THORLABS

Optical Power Meter

PM100USB
Operation Manual

2017

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Contents

We aim to develop and produce the best solution for your application in the field of optical measurement technique. To help us to live up to your expectations and improve our products permanently we need your ideas and suggestions. Therefore, please let us know about possible criticism or ideas. We and our international partners are looking forward to hearing from you.

Thorlabs GmbH

Warning

Sections marked by this symbol explain dangers that might result in personal injury or death. Always read the associated information carefully, before performing the indicated procedure.

Attention

Paragraphs preceeded by this symbol explain hazards that could damage the instrument and the connected equipment or may cause loss of data.

Note

This manual also contains "NOTES" and "HINTS" written in this form.

Please read these advices carefully!

1 General Information

The PM100USB Hand-held Optical Power and Energy Meter is designed to measure the optical power of laser light or other monochromatic or near monochromatic light sources.

The space-saving, battery powered design and compatibility to all Thorlabs “C Series” Photodiode and Thermal sensors, and custom Photodiode and Thermal detectors, featured with a fast USB device interface open a wide range of applications in Manufacturing, Quality Control, Quality Assurance, and R&D for stationary and field use.

The provided software, including drivers and applications for LabVIEW and C makes it easy to integrate the instrument in test and measurement systems.

The unit can be recharged with the supplied AC adapter or via USB connection to a PC or laptop.

1.1 Safety

Attention

The safety of any system incorporating the equipment is the responsibility of the assembler of the system.

All statements regarding safety of operation and technical data in this instruction manual will only apply when the unit is operated correctly as it was designed for.

The PM100USB must not be operated in explosion endangered environments!

Do not obstruct the air ventilation slots in the housing!

Do not remove covers!

Do not open the cabinet. There are no parts serviceable by the operator inside!

This precision device is only serviceable if properly packed into the complete original packaging including the plastic foam sleeves. If necessary, ask for replacement packaging.

Refer servicing to qualified personnel!

Only with written consent from Thorlabs may changes to single components be made or components not supplied by Thorlabs be used.

All modules including control inputs / outputs and the sensor must be connected with duly shielded connection cables.

Attention

The following statement applies to the products covered in this manual, unless otherwise specified herein. The statement for other products will appear in the accompanying documentation.

Note

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Thorlabs GmbH is not responsible for any radio television interference caused by modifications of this equipment or the substitution or attachment of connecting cables and equipment other than those specified by Thorlabs GmbH. The correction of interference caused by such unauthorized modification, substitution or attachment will be the responsibility of the user.
The use of shielded I/O cables is required when connecting this equipment to any and all optional peripheral or host devices. Failure to do so may violate FCC and ICES rules.

Attention

Mobile telephones, cellular phones or other radio transmitters are not to be used within the range of three meters of this unit since the electromagnetic field intensity may then exceed the maximum allowed disturbance values according to IEC 61326-1.

This product has been tested and found to comply with the limits according to IEC 61326-1 for using connection cables shorter than 3 meters (9.8 feet).

1.2 Ordering Codes and Accessories

PM100USB

2 Parts List

Inspect the shipping container for damage.

If the shipping container seems to be damaged, keep it until you have inspected the contents and you have inspected the PM100USB mechanically and electrically.

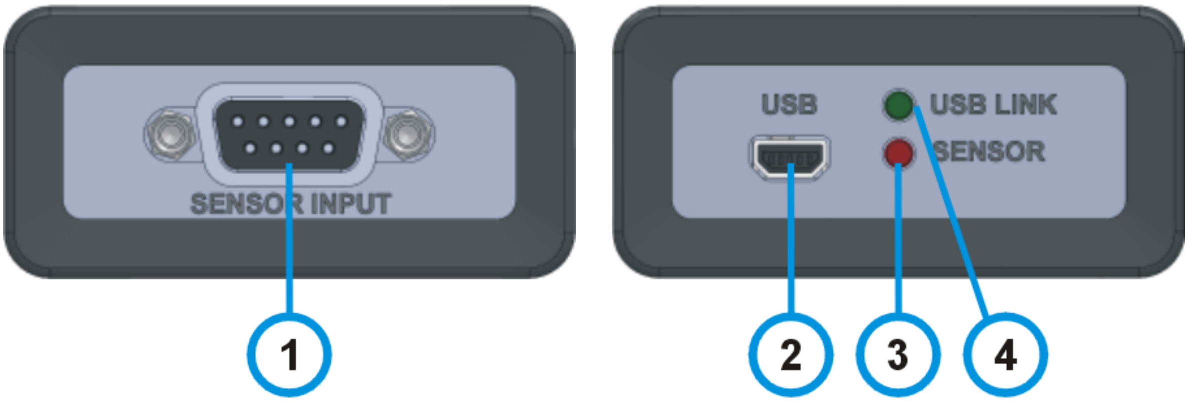
Verify that you have received the following items within the package:

1. PM100USB power/energy meter console
2. USB cable, type ‘A’ to ‘mini-B’
3. Quick-start guide
4. USB memory stick with instrument drivers, user application and operation manual
5. Certificate of Calibration

3 Operating Instruction

- Install software from the supplied data carrier (see section Software Installation).
- Connect a suitable sensor.
- Connect the PM100USB to the PC using the supplied USB cable.
- For detailed instructions, please see section Graphic User Interface.

