yellowish appearance of the skin and whites of the eyes, is present to some degree in almost all newborn infants. This is caused by an elevated level of bilirubin molecule in the blood which results from immaturity of the liver function combined with the destruction of red blood cells present. When these levels are very high, one method of clearing the jaundice is by exposing the newborn to light in the blue spectral region between 400 to 550 nm. The light interacts with the bilirubin, converts it to a substance excreted back into the bloodstream which can then be excreted in the feces. The newborn is placed nude in a 'bilibed' or protected isolette and exposed to fluorescent lights designed or filtered to emit in the blue spectrum. A recent development is the 'biliblanket' that delivers blue light through fiber optics and can be wrapped around the infant. Radiometric measurements of bililights are important in order to ensure proper dosimetry.

Efforts to standardize an action spectral function and measurement procedures for bilirubin are in process. Due to early work in this field, the units of microwatts/cm²/nm were wrongly adopted for radiometric measurement of bililights. To be technically correct the units of watts/cm² should apply.

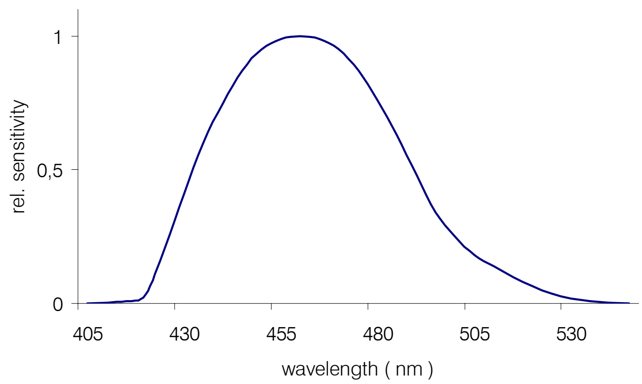


Fig. VI.9. Bilirubin Spectral Function

VI.2. Plant physiology

The study and understanding of the interrelation of optical radiation and plants, seeds and soil is critically important for our existence. Research and control of biochemical factors require a precise and predictable measurement technology.

The absorption of optical radiation in the range of wavelengths between 300 nm and 930 nm initiates photochemical reactions in plants that are essential for plant growth. The three most important reactions of plants to optical radiation are:

Photosynthesis, Phototropism, Photomorphogenesis

Photosynthesis

Photosynthesis is one of the most important biochemical processes on the planet. In the process of photosynthesis green plants absorb carbon dioxide from the atmosphere and water from the soil, combining them with the aid of radiation energy to build sugar, releasing oxygen and water into the atmosphere. This process can bedescribed by the following assimilation formula:

$$6CO_2 + 12H_2O \xrightarrow[674\,kal]{h.v} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

The occurrence of photosynthesis in plants is characterized by the green color of their leaves. This is due to chlorophyll which is absorbed with the photosynthetically active radiation. Accordingly, the absorption of the quanta of radiation energy in the chlorophyll molecules raises the electrons to a higher energy state. As they return to their initial state, the energy released is converted into chemical energy.

Photosynthesis

In general plant physiology, the term **P**hotosynthetically **A**ctive **R**adiation (**PAR**) refers to the radiation in the range of wavelengths between 400 nm and 720 nm. This is the energy that is absorbed by the assimilation pigments in blue-green algae, green algae and higher order plants. The wavelengths for the lower limit (400 nm) and an upper limit (720 nm) are not entirely rigid. Photosynthetic reactions have, for example, been established in some algae at wavelengths shorter than 400 nm. In general, the lower limit depends on the structure and the thickness of the leaf as well as on the chlorophyll content. Some research projects have shown 700 nm as the upper wavelength limit.
In DIN 5031, Part 10 (currently in the draft phase) the spectral response function for photosynthesis is defined, and this is illustrated graphically below. For plant physiology, this range can be divided into three narrower bands:

- 400 nm to 510 nm: strong light absorption by chlorophyll, high morphogenetic effect
- 510 nm to 610 nm: weak light absorption by chlorophyll, no morphogenetic effect
- 610 nm to 720 nm: strong light absorption by chlorophyll, high morphogenetic and ontogenetic effect

This response function can be considered as a mean spectral response function. A number of different investigations have shown that the spectral absorption spectra of various plant types can be very different. These differences can also occur, in a single plant, e.g. in leaves of different ages or with different thicknesses, chlorophyll content, etc.. It should also be noted that the spectral response function for photosynthesis is defined with avoidance of mutual cell shading, experimenting with a young, thin leaf or with a thin layer of algae suspension.
The spectral distribution of the response function for photosynthesis might give the impression that visible radiation in the green range centered around 550 nm contributes very little to the photosynthetic process, and therefore is of minor importance. Just the contrary has been demonstrated by experiment. It is precisely this green radiation that yields the greatest productivity and efficiency in densely populated arrangements of plants or in thick suspensions of micro-organisms. This discovery is important for investigations into the yields of plants in the lower layers of wooded areas or of greenhouse stocks, or in deep water (e.g. in sea plants).

Classical investigations into plant physiology have indicated that photosynthetic bacteria possess special pigments with strong absorption bands in vivo at 750 nm (chlorobium chlorophyll in the green chlorobacteria) or at 800, 850, 870 and 890 nm. In contrast to the blue-green algae, green algae and the higher plants, the absorption spectrum of the photosynthetic bacteria also extends into the UV region as far as about 300 nm.

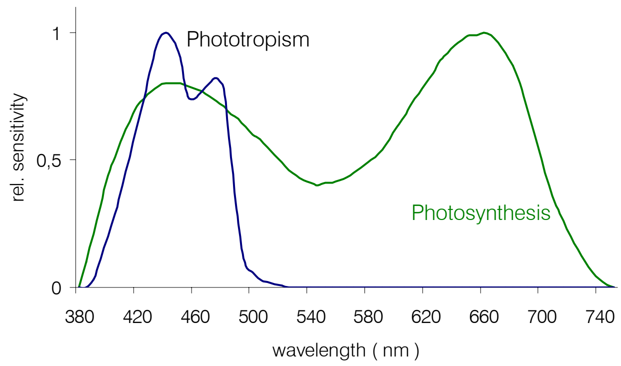


Fig. VI.10. Phototropism (blue) & Photosynthesis (green)

Ultraviolet Radiation Effects

The weakening of the ozone layer has been discussed in public for more than a decade. It presents a serious challenge to plant physiology. Even above Europe, a reduction in the total amount of ozone of 3-6% per decade (since 1978) has been established, which correlates with a measured increase of up to 7% in the level of UV-B radiation in high alpine areas with clean air. In March of 1993 a 15% disappearance of ozone was observed, so that in general an increase in UV-B radiation must be expected.
UV-B radiation penetrates the tissues and leads to molecular changes in DNA, proteins, lipids and phytohormones. At high levels of UV radiation, oxygen radicals are formed, leading to oxidation of proteins and lipids. The result of this is that growth, photosynthesis, and finally productivity and yield are impaired. Some field trials have provided evidence that in the presence of an ozone reduction of 25%, the UV-sensitive soy bean variety Essex, unlike the insensitive Williams variety, undergoes a reduction in photosynthesis, and therefore of yield, of up to 25%. This effect of UV-B radiation (280 nm-313.3 nm) is internationally known as "generalized plant damage", and is evaluated using the UV-B response function according to Caldwell. This GPD response function incorporates the degree of damage, linear growth, the cell division rate and other factors. So in the fields of plant physiology and crop cultivation it is necessary not only to investigate the positive photosynthetic effects of optical radiation, but also the negative effects, mostly due to UV radiation, if the activity and protection mechanisms of plants are to be understood and manipulated.

Phototropism

Phototropism describes the effect of optical radiation on the direction of plant growth. The regions of maximum effect lie in the blue range between 380 nm and 520 nm (see Fig.VI.10). Radiation can have the effect of causing parts of plants to move.

Photomorphogenesis

Photomorphogenesis describes the way in which plants are formed under the influence of optical radiation. Radiation in the red region of the spectrum encourages linear growth, while blue radiation yields small, strong plants. To be more precise, the ratio of the radiation intensities in the range of wavelengths from 690 nm to 780 nm (long wavelength red) to the range of wavelengths from 560 nm to 680 nm (short wavelength red) is of great importance for the plant's biological processes.

