Appendix Beam profiler BP 209 VIS

THORLABS

Thorlabs Beam
Beam Analyzing Software

BP209
M2MS-BP209
Operation Manual

2014

8 Application Note

This chapter contains the background knowledge about the measurement methods of beam profiles.

Beam profiles can be characterized by a number of different parameters. Our aim was to offer measurement of all usual beam parameters based on ISO11146-1.

In the following sections detailed explanations are given to the measured parameters.

8.1 Coordinate systems

Lab System

The lab system (AKA reference system) of coordinates is based on the true X and Y coordinate orientation of the drum in accordance with the marking on the front panel.

Transformed System

The transformed system of coordinates is based on the calculated beam axes (minor and major axes for elliptical fit or for 4σ beam diameter).

8.2 Raw Data Measurements

Beam Width (4σ)

Width on **X** and **Y** axes (centroids), based on the second moment calculation

$$d_{\sigma x} = 4 * \sigma_x = 4 * \sqrt{\frac{\sum\left[(x - x_{centroid})^2 * p(x,y)\right]}{Sum\_Intensity}}$$

$$d_{\sigma y} = 4 * \sigma_y = 4 * \sqrt{\frac{\sum\left[(y - y_{centroid})^2 * p(x,y)\right]}{Sum\_Intensity}}$$

Beam width (4σ) can also be calculated using radial distance (pixel - centroid; **R**).

According to ISO11146-1, if the ellipticity[129] is larger than 0.87, the beam profile may be considered to be of circular symmetry at that measuring location. In this case, ISO11146-1 allows the calculation of only one common 4σ beam width (4σ simplified).

Peak Position

X, Y: position of the pixel with highest intensity (AD value) which is found first with respect to reference position.

R = $\sqrt{X^2 + Y^2}$ = radial distance of same pixel from reference position

Reference position is the sensor's center.

Centroid Position

X, Y and **R** position (first moment), calculated over all pixels with respect to the above reference position.

$$X = SUM\,[x * p(x,y)] / I \qquad Y = SUM\,[y * p(x,y)] / I$$

where:

p(x,y)	intensity at location (x,y);
I	total intensity;
SUM	of pixels taken taken over entire area

AD Saturation

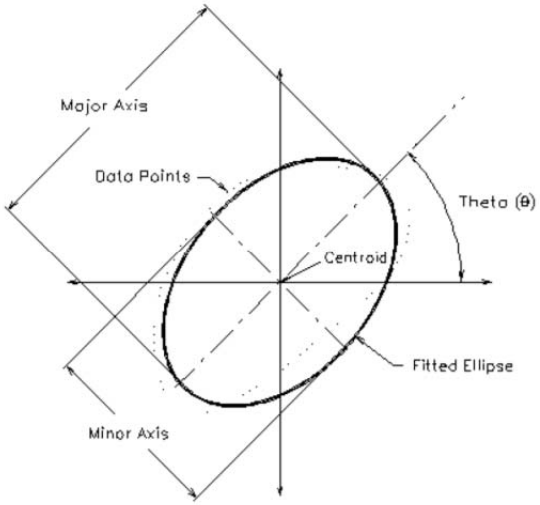
Saturation level of the instrument's AD converter. For a good SNR (signal-to-noise ratio) the saturation level should be not below 40% and not be above 95%.

Total Power

Total power measured through the ND filter [20] in the drum (photo diode current with respect to the typical wavelength dependant responsivity).

8.3 Ellipse (fitted)

The beam shape is fitted to an ellipse using the set clip level (down from the peak).



Diameter (clip level) is given for the minor axis (**min**), major axis (**max**) and their arithmetic **mean** value.

Ellipticity and **Eccentricity** of the beam are defined in ISO 11146-1 as

$$Ellipticity = \frac{d_{min}}{d_{max}} \qquad Eccentricity = \frac{\sqrt{d_{max}^2 - d_{min}^2}}{d_{max}}$$

where d_{min} denotes the minor and d_{max} the major axes of the approximated beam ellipse, respectively.

Orientation denotes the angle θ of the major ellipse axis is with respect to the horizontal x axis and is within the range $-90° < \theta \leq 90$.

8.4 X-Y-Profile Measurement

Beam Width Clip (xx%)

Beam width is the distance between the two points where the opposing edges of a captured beam profile intersect the X or Y axis and the intensity falls to a certain percentage of the peak power. This percentage is called clip level.

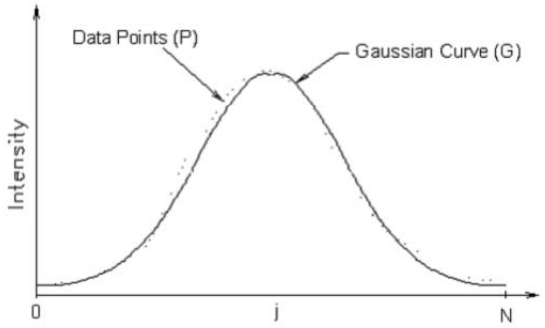
Preferred clip levels are for instance 50 % (Full Width at Half Maximum) and 13.53% (exactly 1/ e^2). Since the Beam software supports a variable clip level, the beam width is always displayed with its clip level in brackets.

Note

Please note that 'Beam Width' is always the diameter, not the radius of the beam.

8.5 Gaussian Fit Measurement

In most instances, the beam profiles of coherent light sources show a distribution more or less close to Gaussian. Such light sources are commonly found in the output of lasers and fibers. A focused Gaussian beam has a waist, after which it diffracts. The Gaussian fit, a least-squares fit of an ideal Gaussian curve to the X-Y cross section profile, can to estimate how close the measured profile is to a Gaussian.