3.1 Operating Elements



1 Connector for power / energy sensor
2 USB connector to PC
3 LED: Sensor detected and ready for operation
4 LED: USB device ready for operation

3.2 Connecting a Power Sensor

The PM100USB supports all Thorlabs 'C-Series photodiode, energy and thermal sensors, that can be easily identified by their red connector housing, compared to older versions of Thorlabs power sensors. The console will not recognize sensors from the 'A' and 'B' series. Please contact Thorlabs for the upgrade of old sensors with 'C-Series' connectors.

To plug or remove a sensor slightly press on the two bolts in the connector housing, that fix it by resilience.

Sensors can be 'hot-swapped' to the console, after recognizing a new valid sensor the type and calibration data will be downloaded to the console in approximately 2 seconds, and the unit is ready to operate with the new sensor.

The PM100USB also supports custom detectors, please refer to System Settings for the console measurement settings; the pin-out of the DB9 sensor connector can be found in Appendix.

4 Measurement Considerations

4.1 Choosing the right sensor

The question of the right sensor depends on many factors starting with the light source to measure and the application. No sensor can cover all applications; the following table shows the main pros and cons of the different power sensor types. Of course this can only be a rough guide because within each sensor group there are special models best suitable for specific applications.

Power Sensors:

Light Source	Photo Diode Sensor			Thermal Sensors		
	Si	Ge	InGaAs	BB	HPB	Volume
Diode Lasers UV - NIR	+++	+	-	++	-	-
Diode Lasers NIR	-	+	+++	++	-	-
High Power Fiber Lasers	-	-	++	++	++	-
ASE Sources	-	-	++	++	-	-
Femtosecond Lasers	-	+	++	++	+	-
Gas Lasers	++	-	-	++	+	-
Excimer Lasers	-	-	-	-	+++	+
YAG Lasers	-	-	-	-	+	+++
LEDs	+	-	-	+++	+	-

4.2 Reducing Noise for high Accuracy Measurements

Noise from grounding, the cable capacitance, temperature effects, stray and ambient light and detector noise are interfering the measurement. This impact is the higher, the lower to measured optical power. Below are given some hints and recommendations how to reduce interferences to a minimum:

- The housing of power sensors is connected to the digital ground of the meter and should be linked to earth ground (e.g. via post mounting).
- Energy sensors should be mounted isolated, because the housing is connected to the meter analog ground.
- The sensor cable conducts very small current or voltage signals. The cable capacitance induces disturbances when the cable is moved. If very small power or energy levels are measured, the cable should be fixed in position.
- With photodiode sensors the bandwidth should be set to “Low” setting; with thermal sensors the acceleration circuit should be shut off.
- The detector noise is lowest with Si or InGaAs sensors.

- For long term measurements in free space applications it is necessary to provide constant ambient light conditions, or shielding the light path from external light sources.
- The temperature should be stable over the time of the measurement.

4.3 Power Measurement of Pulsed Signals

The PM100USB will read the average value of a pulsed signal if the following conditions apply:

Thermal Sensor

For a thermal sensor, pulse length, repetition rate and peak power are uncritical as long as the peak power is lower than the damage threshold of the sensor. A thermal sensor reacts very slow and will integrate the power incident on the active area of the sensor.

Photodiode Sensor

A photodiode sensor can follow short pulses in the ns range. Therefore, it is important that the pulse peak power is within the maximum power range of the sensor. It is also important that the power range is set in such a way, that the peak power won't exceed this range, otherwise the reading will clip at the end of the range, which leads to a wrong average value. Furthermore, it is important to use a power range that can measure the peak value. To find the appropriate power range, the Min-Max display function is very helpful. Depending on pulse length and repetition rate, the bandwidth setting will influence the power reading. It is recommended to use the 'LOW' bandwidth setting for a stable display. If the pulse should be monitored via the analog output, the bandwidth should be set to 'HIGH'.

4.4 Line Width of Light Sources

The line width of light sources can be neglected only when using a broadband thermal or pyro-electric sensor.