Measurement Aim, Measurement Methods

The photochemical processes involved in plant physiology are understood as quantum processes. Associated measuring techniques should also treat them as such. The most important measurements for plant physiology are:

- Analysis of the efficiency of energy conversions in photosynthesis
- Determination of the rate of photosynthesis (yield factor) when exposed to radiation sources having different emission spectra
- Comparison of the rate of photosynthesis in various plant types cultivated under various radiation conditions
- Determination of the protective mechanism and the stress processes of plants in relation to UV radiation and high levels of heat radiation (infrared radiation)

The effect of radiation of various wavelengths on the growth processes taking place within plants can be represented in a number of ways. The rate of photosynthesis is defined as the ratio of the quantity of assimilated carbon dioxide (CO_2) molecules to a suitable radiation input quantity.
These quantities are:

- the irradiance in W/m^2, i.e. the radiant power per unit area of the irradiated object
- or, alternatively, the photosynthetic photon irradiance $E_{p,sy}$. This magnitude is also frequently referred to as the quantum flux density.

Photosynthetic Photon Irradiance $E_{p,sy}$

The radiation conditions used in determining the rate of photosynthesis and the photosynthetic potential of various plant or algae types are not the same in all research institutions. Results obtained under very different radiation conditions, using detector heads with non-uniform rectangular (radiometric) characteristics, and then relating them to one another, may lead to false conclusions. This is because the varying spectra of the radiation sources in use are ignored in obtaining the measurement.
The solution is to evaluate the irradiance with a sensor with an appropriate spectral response function. It is presently assumed that the number of light quanta absorbed is responsible for plant growth, which implies that it is quantum magnitudes effective in plant biology that need to be measured. The most important magnitude is the photosynthetic photon irradiance $E_{p,sy}$.
The photosynthetic photon irradiance $E_{p,sy}$ is defined as follows:
where:

$$E_{p,sy} = \int E_{p,\lambda}(\lambda) d\lambda = \frac{1}{h.c} \int E(\lambda).\lambda.d\lambda$$

$E(\lambda)$ is the spectral irradiance of the light source
λ is the wavelength of the radiation
$E_{p,sy}(\lambda)$ is the spectral photon irradiance = number of photons per second, per unit area and wavelength.
h is Planck's constant
c is the velocity of light.

The unit of photosynthetic photon irradiance, $E_{p,sy}$, is defined as follows:

$$\left[E_{p,sy}\right] = 1 E.s^{-1}.m^{-2} = 1 Mol.s^{-1}.m^{-2}$$

where 1 E = 1 Mol = 6.02* 10^{23} photons (the most commonly used unit is µMol $s^{-1}m^{-2}$).
The limits of integration need to be specified for integration according to the formula. If, for example, the photosynthetic photon irradiance is to be measured in the range of wavelengths between 400 nm and 700 nm, 320 nm and 500 nm and 590 nm to 900 nm, the integration is carried out in the corresponding spectral segments.
This numerical integration can be performed implicitly by means of an integral measuring head. Such a measuring head must, however, satisfy two important conditions:

- © The incident radiation must be evaluated in accordance with the cosine of the angle of incidence, i.e. using a cosine diffuser
- © The spectral sensitivity of the measuring head must be adapted to the l/l_r function. l_r is the reference wavelength, and for the 400-700 nm, 320-500 nm and 590-900 nm ranges it is always the upper limit wavelength, i.e. 700 nm, 500 nm and 900 nm.

The spectral sensitivity of the sensor should be zero outside the responsive spectral zone of interest.

VI.3. UV-Disinfection and Lamp Control

UV radiation can have harmful effects on human skin and eyes, especially during indoor application of high-energy UV irradiators. There is however a positive aspect to UV's hazardous effect on living organisms. Ultraviolet treatment of drinking and wastewater is a well-established, economical and efficient method for killing germs, bacteria, mold and fungus. Its use is becoming more widespread than traditional water treatment techniques employing chlorine and ozone for reasons of cost and environmental factors.

Fig. VI.11.
UV treatment of wastewater

Recently, a field study performed in homeless shelters in New York, Birmingham and New Orleans (TB UV Shelter Study, TUSS) has shown that UV treatment of room air with upper room irradiators leads to a drastic reduction of tuberculosis infection rate.

The CIE divides ultraviolet optical radiation into three ranges:

- UV-A: 315 to 400 nm (skin pigmentation)
- UV-B: 280 to 315 nm (vitamin D synthesis, erythema)
- UV-C: 200 to 280 nm (germicidal action, absorption maximum of DNA). Below 230 nm, UV radiation has enough energy to break chemical bonds.

Short wavelength high energy ultraviolet radiation in the UV-C spectral range from 100 to 280 nm is used in the germicidal/bactericidal sterilization of air and water. UV-C at 253.7 nm is also employed in eprom erasure and the cleaning of sensitive surfaces in the semiconductor industry. UV curing is another area where UV-C is applied.

UV-C Light Sources

Due to its high and pre-dominantly monochromatic output at 253.7 nm, low pressure mercury is the light source of choice in these applications. Medium and high pressure Hg as well as metal halide and other broadband UV sources are also used, especially in UV curing.

Light Source Life-time

The useful lifetime of high power UV-C sources is limited. UV-C intensity must be monitored to ensure process control.

Fig.VI.12.
Upper room UV irradiators help lower tuberculosis infection rates.

VI.4. UV Curing and UV Processing

UV curing is a process in which photocureable chemicals applied to substrates are irradiated with high energy UV or Visible radiation for curing. This energy accelerates polymerization (cross-linking) and consequently the hardening or drying process. The irradiated energy needs to be controlled, since too low a dose will not cure the product, whereas too high a dose will damage it.

In the curing application, dose is used to describe the amount of energy delivered to the target product. It is defined as radiant exposure (energy per unit area) and typically measured as irradiance over time.

J/cm² = W/cm² x seconds

High-power UV sources are used in this process. Because of non-linear ageing, UV output needs to be continuously monitored and controlled.
These high UV levels place special demands on the measurement devices used in this application.
That component of Ultraviolet energy useful for curing makes up only a small part of the spectral bandwidth within the lamp's total emission spectrum and the bare detector's spectral sensitivity. Therefore, optical bandpass filters are used to limit the detector's sensitivity to the spectral range of interest.
Conventionally designed UV irradiation detectors show drift and instability over time due to the hostile ambient conditions found in the UV-curing process. Solarization, 'fogging" effects and even delamination of the filter elements and other optical components can

occur. These effects not only can change the detector's absolute sensitivity but can also change its spectral sensitivity. On recalibration a change in absolute sensitivity may be noted and adjusted but unless a complete spectral test is perfomed a change in spectral sensitivity can go undetected. So what is thought to be a newly recalibrated detector very often will produce erroneous readings when returned to the end user.

A new detector design has been developed based on the integrating element RADIN™, which is not only able to withstand the high UV and temperature conditions of the UV-curing process but also maintain stability and measurement accuracy over long term use. Critical components in the detector are not exposed to direct irradiation but only see a fraction of it.

RADIN is a trade name of Gigahertz-Optik.

The detector response which best matches the absorption spectrum of the photocureable chemical in use is selected. This way the detector spectrally emulates the product to be cured.

The lamp(s) used in the system were selected by the equipment manufacturer for optimal curing within this active bandpass.

When lamp replacement becomes necessary the replacement lamps should be the same in spectral and absolute output as the old ones so that the established process parameters are not invalidated.