Photodiode sensors show a strong dependency on the operating wavelength so if the line width of the light source is greater than 10nm (e.g. LED) there may be an influence on the displayed power. To achieve the best result for broadband light sources with a photodiode sensor it is necessary that the response curve is nearly linear over the line width. When entering the center wavelength of the light source as operation wavelength, the PM100USB will nearly show the right optical power for a symmetrical spectral response shape.

4.5 Temperature Effects on Thermal Sensors

Thermal sensors respond to any temperature differences that occur between thermal disc and heat sink. The measurement result can be interfered by airflow disturbances or by heating up the heat sink, e.g., during long-term exposure of the thermal disc to the laser beam.

To avoid disturbances it is recommended to shield the sensor as good as possible from airflow and to zero it properly in the operating condition. That means for short term measurements zero the cold sensor, for long term measurements zero the sensor when it is in a state of thermal stability (e.g. after 10 minutes light exposure).

4.6 Ambient and Stray Light

Ambient or stray light can strongly affect the measurement accuracy in free-space applications. A permanent background light level can be subtracted by conducting a zero adjustment. In case of varying ambient light like daylight or turning on/off room light, the only solution is a proper shielding of the sensor from ambient and stray light.

4.7 Back Reflection

The surfaces of photodiodes, ND filters and even the black coatings of thermal sensors show a certain kind of back reflection of the incoming light. If this back reflection hits for example a laser diode or a HeNe laser, this may have an impact on the power stability of the laser, therefore it is recommended to slightly tilt the power meter sensor with respect to the laser beam. This way, the back reflection won't enter the laser.

If back reflections must be completely avoided it is advised to use a S14xC series integrating sphere sensor where the incoming light gets nearly completely absorbed in the sensor.

4.8 Beam Diameter vs. Active Sensor Area

Most sensors are not completely uniform in their response over the active area; except integrating sphere sensors. To overcome uniformity issues the incident beam should have a diameter larger than 10% of the active sensor area.

Another important point is the maximum allowed power and energy density of the sensor. The maximum ratings are given in the sensor specifications. The PM100USB can display the actual power or energy density for a known beam diameter. For high power or high energy beams a good efficiency can be reached by selecting a sensor with a detector size about 20% - 30% larger than the beam diameter.

It is also important not to overfill the sensor. That means, that the beam size in the plane of sensor's active area must not exceed the size of the active area.

4.9 Fiber Based Measurements

Laser light is emitted from an optical fiber tip in a conical shape, with an angle twice the acceptance angle of the fiber. The acceptance angle is calculated by:

$$\Theta = n^* \arcsin(NA)$$

where NA - numerical aperture of the fiber
n - refraction index; in air n = 1

Fore typical single mode fibers the total angle 2*Q of the emitted light is between 15° and 25°, for an angled connector (APC) the cone is tilted by approximately 4° from the fiber axis.

This expansion of the beam has to be considered to avoid overfilling the detector and getting wrong results. On the other hand for measurements with high power fiber lasers a certain gap between fiber tip and detector surface has to be kept to decrease the power density.

Thorlabs offers fiber adapters with the most common connectors that are verified with the S12xC series optical sensors and with most thermal sensors.

For large divergence angles or fiber measurements that are critical to back-reflections it is recommended to use an integrating sphere sensor of the S14xC series.

Another good choice for fiber based measurements are the fiber heads of the S15xC series. They plug directly to the meter and have no cable between sensor and console. This minimizes measurement interferences.

4.10 Energy Measurement using Pyroelectric Sensors

The selection of the best suitable pyroelectric energy sensor must be made with respect to the following parameters:

Energy to Measure

The maximum allowed energy is limited by the absorption layer (too high energy causes mechanical damages on the layer) and by the sensor material, that must not exceed a certain temperature level. It is also important to pay attention to the maximum energy density, to the average power and to the maximum power density during a pulse.

To the lower end, the detection is limited by the resolution and the minimum settable trigger level of the display unit, as well as by the noise level. To minimize the noise level and to avoid ground loops it is recommended to mount the detectors using the supplied isolation adapters.

Beam Diameter

The active area of the detector should be selected in such way, that it has a slightly larger diameter than the incident beam. Not necessarily the beam should cover most of the sensor area, but the maximum allowed energy density must not be exceeded.

Repetition Rate

The maximum pulse repetition rate depends on the combination of the internal capacitance of the detector and the load resistor. The display unit has an input resistor of 1MΩ (like the typical input resistor of an oscilloscope).

Pulse Length

Energy sensors can detect and measure pulses with a duration from sub-nano-second range to approximately 2 ms. The max. pulse duration depends on

- the electrical time constant of the sensor, given by detector capacity and load resistance
- the thermal time constant of the sensor.

Usually the latter is the more significant.