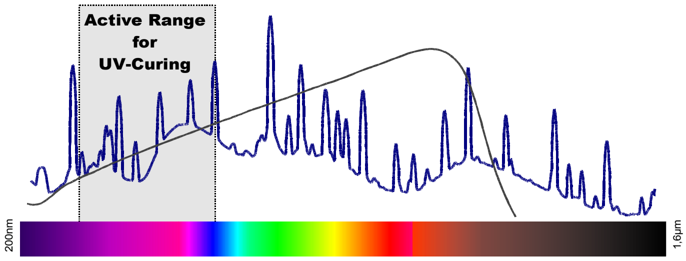


Fig. VI.13. UV Curing Spectral Region

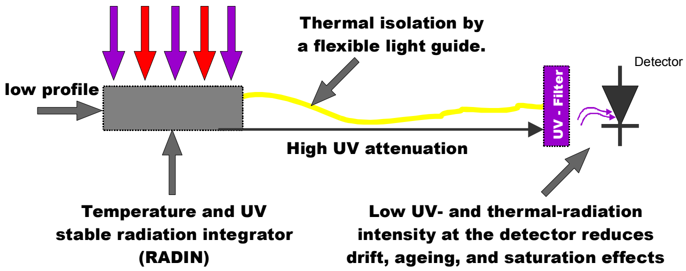


Fig. VI.14. Horizontal UV Detector Design

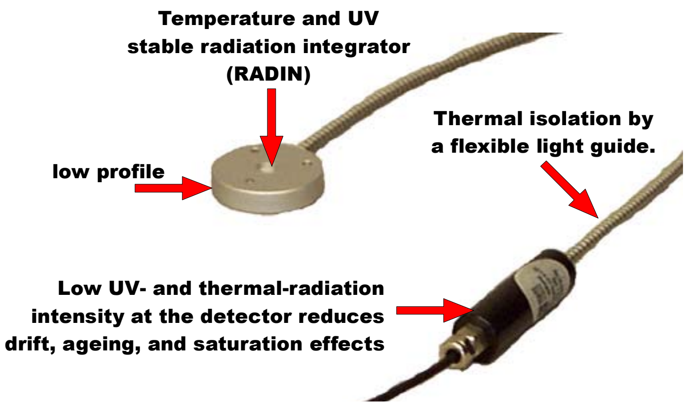


Fig. VI.15. UV Curing Detector

It should be noted that information on the spectral response function of the detector in use should be provided along with any statement of measured magnitude to properly 'frame' the results. UV detectors from different manufacturers can have very different spectral responses.This means that they will not read the same under the same test conditions.

Due to the many errors involved with UV measurement, even two detectors from the same manufacturer can read much differently.

Normally in the field, readings within ± 10% are considered acceptable in the UV-A range.

Uncertainties get progressively worse as you move to the shorter wavelengths.

It is important to remember that the UV meter is after all a scientific instrument which is asked to perform reliably and repeatably in very hostile environments.

Maintaining calibration cycles at the manufacturer recommended interval is necessary. If unacceptable levels of change are seen on recalibration, the cycle time should be shortened (staircase method). This way you end up with a recalibration program tailored to your specific requirements.

Also consider having a second instrument on hand which is used only for an in-house calibration check of the working production unit(s).

VI.5. Colorimetry

Color is the attribute of visual perception consisting of any combination of chromatic and achromatic content. This attribute can be described by chromatic color names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic color names such as white, grey, black, etc., and qualified by bright, dim, light, dark or by combinations of such names.

Perceived color depends on the spectral distribution of the color stimulus, on the size, shape, structure and surroundings of the stimulus area, on the state of adaptation of the observer's visual system, and on the person's experience of prevailing and similar situations of observation. For more details about theory, see paragraph II.9 of this tutorials.

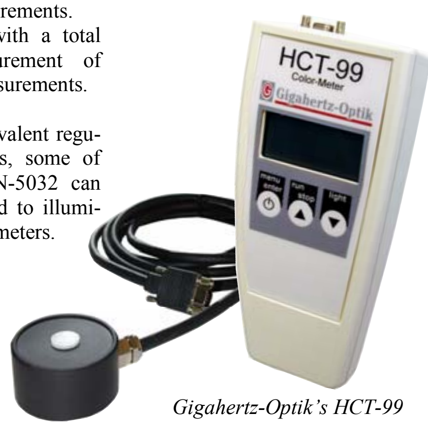
Color and Illuminance Measurement

In many applications involving the measurement of color or of the color temperature of self-emitting light sources, the same measurement geometry is used as for illuminance. Appropriate absolute calibration of the measuring system allows the illuminance of a reference plane in Lux (lx) to be determined, in addition to the colorimetric parameters. If the incident light is falling diffusely, this measurement requires the measuring system to have a field of view adapted to the cosine function. Only in this way can the laws for the incidence of diffuse radiation from one or more sources of radiation be satisfied. Detectors used to determine absolute illuminance must therefore have a cosine spatial function as their measurement geometry. If the incident radiation is not parallel, the accuracy of the cosine function is critically important to the result of the measurement. In Germany, DIN 5032, Part 7 classifies the quality of devices for measuring illuminance (luxmeters/photometers) according to the accuracy of their measurement into:

Devices of class A, with a total uncertainty of measurement of 7.5 % for precise measurements.

Devices of class B, with a total uncertainty of measurement of 10 % for operating measurements.

Since there are no equivalent regulations for colorimeters, some of the regulations in DIN-5032 can also be usefully applied to illuminance measuring colorimeters.



Gigahertz-Optik's HCT-99

Light Measurement Applications

Color and Luminous Flux Measurement

Luminous flux is the quantity used to define all of the emitted radiation in all directions by a light source in the photometric unit, Lumens (lm). One of its purposes is to reference the efficiency of incandescent lamps, arc lamps, light emitting diodes, etc., as this is derived from the relationship between the input electrical power and the luminous flux.
In cases where the light source emits in an approximately parallel beam it is possible to measure the luminous flux with a photodetector assuming that the diameter of the beam is less than that of the detector measurement aperture. If the light beam is highly divergent, or if a 4π radiation characteristic must be considered, a measurement geometry must be used that ensures that all of the radiated light is evaluated, regardless of the direction in which it is emitted.
The measurement geometry most often used for highly divergent sources is a hollow body, ideally formed as a hollow sphere, with a diffusely reflecting interior wall. Such ”integrating spheres” are known in Germany as Ulbricht spheres. The figure below illustrates the principle of its construction.

Fig. VI.16. Color and Luminous Flux Measurement Instrument with a 150 mm Integrating Sphere

Color and Luminous Intensity Measurement

The quantity of luminous intensity specifies the light flux emitted by a light source in a particular direction within a specified solid angle in the photometric units of Candela (cd). One area where it is applicable is when lamps and projectors are used in imaging systems (lens systems, reflectors), and the subsequent distribution of luminous intensity from the illumination or spotlight system must be calculated.
In order to measure luminous intensity, the field of view of the color detector must be restricted to the desired solid angle. This is usually accomplished using steradian adapter tubes that limit the detector head’s field of view. It is important that the inner walls of these tubes are designed to exhibit low reflectance. Steradian tubes that attach to the front end of the detector can be used for this purpose.

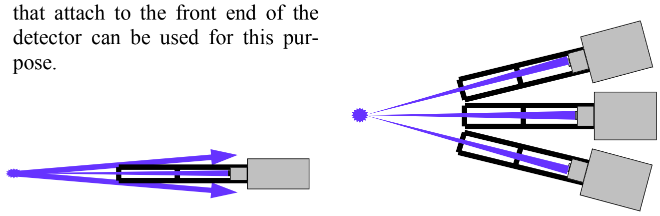


Fig. VI.17. Typical Measurement Geometries

Color and Luminance Measurement

The quantity of luminance is used to evaluate the intensity of light from surface emitters in the photometric units of Candela/square metre (cd/m^2). A defined angular field of view for the color measuring device is needed in order to measure luminance. This can be accomplished using either steradian tubes or lens systems.

Fig. VI.18. Color Detector Head for Measurement of Luminous Intensity and Luminance,

Color Temperature Measurement

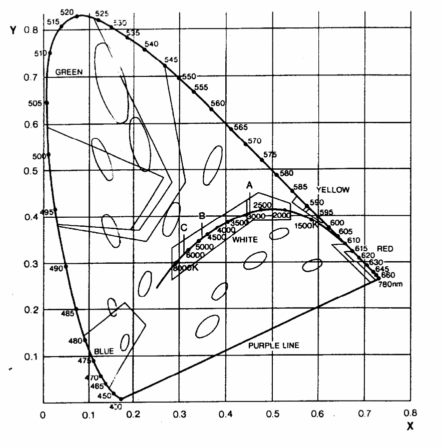
Color temperature is a simplified way to characterize the spectral properties of a light source. While in reality the color of light is determined by how much each point on the spectral curve contributes to its output, the result can still be summarized on a linear scale.
Low color temperature implies warmer (more yellow/red) light while high color temperature implies a colder (more blue) light. Daylight has a rather low color temperature near dawn, and a higher one during the day. Therefore it can be useful to install an electrical lighting system that can supply cooler light to supplement daylight when needed, and fill in with warmer light at night. This also correlates with human feelings towards the warm colors of light coming from candles or an open fireplace at night.
Standard unit for color temperature is **Kelvin (K)**.
The kelvin unit is the basis of all temperature measurement, starting with 0 K (= -273.16° C) at the absolute zero temperature. The "size" of one kelvin is the same as that of one degree Celsius, and is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water, which positions 0° Celsius at 273.16 K.