Wavelength

The sensors are typically calibrated at one wavelength, for other wavelengths a sensor specific correction curve is stored in the memory in the sensor connector. The black coating is nearly linear flat over a wavelength range from 185nm to > 25µm; the ceramic coating is also suitable for this wavelength range, but is not linear over the entire wavelength range.

5 Appendix

5.1 Technical Data

General Data	
Detector Compatibility	Photodiode Sensors S100C Series Thermal Sensors S3xxC / S4xxC Series Pyroelectric Sensors EC100C/ES200C Series Photodiodes (max. 5 mA) Thermopiles (max. 1 V) Pyros (max. 100 V)
Display Type	External PC - Windows Application
Display Update Rate (max)	Up to 300 Hz, depending on PC and settings
Display Format	Numerical, Bar Graph, Trend Graph, Statistics, Histogramm (Utility Software)
Current Input (Photodiode Sensors)	
Connector	DB9F, left side
Units	W, dBm, W/cm², A
Measurement Ranges	6 decades; 50 nA - 5 mA Ranges selectable in W or A, sensor depending
Display Resolution	1 pA / responsivity value (A/W)
AD Converter	16 bit
Accuracy	± 0.2 % f.s. (5µA - 5mA) ± 0.5 % f.s. (50nA)
Input Bandwidth (Analog)	DC - 100kHz, depending on sensor and settings
Wavelength Correction	nm (A/W)
Beam Diameter Setting	1/e²
Voltage Input (Thermopile Sensors)	
Connector	DB9F, left side
Units	W, dBm, W/cm², V
Measurement Ranges	4 decades; 1 mV - 1V Ranges selectable in W or V, sensor dependent
Display Resolution	1 µV / responsivity value (V/W)
AD Converter	16 bit
Accuracy	± 0.5 % f.s. (10 mV - 1 V range) ± 1.0 % f.s. (1 mV range)
Input Bandwidth (Analog)	DC - 10Hz, depending on sensor and settings
Wavelength Correction	Sensor depending; nm, (V/W)
Beam Diameter Setting	1/e²

Voltage Input (Pyroelectric Sensors)	
Connector	DB9F, left side
Units	J, J/cm², W, W/cm², V
Measurement Ranges	4 decades; 100 mV - 100V Ranges selectable in J or V, sensor dependent
Display Resolution	100 µV / responsivity value (V/J)
AD Converter	16 bit
Accuracy	± 0.5 % f.s.
Trigger Threshold	0.1 % to 99.9 % f.s.
Input Bandwidth (Analog)	3 kHz
Input Impedance	1 MΩ
Wavelength Correction	Sensor depending; nm, (V/J)
Beam Diameter Setting	1/e²
Sensor Temperature Control	
Supported temperature sensor	Thermistor
Temperature measurement range	-10°C ... +80°C

Interface	
Type	USB2.0
Connector	Mini USB, left side
Power Supply	
External power supply	5V DC via USB
Accessories	
USB cable A to Mini-B, 2 m	
USB Stick with - Application Software - Instrument Drivers - Thorlabs Instrument Communicator - Thorlabs DFU (Device Firmware Upgrade) Wizard	
General	
Operating Temperature Range [1])	0 to + 40 °C
Storage Temperature Range	-40 to +70 °C
Dimensions (W x H x D)	93.1 mm x 60.4 mm x 28.7 mm (3.67" x 2.38" x 1.13")
Weight	approx. 0.15 kg
Relative Humidity	max. 80 % up to 31° C, decreasing to 50 % at 40° C
Operation Altitude	< 3000 m

[1]) non-condensing
All technical data are valid at 23 ± 5°C and 45 ± 15% rel. humidity (non condensing)

Current Input Photo Diode Sensors

<table>
<tr><th>Current Range</th><th>Display Resolution</th><th>Measurement Accuracy</th></tr>
<tr><td>5 mA</td><td>1µA</td><td rowspan="5">± 0.2 % f.s.</td></tr>
<tr><td>500 µA</td><td>100 nA</td></tr>
<tr><td>50 µA</td><td>10 nA</td></tr>
<tr><td>5 µA</td><td>1 nA</td></tr>
<tr><td>500 nA</td><td>100 pA</td></tr>
<tr><td>50 nA</td><td>10 pA</td><td>± 0.5 % f.s.</td></tr>
</table>

Voltage Input Thermal Sensors

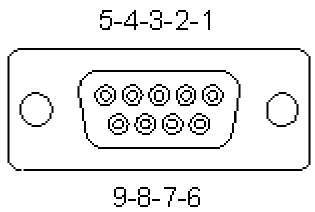
<table>
<tr><th>Voltage Range</th><th>Display Resolution</th><th>Measurement Accuracy</th></tr>
<tr><td>1 V</td><td>100 µV</td><td rowspan="3">± 0.5 % f.s.</td></tr>
<tr><td>100 mV</td><td>10 µV</td></tr>
<tr><td>10 mV</td><td>1 µV</td></tr>
<tr><td>1 mV</td><td>0.1 µV</td><td>± 1.0 % f.s.</td></tr>
</table>

Voltage Input Pyroelectrical Sensors

<table>
<tr><th>Voltage Range</th><th>Display Resolution</th><th>Measurement Accuracy</th></tr>
<tr><td>100 V</td><td>100 mV</td><td rowspan="4">± 0.5 % f.s.
.</td></tr>
<tr><td>10 V</td><td>10 mV</td></tr>
<tr><td>1 V</td><td>1 mV</td></tr>
<tr><td>0.1V</td><td>100 µV</td></tr>
</table>

5.2 Pin Assignment of the Sensor Connector

The PM100USB is capable to support custom made detectors. Please read carefully the following instruction prior to connecting a self made sensor.



Pin-out of the 9pin DSUB sensor connector (female)

pin	connection
3	AGND (analog ground): photodiode ground (anode), thermal and pyro sensor ground
4	photodiode cathode
5	pyroelectric sensor +
8	thermal sensor +
7	PRESENT: Connect this pin via a 1kΩ – 10kΩ resistor to pin 3 (AGND) to enable a custom sensor
1	+5V (max. current 50mA from this pin)
6	DGND (digital ground)
9	n.c.

Warning

Pin 2 is uniquely used for the EEPROM Digital I/O (memory in Thorlabs sensor heads) and MUST NOT be used. Connecting this pin may cause malfunction of the PM100USB.

5.3 Tutorial

Content

Definitions and explanations: This section gives an overview on specifications, their definitions and application to sensor families.

Calculations: Here common formulas are given - power, energy and densities can be calculated based on different given parameters.

5.3.1 Definitions and explanations

In this section the key parameters of Thorlabs Power Meters and Sensors are commented.

5.3.1.1 Console Specifications

- **Measurement Ranges**

  It is important to keep in mind, that the optical power (energy) measurement is based on a current measurement (photodiode sensors) or on a voltage measurement (thermal and pyroelectric sensors). That's why the measurement ranges are stated sensor dependent - for photodiode sensors are stated the current ranges, for thermal and energy sensors - voltage ranges.

- **Display Resolution**

  Note:

  The resolution is the minimum detectable change of power (energy), it is **not** the minimum measurable power (energy)!

  As the console measures a current or a voltage, the display resolution can be stated only in A or V. In the specifications the resolution is stated for the most sensitive measurement range. The optical power resolution depends on the actual sensor's responsivity.

  Current input (photodiode sensors): The resolution is specified to "1 pA / responsivity value (A/W)". This means, that the PM100USB has in the lowest measurement range (50 nA) a resolution of 1 pA. The responsivity of a photo diode sensor is wavelength dependent, thus the power resolution is wavelength dependent as well.

  Example: A S120C sensor has a responsivity of 7.35 × 10^{-2} A/W at 930 nm, and 5.05 × 10^{-3} A/W at 455 nm. In the lowest measurement range the displayed power resolution is at 930 nm

$$\delta_{935nm} = \frac{1 \cdot 10^{-12}\,\text{A}}{7.35 \cdot 10^{-2}\,\text{A}/\text{W}} = 1.36 \cdot 10^{-11}\,\text{W} = 13.6\,\text{pW}$$

  and at 455 nm

$$\delta_{455nm} = \frac{1 \cdot 10^{-12}\,\text{A}}{5.05 \cdot 10^{-3}\,\text{A}/\text{W}} = 1.98 \cdot 10^{-10}\,\text{W} = 198\,\text{pW}$$

In contrast to above resolution values, the minimum measurable optical power for S120C is 50 nW. This should make clear the difference between resolution and minimum power.

Voltage input (thermopile sensors): The resolution is specified to "1 µV / responsivity value (V/W)". This means, that the PM100USB has in the lowest measurement range (1 mV) a resolution of 1 µV. The power resolution depends on the used sensor.

Voltage input (pyroelectric sensors): The resolution is specified to "100 µV / responsivity value (V/J)". This means, that the PM100USB has in the lowest measurement range (200 mV) a resolution of 100 µV. The energy resolution depends on the used sensor.

- **Accuracy** of the PM100USB is the current (voltage) measurement accuracy. It is given in % f.s. (% of the full scale value). Please note that the console's accuracy is different from the sensor's measurement uncertainty.
- **Wavelength Correction** is value that can be entered to the console in order to apply the correct responsivity and to get this way a correct measurement result.