Light sources are sometimes described by their correlated color temperatures (CCT). The correlated color temperature of a source is the temperature of a black body radiator that is most similar to the source. A blackbody radiator is an ideal surface that absorbs all energy incident upon it, and re-emits all this energy. The spectral output distribution of an incandescent (tungsten) lamp approximates a blackbody at the same temperature. Correlated color temperature is typically presented using the absolute centigrade scale, degrees Kelvin (K).

Some typical color temperatures are:

- 1500 K, Candlelight
- 3000 K, 200 W incandescent lamp
- 3200 K, sunrise / sunset
- 3400 K, Tungsten lamp
- 5500 K, sunny daylight around noon

For many color measurement tasks it is important to determine the color temperature of luminous objects. According to DIN 5031-P.5, the color temperature t_c of a radiator requiring characterization is the temperature of a Planckian radiator at which it emits radiation of the same color type as that of the radiator being characterized. The color temperature is calculated and displayed by the meter. The calculation of color temperature is performed using an algorithm according to Qiu Xinghong, which enables very good research results for the color temperature range from 1667°K to 25000°K to be obtained.



VI.6. Photostability

The current ICH (International Conference for Harmonization) guidelines specify that drug and drug products must be phototested to ensure that exposure to light does not cause photochemical degradation of the product or packaging. The product under test must receive a measured dose of both UV-A (200 watt-hours per square meter) and Visible (1.2 million lux-hours) optical radiation exposure. This requires both radiometric and photometric measurements in terms of illuminance in lux and UV-A (315 to 400 nm) irradiance in W/m² multiplied by exposure time in hours.
It is important to note that total or absolute UV-A is implied. No effective UV-A spectral function is specified. Ideally for total UV-A measurements, the perfect broadband UV-A detector would have a flat square-wave spectral shape starting at 315 to 400 nm for 100% response at each wavelength across this spectrum with no response outside this bandpass. Most currently available UV-A detectors have a 'bell' shaped spectral response which, if uncorrected through calibration or redesign of spectral function, will read >25% too low on the UV-A fluorescent source, and >40% too low for Xenon + glass ID65 type light sources.
Note that UV-A fluorescent and Xenon or Metal Halide simulated ID65 light sources are the only sources specified in the ICH guidelines.
A closer approximation to an ideal UV-A broadband detector has recently been developed for photobiological and photostability applications by Gigahertz-Optik. Compared to the ideal UV-A spectral function the typical detector total area error is 34% while the Gigahertz-Optik 'flat' UV-A detector is only 14%.
The guidelines also state that to ensure spectral conformity of the light source(s) a phototester 'may rely on the spectral distribution specifications of the light source manufacturer'. It has been found in actual practice that either the spectral data is not available or typical data is not reliable due to ageing effects of the source and other factors. This is another important reason for using photodetectors with the best spectral match to the ideal functions.

Most often the phototesting is performed in a photostability chamber with long fluorescent light sources mounted above the products under test. For larger profile products, light sources may also be mounted along the sides of the chamber to fully immerse the target. Since this is an extended source type of measurement rather than a point source configuration, the detector angular responsivity should be cosine corrected using a diffuser. This way the incoming light signals are properly weighted according to the cosine of the angle of incidence.
Then the detector properly emulates the target in the way the light signal is received.

Profiling the photostability chamber for uniformity over the exposure plane is an important procedure since products placed in different areas inside the chamber should be uniformly exposed to the same light levels. Moving the detector or using multiple detectors in multiplex mode maps the exposure levels at various locations across the exposure plane.
Some of the photostability chambers manufactured today are equipped with internal light sensors to continuously monitor the light and UV-A output.
Maintaining accuracy and reliability in on-line continuous monitoring of UV applications is a daunting challenge.

Without proper protection engineered into the detector, changes due to solarization, temperature effects and ensuing calibration drift can occur. It is advisable to do a third party check using a qualified radiometer/photometer.

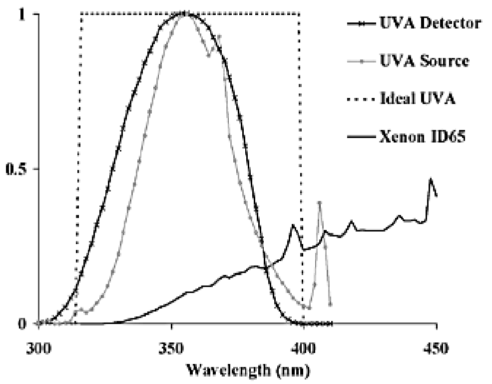


Fig. VI.19. Typical UV-A Spectral Function

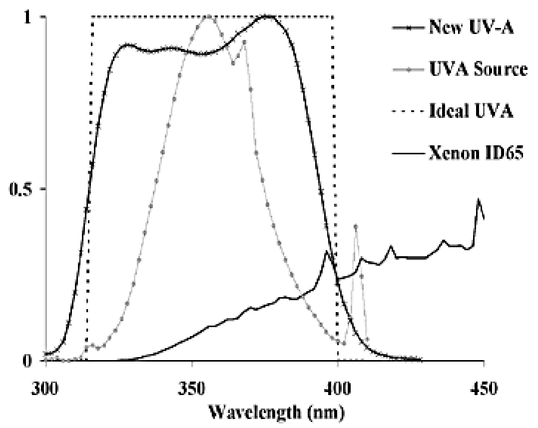


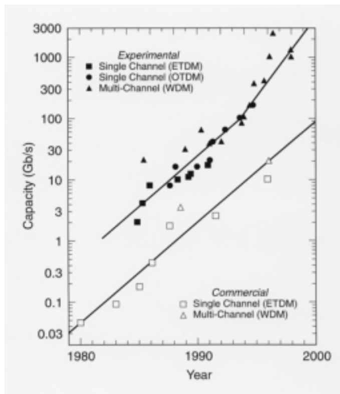
Fig. VI.20. Flat UV-A Spectral Function

VI.7. Telecommunication

An ongoing revolution occurring in the field of telecommunications is the development of small laser diodes and high capacity optical fibres. Without optical fibre telecommunication devices the highly convenient availability of huge amounts of information at comparatively low costs, as provided by the Internet, would not be possible.

The measurement of the power output of laser diodes or fibers is a daily routine in the field of telecommunication components testing. Optical power meters using a bare detector claim high sensitivity but at a cost of potential measurement inaccuracies caused by the effects of polarization, local saturation, signal 'bounce-back' and beam misalignment. Also, the use of large size photodiodes required to reduce source to detector misalignment, increases cost.
A welcome alternative is the integrating sphere which is able to collect all of the source optical radiation output independent of beam geometry. In the world of photonics, the integrating sphere is well known for its ability to reliably and accurately measure total flux from fibers, laser diodes, lasers, LEDs and any other optical radiation or light source. Since all of the incoming signal is captured and reflected inside the sphere multiple times before reaching the baffled detector mounted to it, the adverse effects of polarization, local saturation, signal 'bounce-back' and beam misalignment are reduced.

Fig. VI.21. During the last two decades, optical fibre capacity has increased by a factor of about 1000. For comparison, commercial state of the art wire connections range in the region of about 0.1 Gigabit per second (Gb/s).



VI.8. LEDs Measurements

Presently, a slow but steady large scale technological change is taking place: The traditional incandescent bulb is being replaced more and more by special semiconductor devices called **light emitting diodes** or **LEDs**. Over the past decade, LEDs have caught up in efficiency and now offer an economical alternative to incandescent bulbs even for bright signal lamps such as traffic and automotive lighting. A high percentage of an incandescent bulb's total light output is lost when passed through a coloured filter. In contrast, an LED emits light of only the desired color, thus no filtering is necessary and consumption of electrical energy can be reduced by up to 90%. Low power consumption and a typical LED lifetime of 100,000 hours (compared to about 1000 hours for incandescent bulbs), drastically reducing maintenance, often equates to significant overall cost reduction when LEDs replace traditional lighting. As an example, the city of Denver, which recently has replaced some 20000 incandescent bulbs in traffic light signals with LED devices, estimates the total savings to about $300 per signal, calculated for the lifetime of an LED device.
At the current level of technology, the broad application of LED devices as sources of artificial light is restricted by comparatively high production costs. However, the LEDs high-energy efficiency and low operating voltage leads to their use when power consumption is a critical parameter as when batteries or solar cells must be used to power the lamps.

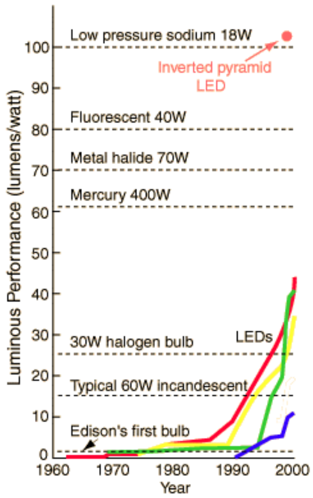


Fig. VI.22. Efficiency of red, green, white and blue LEDs has dramatically increased during the last

V1.9 LASER Measurements

The most commonly encountered monochromatic source is the laser. Because of its monochromatic and coherent radiation, high power intensity, fast modulation frequency and beam orientated emission characteristics, the laser is the primary source used in fiber optic communication systems, range finders, interferometers, alignment systems, profile scanners, laser scanning microscopes and many other optical systems.
Traditional monochromatic radiometric applications are found in the range of optical spectroscopy with narrow band-pass filtered detectors and scanning monochromators used as monochromatic detection systems or monochromatic light sources.
Optical radiation describes the segment of electromagnetic radiation from l=100 nm to l=1 mm. Most lasers used in measurement instrumentation and fiber optic telecommunications systems work predominantly in the 200 to 1800 nm wavelength range.
Because of the monochromatic emission spectrum and fixed output wavelength, detectors used to measure laser power do not need a radiometric broadband characteristic. This means that the typical spectral sensitivity characteristic of Si or InGaAs photodiodes can be used without requiring spectral correction.
For absolute power measurements the bare detector's spectral response can be calibrated at a single wavelength or over its complete spectral range (typically done in 10 nm increments).
The corresponding calibration factor for that specific wavelength is selected when making the laser power measurement. Some meters offer the capability of selecting a wavelength by menu on the display. The meter then calculates the reading by applying the calibration factor for the wavelength selected and displays the measurement result.
There are two typical measurement strategies for laser power detection:

- Lasers with collimated (parallel) beams are typically measured with a flat-field detector, whose active size is larger than the laser beam diameter. Because of the high power of lasers, the responsivity of the detector may have to be reduced by an attenuation filter. But there is a risk of measurement errors due to polarization effects, surface reflections from optical surfaces in the light path and misalignment of the beam on the detector.
- Lasers with non-collimated (divergent) beams cannot be measured with a flat-field detector because of the different angles of incidence. The power output of these lasers is typically measured with detectors combined with an integrating sphere which collects all incoming radiation independent of the angle of incidence.
- Here are more unique features offered by the integrating sphere: Through multiple internal reflections, the sphere offers high attenuation for high power measurements. The max. power is limited by the sphere's upper operating temperature limit.
  Also through multiple internal reflections, measurement errors caused by polarization effects with flat-field detectors do not occur
  The sphere port diameter can be enlarged by increasing the sphere diameter which allows measurement of larger diameter beams
- *Laser Stray-light:* Although very useful, laser radiation can pose a health risk to the human eye. Even stray-light from lasers may be hazardous due to the typically high power levels found. The EN 60825 standard describes the risk and measurement methods for risk classification. Laser stray-light can be assessed with the use of a detector head with a 7 mm dia. free aperture to mimic the open pupil.

V1.10 Non-Destructive Testing

The American Society for Nondestructive Testing defines NDT as the examination of an object with technology that does not affect the object's future usefulness. The term NDT includes many methods that can:

- Detect internal or external imperfections
- Determine structure, composition or material properties
- Measure geometric characteristics

Liquid Penetrant Testing (PT), Magnetic Particle Testing (MT) and Visual and Optical Testing (VI) are test methods used to detect defects in materials with the aid of optical radiation or light.
The light levels used in these operations are critical to the integrity of the inspection process so radiometric and photometric measurements are made for quality control purposes.
American Society for Testing and Materials (ASTM), MIL and DIN standard practices exist to help ensure uniformity in these examinations.
Liquid Penetrant Testing using the dye penetration examination process is a widely used method for the detection of surface defects in nonporous metal and non-metal materials. Two different methods are in use:
Dye Penetration Process:
A colored liquid or dye is applied to the surface of the test object which, through capillary action, penetrates into any existing surface defect(s). After removing any excess, an absorptive white layer is applied, drawing the colored liquid out of the defect making it visible. Adequate illumination of the test object with white light is critical to create good contrast.
Fluorescent Penetrating Agent:
For highest sensitivity, a fluorescent dye is used as the penetrating liquid and the test is carried out under ultraviolet lighting. UV-A sources known as 'blacklights' are most commonly used. To reliably test with fluorescent agents, an adequate level of UV-A irradiance containing a very low proportion of white (visible) light must be generated at the object under test.
Magnetic Particle Testing and of course **Visual and Optical Testing** both rely on ensuring adequate light levels for quality control of the examination.

DIN EN 1956, ASTM and MIL Standards exist that describe the general conditions and standard practices for the penetrant test examinations, including the procedures to be followed. The minimum requirements for the illumination or irradiation conditions, test procedures to be used for checking these levels and suitable measurement equipment specifications are also covered.
It is particularly emphasized in these standards that the calibration of the radiometer and photometer used to measure the illuminance and irradiance must be carried out with the aid of calibration standards that can be traced back to national standards. The test certificate must document the calibration testing.
The calibration method must also be considered.
Many of the UV-A radiometers used in this application are calibrated at a single point at the peak of the detector spectral response, typically 360 nm or simply adjusted to some reading on a particular light source. To reduce measurement errors due to light sources with different spectral outputs, Gigahertz-Optik uses the integral calibration method where the detector is calibrated to a measured UV-A integrated spectral irradiance standard.
To reduce spectral errors even further, the Gigahertz-Optik UV-A detector exhibits a nearly flat response across the UV-A bandpass with a sharp cut-off at 400 nm to eliminate visible stray light from contaminating the UV reading.
The spectral response function of the photometric sensor is very important for the same reasons. Spectral errors when measuring lux or foot-candles can occur when testing light sources different from the source used for calibration. A detector that very closely matches the CIE photopic function is required for accurate photometry. The Gigahertz-Optik photopic sensor's spectral function is within DIN Class B limits of <6% fidelity to the CIE photopic curve.
The detector spatial response (angular response) is another important factor and potential error source.
Since the detector is fully immersed in light from all directions, including any ambient contribution, it should be cosine corrected, using a diffuser. This way the incoming light signals are properly weighted according to the cosine of the incident angle. The detector receives the light signals in the same way as a flat surface does, so in effect the detector emulates the sample under test. If the detector spatial response does not closely match the true cosine function, significant errors in readings will result

UV sources pose a potential health hazard risk to the skin and eye. UV-A sources used in PT emit some levels of the most harmful UV-C and UV-B rays. The UV-A rays are considered less of a risk, but the ACGIH/ICNIRP guidelines do state Threshold Limit Values for UV-A at 1 mW/cm² for an eight-hour exposure period. For UV-B, the TLV is much less at 0.1 Effective □W/cm². So UV exposure of workers in PT environments should be tested to ensure safety as well as for quality control..