  In case of a calibrated Thorlabs sensor, the actual wavelength is entered directly. The console retrieves the according responsivity from the calibration table, which is saved to the sensor's memory, and uses this value for power (energy) calculation.

  In case of a custom sensor, the console needs to be set to the correct sensor type (photodiode, thermal or pyroelectric sensor) and the responsivity needs to be entered as numerical value.

5.3.1.2 Sensor Specifications

1. **Common parameters**

- **Wavelength Range:** Within this range the sensor is calibrated and thus able to measure with the specified measurement uncertainty.
- **Resolution** is the minimum detectable change of the measured parameter. The resolution is always specified for a certain console type and bandwidth setting.
- **Measurement uncertainty** states the measurement accuracy and is specified for the entire wavelength range of the sensor. For some sensor types, an alternative value might be specified for a partial wavelength range.

2. **Photo Diode Sensors (S12xC, S13xC and S15xC Series)**

- **Optical Power Range** specifies the minimum and maximum measurable power. Exceeding the upper limit leads to sensor saturation and wrong measurement results. If pulsed signals are measured, the pulse peak power must not exceed the max. measurable power in order to avid saturation. Underrunning the lower limit leads to increased measurement uncertainty due to noise impact.

- **Max. Average Power Density** must not be exceeded to avoid damages to the sensor. For definition and calculation, please see section Calculations.
- **Max. Pulse Energy** is an alternative specification to max. average power density, which must not be exceeded. In case of the S15xC fiber sensors, the max. pulse energy density is given. The reason is that fibers may have a very small beam diameter at the fiber tip, leading to high energy densities. For definition and calculation, please see section Calculations.

3. Integrating Sphere Sensors (S14xC Series) and Thermal Sensors (S3xxC / S4xxC Series)

- **Optical Power Range** specifies the minimum and maximum measurable power. Exceeding the upper limit leads to sensor saturation and wrong measurement results. If pulsed signals are measured, the pulse peak power must not exceed the max. measurable power in order to avid saturation. Underrunning the lower limit leads to increased measurement uncertainty due to noise impact.
- **Max. Average Power Density** must not be exceeded to avoid damages to the sensor. For definition and calculation, please see section Calculations.
- **Max. Pulse Energy Density** is an alternative specification to max. average power density, which must not be exceeded. For definition and calculation, please see section Calculations.
- **Max. Intermittent Power (2 min. Max.)** can be applied to the sensor for max. 2 minutes without damages to the sensor. In case of pulsed signals, the average power of the pulse train is considered. Please note that this specification is higher than the max. measurable power, consequently the sensor will enter saturation and the measurement result will not be correct.

4. Pyroelectric Energy Sensors (ESxxxC Series)

- **Optical Energy Range** specifies the minimum and maximum measurable energy. Take care about the correct trigger level setting, particularly if measure energy levels, close to the lower limit of the measurement range - sensor noise may interfere the correct triggering to the pulse edge, which leads to wrong measurement results.
- **Max. Power Density** is related to the pulse peak power and must not be exceeded to avoid damages to the sensor. For definition and calculation, please see section Calculations.

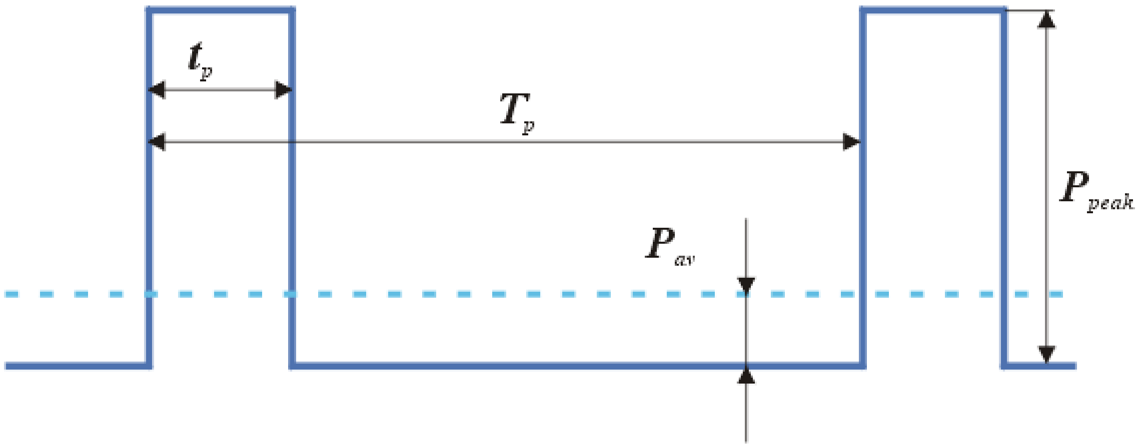
- **Max. Pulse Energy Density** is an alternative specification to max. average power density, which must not be exceeded. For definition and calculation, please see section Calculations.
- **Max. Average Power** must not be exceeded to avoid damages to the sensor as a consequence of overheating.