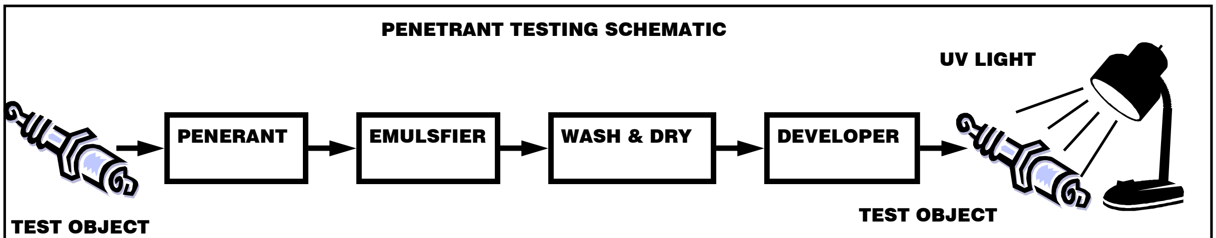


Fig. V.23. Penetrant Testing Schematic

VI.11. Transmission & Reflection

'Measurement with Light' refers to the use of optical radiation as a tool for performing a measurement task. Reflectance and transmittance meters employ both light sources and a detection system. A spectrophotometer is a good example of this type of instrument.
Light describes optical radiation visible to the human eye over the wavelength range from 380 to 780 nm. The eye's sensitivity to light varies over this spectral range peaking at 555 nm. This same CIE defined V(λ) photometric action function applies to any application where light must be evaluated for visual purposes including reflection and transmission.
DIN 5036-part 3 and CIE 130-1998 recommend an integrating sphere with a minimum diameter of 50 cm for the measurement of photometric material properties such as light transmittance/reflectance, diffuse transmittance/reflectance and regular transmittance/reflectance.

VII.1. Relevant quantities, their symbols and units

Quantity	Symbol	Unit(s)
Wavelength	λ	1 nanometer = 1 nm = 10^{-9} m / 1 Ångstrøm = 1 Å = 10^{-10} m
Power	P	1 Watt = 1 W
Solid angle	Ω	1 steradian = 1 sr
Radiant power or radiant flux	Φ_e	1 Watt = 1 W
Radiant intensity	I_e	1 W sr^{-1}
Radiance	L_e	1 W sr^{-1} m^{-2}
Irradiance	E_e	1 W m^{-2}
Radiant exitance	M_e	1 W m^{-2}
Luminous flux	Φ_v	1 lumen = 1 lm photopic: 1 lm corresponds to Φ_e = 1/683 W at λ_m = 555 nm scotopic: 1 lm corresponds to Φ_e = 1/1700 W at λ'_m = 507 nm
Luminous intensity	I_v	1 candela = 1 cd = 1 lm / sr
Luminance	L_v	1 lm sr^{-1} m^{-2} = 1 cd m^{-2} = *1 nit* *1 stilb = 1 sb = 1 cd* m^{-2} *1 apostilb = 1 asb = 1/π cd* m^{-2} *1 lambert = 1 L =* $10^4/\pi$ *cd* m^{-2} *1 footlambert = 1 fl = 3.426 cd* m^{-2}
Illuminance	E_v	1 lux = 1 lx = 1 lm m^{-2} *1 phot = 1 ph =* 10^4 *lx* *1 footcandle = 1 fc = 1 lm* ft^{-2} *= 10.764 lx*

Quantity	Symbol	Unit(s)
Luminous exitance	M_v	1 lm m^{-2}
Spectral radiant power	$\Phi_\lambda(\lambda)$	1 W nm^{-1}
Spectral radiant intensity	$I_\lambda(\lambda)$	1 W sr^{-1} nm^{-1}
Spectral radiance	$L_\lambda(\lambda)$	1 W sr^{-1} m^{-2} nm^{-1}
Spectral irradiance	$E_\lambda(\lambda)$	1 W m^{-2} nm^{-1}
Spectral radiant exitance	$M_\lambda(\lambda)$	1 W m^{-2} nm^{-1}

*Table VII.IV. **Units in italic** are not SI units, not consistent with CIE regulations and **should not be used** !*

VII.2. Summary of radiometric and photometric quantities

Quantification of electromagnetic radiation ...	Radiometric quantity	Spectral quantity	Photometric quantity	quantity depends on
... emitted by a source in total	radiant power Φ_e W	spectral radiant power $\Phi_\lambda(\lambda)$ W nm^{-1}	luminous flux Φ_v lm (lumen)	-
... emitted in a certain direction	radiant intensity I_e W sr^{-1}	spectral radiant intensity $I_\lambda(\lambda)$ W sr^{-1} nm^{-1}	luminous intensity I_v lm / sr = cd	direction
... emitted by a location on a surface	radiant exitance M_e W m^{-2}	spectral radiant exitance $M_\lambda(\lambda)$ W m^{-2} nm^{-1}	luminous exitance M_v lm m^{-2}	position on source's surface
... emitted by a location on a surface in a certain direction	radiance L_e W sr^{-1} m^{-2}	spectral radiance $L_\lambda(\lambda)$ W sr^{-1} m^{-2} nm^{-1}	luminance L_v lm sr^{-1} m^{-2} = cd m^{-2}	position on source's surface and direction
... impinging upon a surface	irradiance E_e W m^{-2}	spectral irradiance $E_\lambda(\lambda)$ W m^{-2} nm^{-1}	illuminance E_v lm m^{-2} = lx	position on irradiated surface

Table VII.V – Radiometric and photometric quantities

Radiometric quantities:

In the following relations, X has to be replaced by one of the symbols Φ, I, L or E:

$$X_e = \int_0^\infty X_\lambda(\lambda)d\lambda \quad \text{or} \quad X_{e,range} = \int_{\lambda_1}^{\lambda_2} X_\lambda(\lambda)d\lambda$$

with λ_1 and λ_2 denoting the lower and the upper limit of the respective wavelength range (for instance, UVA)

Photometric quantities:

In the following relations, X has to be replaced by one of the symbols Φ, I, L or E:

Photopic vision: $X_v = K_m \cdot \int_0^\infty X_\lambda(\lambda)\cdot V(\lambda)\,d\lambda$ with K_m = 683 lm / W Scotopic vision: $X_v = K'_m \cdot \int_0^\infty X_\lambda(\lambda)\cdot V'(\lambda)\,d\lambda$ with K'_m = 1700 lm / W

Basic integral relations between radiometric and photometric quantities:

In the following, x has to be replaced either by e (denoting radiometric quantities) or v (denoting photometric quantities).

$$\Phi_x = \int_{4\pi} I_x d\Omega \qquad I_x = \int_{\text{emitting surface}} L_x \cos(\vartheta)\, dA \qquad M_x = \int_{2\pi} L_x \cos(\vartheta)\, d\Omega$$

VII.3. Sources and references for figures

Fig. II.1: http://www.cameraguild.com/technology/colorimetry.htm
Fig. II.3: http://sedac.ciesin.org/ozone/docs/AS.html
Fig. II.5: adapted from http://www.salsburg.com/lightcolor/lightcolor.html
Fig.II.6: adapted from http://whatis.techtarget.com/definition/0,,sid9_gci528813,00.html
Fig. II.11: http://omlc.ogi.edu/classroom/ece532/class1/intensity_flashlight.html
Fig. II.13: adapted from http://www.cameraguild.com/technology/colorimetry.htm
Fig. II.16: http://math.nist.gov/~FHunt/appearance/brdf.html
Fig. II.17: http://lsvl.la.asu.edu/askabiologist/research/seecolor/rodsandcones.html
Fig. II.19: http://www.cs.princeton.edu/courses/archive/fall99/cs426/lectures/raster/img013.gif
Fig. II.22: http://home.wanadoo.nl/paulschils/10.02.htm
Fig. VI.1: http://www.coolibar.com/skin-cancer-in-the-us.html
Fig. VI.11: http://www.mindfully.org/Water/UV-Disinfection-Wastewater.htm
Fig. VI.12: http://www.news.ucf.edu/FY2001-02/011205.html
Fig. VI.22: http://www.bell-labs.com/history/physicscomm/images/br_v_t6w.gif
Fig. VI.23: http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/leds.html