5.3.2 Calculations

In this section a collection of formulas is given to ease the conversion of pulse train parameters.

Note

All formulas below are given for rectangular pulses.



Pulse diagram

t_P pulse duration
T_P pulse period
P_{Peak} pulse peak power
P_{av} pulse average power

Repetition rate is related to pulse period:

$$f_p = \frac{1}{T_P} \quad [1]$$

Duty cycle is the ratio of pulse duration to pulse period:

$$D = \frac{t_P}{T_P} = t_P \cdot f_p$$

Pulse average power:

$$P_{av} = \frac{t_P}{T_P} P_{peak} = t_P \cdot f_p \cdot P_{peak} \quad [2]$$

Pulse peak power:

$$P_{peak} = \frac{T_P}{t_P} P_{av} = \frac{P_{peak}}{t_P \cdot f_p} \quad [3]$$

Energy: The measurement unit of energy is J (Joule) - 1J is the energy that is necessary to provide the power of 1 W(att) during 1s(ec). It can be calculated from the peak power of the pulse and the pulse duration:

$$W = P_{peak} \cdot t_P \quad [4]$$

By substitution of peak power by average power (formula [3]), the energy can be calculated from average power and repetition rate:

$$W = \frac{P_{av}}{f_P} \quad [5]$$

Power (Energy) Density

is the power (energy) per unit of beam area. The formulas below are based on a circular beam shape with the beam diameter d_B and an area of

$$A = \frac{\pi}{4} d_B^2$$

If the beam shape is not circular, the area must be calculated using the appropriate formula. For example, if the beam shape is elliptical with d_1 (long axis) and d_2 (short axis), the beam area is

$$A = \frac{\pi}{4} d_1 \cdot d_2$$

Average Power Density Ψ_{av}

The average power density is the ratio of the average power of the light beam to the area illuminated by this beam.

Given parameters	Formula
P_{av} (average power), d_B (beam diameter)	$\Psi_{av} = 4 \frac{P_{av}}{\pi \cdot d_B^2}$
P_{peak} (pulse peak power), f_P (repetition rate), t_P (pulse duration), d_B (beam diameter)	$\Psi_{av} = 4 \frac{P_{peak} \cdot t_P \cdot f_P}{\pi \cdot d_B^2}$
W (pulse energy), f_P (repetition rate) d_B (beam diameter)	$\Psi_{av} = 4 \frac{W \cdot t_P}{\pi \cdot d_B^2}$

Peak Power Density Ψ_{peak}

Given parameters	Formula
P_{peak} (pulse peak power), d_B (beam diameter)	$\Psi_{peak} = 4\frac{P_{peak}}{\pi \cdot d_B^2}$
W (pulse energy), t_P (pulse duration), d_B (beam diameter)	$\Psi_{peak} = 4\frac{W}{\pi \cdot d_B^2 \cdot t_P}$
P_{av} (average power), f_P (repetition rate), t_P (pulse duration), d_B (beam diameter)	$\Psi_{peak} = 4\frac{P_{av}}{\pi \cdot d_B^2 \cdot t_P \cdot f_P}$

Pulse Energy Density ξ

Given parameters	Formula
W (pulse energy), d_B (beam diameter)	$\xi = 4\frac{W}{\pi \cdot d_B^2}$
P_{peak} (pulse peak power), t_P (pulse duration), d_B (beam diameter)	$\xi = 4\frac{P_{peak} \cdot t_P}{\pi \cdot d_B^2}$
P_{av} (average power), f_P (repetition rate), d_B (beam diameter)	$\xi = 4\frac{P_{av}}{\pi \cdot d_B^2 \cdot f_P}$

5.4 Certifications and Compliances

EU Declaration of Conformity

in accordance with EN ISO 17050-1:2010

We: Thorlabs GmbH

Of: Hans-Boeckler-Str. 6, 85221 Dachau/München, Deutschland

in accordance with the following Directive(s):

2014/30/EU	Electromagnetic Compatibility (EMC) Directive
2011/65/EU	Restriction of Use of Certain Hazardous Substances (RoHS)

hereby declare that:

Model: ***PM100USB***

Equipment: ***Optical Power and Energy Meter - USB Only Interface***

is in conformity with the applicable requirements of the following documents:

EN 61326-1	Electrical Equipment for Measurement, Control and Laboratory Use - EMC Requirements	2013
EN 61010-1	Safety requirements for electrical equipment for measurement, control, and laboratory use	2010

and which, issued under the sole responsibility of Thorlabs, is in conformity with Directive 2011/65/EU of the European Parliament and of the Council of 8th June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, for the reason stated below:

does not contain substances in excess of the maximum concentration values tolerated by weight in homogenous materials as listed in Annex II of the Directive

I hereby declare that the equipment named has been designed to comply with the relevant sections of the above referenced specifications, and complies with all applicable Essential Requirements of the Directives.