VII.4. Most relevant CIE- DIN- and ISO-publications and regulations

VII.4.a. DIN Publications

DIN 4512-8, Ausgabe:1993-01
Photographische Sensitometrie; Bestimmung der optischen Dichte; Geometrische Bedingungen für Messungen bei Transmission
DIN 4512-9, Ausgabe:1993-01
Photographische Sensitometrie; Bestimmung der optischen Dichte; Spektrale Bedingungen
DIN 5030-2, Ausgabe:1982-09
Spektrale Strahlungsmessung; Strahler für spektrale Strahlungsmessungen; Auswahlkriterien
DIN 5031 Beiblatt 1, Ausgabe:1982-11
Strahlungsphysik im optischen Bereich und Lichttechnik; Inhaltsverzeichnis über Größen, Formelzeichen und Einheiten sowie Stichwortverzeichnis zu DIN 5031 Teil 1 bis Teil 10
DIN 5031-2, Ausgabe:1982-03
Strahlungsphysik im optischen Bereich und Lichttechnik; Strahlungsbewertung durch Empfänger
DIN 5033-7, Ausgabe:1983-07
Farbmessung; Meßbedingungen für Körperfarben
DIN 5037 Beiblatt 1, Ausgabe:1992-08
Lichttechnische Bewertung von Scheinwerfern; Vereinfachte Nutzlichtbewertung für Film-, Fernseh- und Bühnenscheinwerfer mit rotationssymmetrischer Lichtstärkeverteilung
DIN 5037 Beiblatt 2, Ausgabe:1992-08
Lichttechnische Bewertung von Scheinwerfern; Vereinfachte Nutzlichtbewertung für Film-, Fernseh- und Bühnenscheinwerfer mit zu einer oder zwei zueinander senkrechten Ebenen symmetrischer Lichtstärkeverteilung
DIN 5039, Ausgabe:1995-09
Licht, Lampen, Leuchten - Begriffe, Einteilung
DIN 5042-1, Ausgabe:1980-10
Verbrennungslampen und Gasleuchten; Einteilung, Begriffe
DIN 5043-1, Ausgabe:1973-12
Radioaktive Leuchtpigmente und Leuchtfarben; Meßbedingungen für die Leuchtdichte und Bezeichnung der Pigmente
DIN 19010-1, Ausgabe:1979-03
Lichtelektrische Belichtungsmesser; Skalen, Kalibrieren
DIN 58141-5, Ausgabe:1993-11
Prüfung von faseroptischen Elementen; Bestimmung der Faserbruchrate von Licht- und Bildleitern
DIN 58141-10, Ausgabe:1997-02
Prüfung von faseroptischen Elementen - Teil 10: Bestimmung der Beleuchtungsstärke und des effektiven Öffnungswinkels von Kaltlichtquellen
ISO 31-6, Ausgabe:1992-09
Größen und Einheiten; Teil 6: Licht und verwandte elektromagnetische Strahlung
ISO 8599, Ausgabe:1994-12
Optik und optische Instrumente - Kontaktlinsen - Bestimmung des Spektral- und Licht-Transmissionsgrades

VII.4.b. CIE Publications

13.3-1995: Method of measuring and specifying colour rendering of light sources New edition (including Disk D008)
15.2-1986: Colorimetry, 2nd ed.
16-1970: Daylight
17.4-1987: International lighting vocabulary, 4th ed. (Joint publication IEC/CIE)
18.2-1983: The basis of physical photometry, 2nd ed.
19.21-1981: An analytic model for describing the influence of lighting parameters upon visual performance, 2nd ed., Vol.1.: Technical foundations
19.22-1981: An analytic model for describing the influence of lighting parameters upon visual performance, 2nd ed., Vol.2.: Summary and application guidelines
38-1977: Radiometric and photometric characteristics of materials and their measurement
39.2-1983: Recommendations for surface colours for visual signalling, 2nd ed.
40-1978: Calculations for interior lighting: Basic method
41-1978: Light as a true visual quantity: Principles of measurement
44-1979: Absolute methods for reflection measurements
46-1979: A review of publications on properties and reflection values of material reflection standards
51.2-1999: A method for assessing the quality of daylight simulators for colorimetry (with supplement 1-1999)
52-1982: Calculations for interior lighting: Applied method
53-1982: Methods of characterizing the performance of radiometers and photometers
55-1983: Discomfort glare in the interior working environment
59-1984: Polarization: Definitions and nomenclature, instrument polarization
60-1984: Vision and the visual display unit work station
63-1984: The spectroradiometric measurement of light sources
64-1984: Determination of the spectral responsivity of optical radiation detectors
65-1985: Electrically calibrated thermal detectors of optical radiation (absolute radiometers)
69-1987: Methods of characterizing illuminance meters and luminance meters: Performance, characteristics and specifications
70-1987: The measurement of absolute luminous intensity distributions
75-1988: Spectral luminous efficiency functions based upon brightness matching for monochromatic point sources, 2° and 10° fields
76-1988: Intercomparison on measurement of (total) spectral radiance factor of luminescent specimens
78-1988: Brightness-luminance relations: Classified bibliography
82-1989: CIE History 1913 - 1988
84-1989: Measurement of luminous flux
85-1989: Solar spectral irradiance
86-1990: CIE 1988 2° spectral luminous efficiency function for photopic vision
87-1990: Colorimetry of self-luminous displays - A bibliography
95-1992: Contrast and visibility
96-1992: Electric light sources - State of the art - 1991
98-1992: Personal dosimetry of UV radiation
101-1993: Parametric effects in colour-difference evaluation
105-1993: Spectroradiometry of pulsed optical radiation sources
106-1993: CIE Collection in photobiology and photochemistry (1993):
106/1: Determining ultraviolet action spectra
106/2: Photokeratitis
106/3: Photoconjunctivitis
106/4: A reference action spectrum for ultraviolet induced erythema in human skin
106/5: Photobiological effects in plant growth
106/6: Malignant melanoma and fluorescent lighting
106/7: On the quantification of environmental exposures: limitations of the concept of risk-to-benefit ratio
106/8: Terminology for photosynthetically active radiation for plants
108-1994: Guide to recommended practice of daylight measurement (including disk)
109-1994: A method of predicting corresponding colours under different chromatic and illuminance adaptations
114-1994: CIE Collection in photometry and radiometry
114/1: Survey of reference materials for testing the performance of spectrophotometers and colorimeters
114/2: International intercomparison on transmittance measurement - Report of results and conclusions
114/3: Intercomparison of luminous flux measurements on HPMV lamps
114/4: Distribution temperature and ratio temperature
114/5: Terminology relating to non-selective detectors
114/6: Photometry of thermally sensitive lamps
116-1995: Industrial colour difference evaluation
118-1995: CIE Collection in colour and vision
118/1: Evaluation of the attribute of appearance called gloss
118/2: Models of heterochromatic brightness matching
118/3: Brightness-luminance relations
118/4: CIE guidelines for co-ordinated research on evaluation of colour appearance models for reflection print and self-luminous display image comparisons
118/5: Testing colour appearance models: Guidelines for co-ordinated research
118/6: Report on colour difference literature
118/7: CIE guidelines for co-ordinated future work on industrial colour-difference evaluation
121-1996: The photometry and goniophotometry of luminaries
124-1997: CIE Collection in colour and vision, 1997
124/1: Colour notations and colour order systems
124/2: On the course of the disability glare function and its attribution to components of ocular scatter
124/3: Next step in industrial colour difference evaluation - Report on a colour difference research meeting
125-1997: Standard erythema dose
127-1997: Measurement of LEDs
130-1998: Practical methods for the measurement of reflectance and transmittance
134-1999: CIE Collection in photobiology and photochemistry, 1999
134/1: Standardization of the terms UV-A1, UV-A2 and UV-B
134/2: UV protection of the eye
134/3: Recommendations on photobiological safety of lamps. A review of standards
135-1999: CIE Collection in vision and colour and in physical measurement of light and radiation, 1999
135/1: Disability glare
135/2: Colour rendering (TC 1-33 closing remarks)
135/3: Supplement 1-1999 to CIE

Appendix

51-1981: Virtual metamers for assessing the quality of simulators of CIE illuminant D50
135/4: Some recent developments in colour difference evaluation
135/5: Visual adaptation to complex luminance distribution
135/6: 45°/0° spectral reflectance factors of pressed polytetrafluoroethylene (PTFE) powder
138-2000: CIE Collection in Photobiology and Photochemistry, 2000
138/1: Blue light photochemical retinal hazard
138/2: Action spectrum for photocarcinogenesis (non-melanoma skin cancers)
138/3: Standardized protocols for photocarcinogenesis safety testing
138/4: A proposed global UV index
139-2001: The influence of daylight and artificial light on diurnal and seasonal variations in humans - a bibliography (also available as disk)
142-2001: Improvement to industrial colour difference evaluation
148:2002: Action spectroscopy of skin with tunable lasers
149:2002: The use of tungsten filament lamps as secondary standard sources
151:2003: Spectral weighting of solar ultraviolet radiation
CIE Draft Standard DS 010.3-2002: Photometry - The CIE system of physical photometry
CIE Draft Standard DS 012.2:2002: Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour
CIE Draft Standard DS 013.2:2002: International standard global UV index
CIE Draft Standard DS 015:2002: Lighting of work places - outdoor work places

VII.5 National Calibration Laboratories

DKD – German Accreditation Institution

The German accreditation institution DKD (Deutscher Kalibrierdienst) was founded by German trade and industry and the German state represented by the Physikalisch-Technische Bundesanstalt (PTB), the German national standards laboratory. The basic idea of the DKD is to transfer as many PTB responsibilities to industry as possible, including the calibration of measurement and testing equipment. The DKD ensures the traceability of measurement and testing equipment to national standards by the accreditation and continuous auditing of industrial calibration laboratories. Therefore, calibrations carried out by DKD accredited laboratories offer a secured traceable and well-documented link to national calibration standards. An uninterrupted traceable chain of calibration links to national standards is absolutely necessary for acceptance of measurement devices by any quality management system. The qualification of the traceability to national standards is the job of the Physikalisch-Technische Bundesanstalt (PTB), the German national standards laboratory. The PTB will define, realize, keep and transmit the physical quantities of the SI-system, such as a meter, a second, a kilogram, a candela, etc. To ensure objective results, equal standards must be used. The calibration of measurement and testing arrangements based on SI-units is a basis for correct, comparable, recognizable and therefore measurable values, which can be audited. Within the DIN ISO 9000 ff. standard the relationship between quality management and calibration are intertwined in part for continuous control of measurement and testing equipment. Without exception, DKD accredited calibration laboratories fulfill the requirements of the European standard EN 45001 (general criteria to operate a testing laboratory, May 1990). Outside of Europe this standard is not compulsory. Instead of this the ISO/IEC Guide 25 (General requirements on the competence of testing and calibration laboratories, December 1990) is recognized. In content, EN 45001 and ISO/IEC Guide 25 are identical. This is the basis for the mutual appreciation between the European cooperation for Accreditation (EA) and its extra-European partners. In 1999 ISO/IEC 17025 took the place of EN 45001 and ISO/IEC Guide 25 which eliminated any formal differences.

Existing DKD calibration laboratories automatically qualify for ISO/IEC/EN 17025 conformance.
DKD homepage: http://www.dkd.info/

The European position of the DKD is noted by its membership in the European Cooperation for Accreditation of Laboratories (EAL) in Rotterdam, which was founded out of the Western European Calibration Cooperation (WECC) and the Western European Laboratory Accreditation Cooperation (WELAC) in 1994. Within the EAL different national accreditation institutes cooperate with the goal of international acceptance of calibration certificates of the EAL-calibration laboratories. In November 2000, 34 accreditation institutions from 28 countries, including the PTB, the accreditation institution of the DKD, signed a Mutual Recognition Arrangement (MRA) of the International Laboratory Accreditation Cooperation (ILAC). More information about this arrangement and the participating countries is available online at

http://www.ilac.org.

PTB – Physikalisch-Technische Bundesanstalt

The Physikalisch-Technische Bundesanstalt (PTB) is the highest technical authority for metrology in Germany. The PTB define, realize, keep and transmit the physical quantities of the SI-system, such as a meter, a second, a kilogram, a candela, etc. The PTB is the official accreditation institution for DKD calibration laboratories for optical radiation measurement quantities such as Gigahertz-Optik. The PTB is also actively working on bilateral acceptance on national standards. Because of their activities in 1995 a Statement of Intent on Traceability of Measurement Standards was signed between the Physikalisch-Technische Bundesanstalt (PTB) and the National Institute of Standards and Technology (NIST) USA. The Equivalence of the National Standards of NIST and PTB for the SI Units of Luminous Intensity and Luminous Flux was officially recognized in April 1999.

PTB homepage:
http://www.ptb.de/

NRC – National Research Council Canada

The NRC's Institute for National Measurement Standards Photometry and Radiometry Group maintains photometric, radiometric, spectrophotometric and colorimetric standards, and provides associated, high-accuracy measurement services to industry, university, and government clients involved with lighting, transportation, manufacturing, telecommunications, public health and safety, and the environment.NRC INMS Photometry & Radiometry Home Page Last Updated: 2001-07-18 (http://www.nrc.ca/inms/phot_rad/prei.html)

NIST – U.S. National Institute of Standards and Technology

The Optical Technology Division of NIST's Physics Laboratory has the mandate to provide a high quality national measurement infrastructure to support industry, government, and academia who are reliant upon optical technologies for their competitiveness and success. As a part of this mandate, the Division has the institutional responsibility for maintaining two SI base units: the unit for temperature, the kelvin, above 1234.96 K and the unit of luminous intensity, the candela. As part of its responsibilities the Division: Develops, improves, and maintains the national standards for radiation thermometry, spectroradiometry, photometry, colorimetry, and spectrophotometry; provides National measurement standards and support services to advance the use and application of optical technologies spanning the ultraviolet through microwave spectral regions for diverse industrial, governmental, and scientific uses; disseminates these standards by providing measurement services to customers requiring calibrations of the highest accuracy and contributes to the intellectual reservoir of technical expertise by publishing descriptions of NIST developed advances in appropriate scientific journals and books; conducts basic, long term theoretical and experimental research in photophysical and photochemical properties of materials, in radiometric and spectroscopic techniques and instrumentation, and in application of optical technologies in nanotechnology, biotechnology, optoelectronics, and in diverse industries reliant upon optical techniques. NIST Physics Laboratory Optical Technology Division Home Page, Last updated: April 2002

(http://www.physics.nist.gov/Divisions/Div844/about_otd.html)

NPL – National Physical Laboratory UK

The NPL is UK's National Standards Laboratory for Physical Measurements. NPL's Optical Radiation Measurement (ORM) Group provides services which are the backbone for optical radiation measurements in the UK and internationally.
Here the UK's Primary Standards and scales are maintained, and pioneering research in measurement science is carried out. ORM anticipates and responds to industrial and academic measurement requirements throughout the IR, Visible, and UV spectra, providing a comprehensive range of Measurement and Calibration Services, Instrumentation Products, Training and Consultancy.

Some of the range of Measurement and Calibration Services, traceable to national standards, available in this field, includes the characterization and calibration of:

- All types of optical radiation sources
- Optical radiation detectors and associated devices
- Optical properties of materials and components
- Aspects of appearance including colour, haze and gloss

The development of NPL's Primary Standards and Measurement Scales, enables the UK to maintain the highest accuracy optical measurement references in the world as well as to enable the fostering of new ideas and techniques. Areas in which NPL is a recognized world leader include the development of the first cryogenic radiometer and the use of lasers for radiometry. NPL ORM Introduction Web Page: http://www.npl.co.uk/optical_radiation/

Appendix

VII.5 National Calibration Laboratories

See chapter Calibration Services in this catalogue or on Gigahertz-Optik's homepage

Deutscher Kalibrierdienst (DKD)

Akkreditierungsstelle bei der

Physikalisch-Technischen Bundesanstalt (PTB)

vertreten im

Deutschen AkkreditierungsRat

Akkreditierung

Die Akkreditierungsstelle des **Deutschen Kalibrierdienstes** akkreditiert hiermit das

Kalibrierlaboratorium für optische Strahlungsgrößen

bei

Gigahertz-Optik GmbH

Fischerstraße 4

82178 Puchheim bei München

als Kalibrierlaboratorium nach DIN EN ISO/IEC 17025 für Kalibrierungen in den Bereichen:

spektrale Empfindlichkeit, spektrale Bestrahlungsstärke

Bestandteil der Urkunde ist: Anlage 03 (1 Seite), 2002-10-28

DAR-Registriernummer: DKD-K-10601-03
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Braunschweig, 2002-10-28

Dr.-Ing. Wolfgang Bosch
Leiter der Akkreditierungsstelle

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
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