Signed:  *On:* 19 June 2017

Name: Dorothee Jennrich

Position: General Manager

EDC - PM100USB -2017-06-19

CE

5.5 Warranty

Thorlabs warrants material and production of the PM100USB for a period of 24 months starting with the date of shipment. During this warranty period Thorlabs will see to defaults by repair or by exchange if these are entitled to warranty.

For warranty repairs or service the unit must be sent back to Thorlabs. The customer will carry the shipping costs to Thorlabs, in case of warranty repairs Thorlabs will carry the shipping costs back to the customer.

If no warranty repair is applicable the customer also has to carry the costs for back shipment.

In case of shipment from outside EU duties, taxes etc. which should arise have to be carried by the customer.

Thorlabs warrants the hard- and/or software determined by Thorlabs for this unit to operate fault-free provided that they are handled according to our requirements. However, Thorlabs does not warrant a fault free and uninterrupted operation of the unit, of the software or firmware for special applications nor this instruction manual to be error free. Thorlabs is not liable for consequential damages.

Restriction of Warranty

The warranty mentioned before does not cover errors and defects being the result of improper treatment, software or interface not supplied by us, modification, misuse or operation outside the defined ambient stated by us or unauthorized maintenance.

Further claims will not be consented to and will not be acknowledged. Thorlabs does explicitly not warrant the usability or the economical use for certain cases of application.

Thorlabs reserves the right to change this instruction manual or the technical data of the described unit at any time.

5.6 Copyright and Exclusion of Reliability

Thorlabs has taken every possible care in preparing this document. We however assume no liability for the content, completeness or quality of the information contained therein. The content of this document is regularly updated and adapted to reflect the current status of the hardware and/or software. We furthermore do not guarantee that this product will function without errors, even if the stated specifications are adhered to.

Under no circumstances can we guarantee that a particular objective can be achieved with the purchase of this product.

Insofar as permitted under statutory regulations, we assume no liability for direct damage, indirect damage or damages suffered by third parties resulting from the purchase of this product. In no event shall any liability exceed the purchase price of the product.

Please note that the content of this document is neither part of any previous or existing agreement, promise, representation or legal relationship, nor an alteration or amendment thereof. All obligations of *Thorlabs* result from the respective contract of sale, which also includes the complete and exclusively applicable warranty regulations. These contractual warranty regulations are neither extended nor limited by the information contained in this document. Should you require further information on this product, or encounter specific problems that are not discussed in sufficient detail in the document, please contact your local *Thorlabs* dealer or system installer.

5.7 Thorlabs 'End of Life' Policy (WEEE)

As required by the WEEE (Waste Electrical and Electronic Equipment Directive) of the European Community and the corresponding national laws, Thorlabs offers all end users in the EC the possibility to return “end of life” units without incurring disposal charges.

This offer is valid for Thorlabs electrical and electronic equipment

- sold after August 13th 2005
- marked correspondingly with the crossed out “wheelie bin” logo (see figure below)
- sold to a company or institute within the EC
- currently owned by a company or institute within the EC
- still complete, not disassembled and not contaminated

As the WEEE directive applies to self contained operational electrical and electronic products, this “end of life” take back service does not refer to other Thorlabs products, such as

- pure OEM products, that means assemblies to be built into a unit by the user (e. g. OEM laser driver cards)
- components
- mechanics and optics
- left over parts of units disassembled by the user (PCB’s, housings etc.).

Waste treatment on your own responsibility

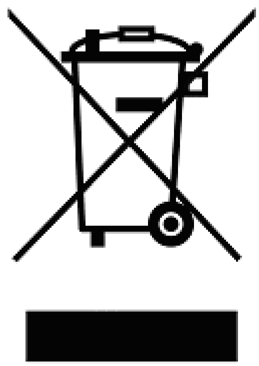
If you do not return an “end of life” unit to Thorlabs, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

WEEE Number (Germany) : DE97581288

Ecological background

It is well known that waste treatment pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS Directive is to reduce the content of toxic substances in electronic products in the future.

The intent of the WEEE Directive is to enforce the recycling of WEEE. A controlled recycling of end-of-life products will thereby avoid negative impacts on the environment.



Crossed out "Wheelie Bin" symbol

5.8 Thorlabs Worldwide Contacts

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