Gaussian Intensity

is the correlation between the beam profiles in a line (X) and column (Y) and its appropriate Gaussian curve fit

Gaussian Diameter

is the width of the Gaussian fit at the $1/e^2$ intensity level.

8.6 Bessel Fit

Different from Gaussian beams, a Bessel beam is non-diffractive - it does not spread out. Its distribution can be described by a Bessel function of the first kind.

Ideal Bessel beams do not exist, but a good approximation - a Bessel-Gauss beam - can be achieved by focusing a Gaussian beam using an axicon lens, a narrow annular aperture, or a TAG (Tunable Acoustic Gradient index of refraction) lens. The outout of some step index fibers can also have a profile close to a Bessel beam.

The Bessel fit allows to estimate how close a given beam profile is to a Bessel distribution.

9 Appendix

9.1 Technical Data Beam Profiler

All technical data are valid at 23 ± 5°C and 45 ± 15% rel. humidity

Operating Temperature	+5 ... +35 °C
Storage Temperature	-40 ... +70 °C
Warm-up time for rated accuracy	15 min

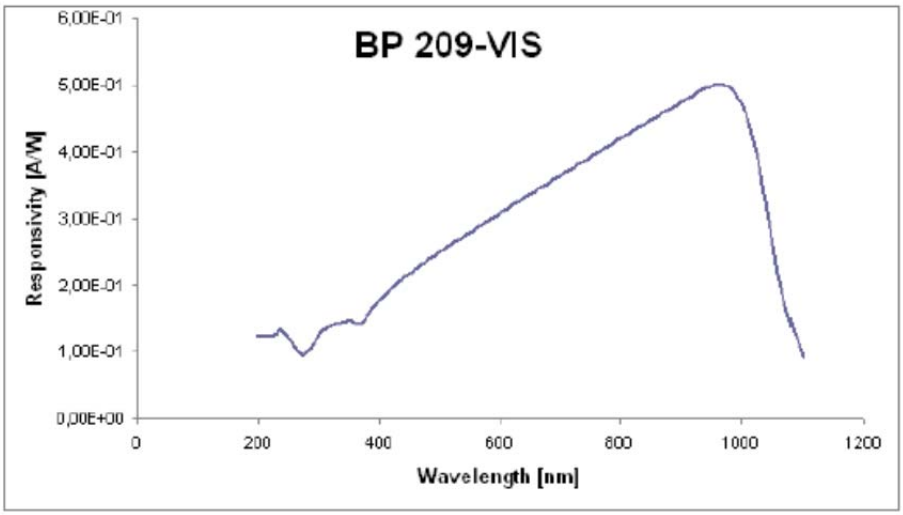
Beam Profiler

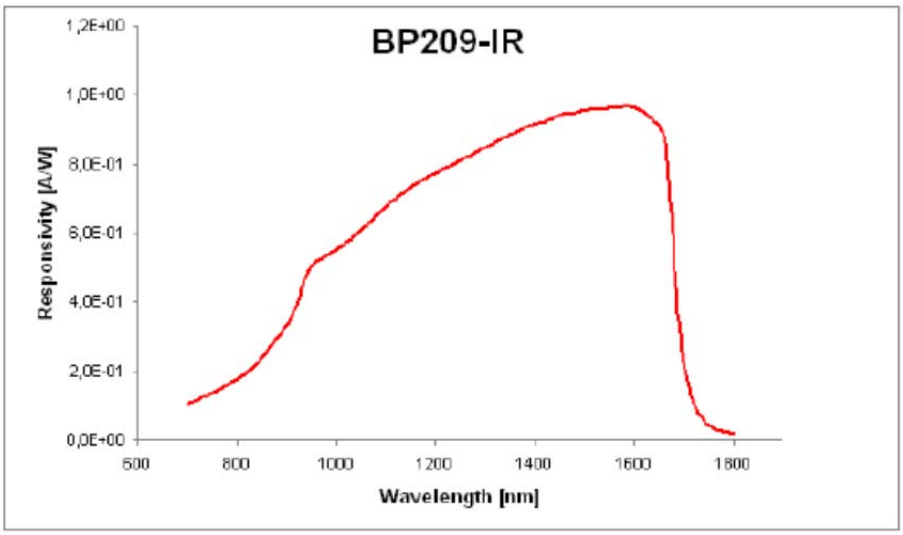
Model	BP209-VIS	BP209-VIS/M	BP209-IR	BP209-IR/M
Wavelength Range	200 - 1100 nm		900 - 1700 nm	
Detector Type	Si, UV enhanced		InGaAs	
Aperture Diameter	9 mm *			
Scan Method	Scanning Slits, Knife Edge			
Slit Size	5 µm and 25 µm			
Minimum Beam Diameter	2.5 µm			
Maximum Beam Diameter	9mm			
Sampling Resolution	0.12 to 1.24 µm (depending on scan rate and aperture width)			
Scan Rate	2.0 to 20.0 s^{-1} (continuously variable)			
Power Range	10nW to 10W (depending on beam diameter and model)			
Amplifier Bandwidth	16 to 1000 kHz in 11 steps (@ -1dB)			
Sample Frequency	0.2872 to 2.0MHz			
Dynamic Range	78 dB (Amplifier Switchable)			
PD Bias Voltage	0 / -1.5 V (switchable)			
Signal Digitization	15 bit			
Head Size	Ø 80mm x 60mm (including rotation mount)			
Minimum Pulse Rate	10 Hz			

* beam diameter error <10% at 9 mm Ø.

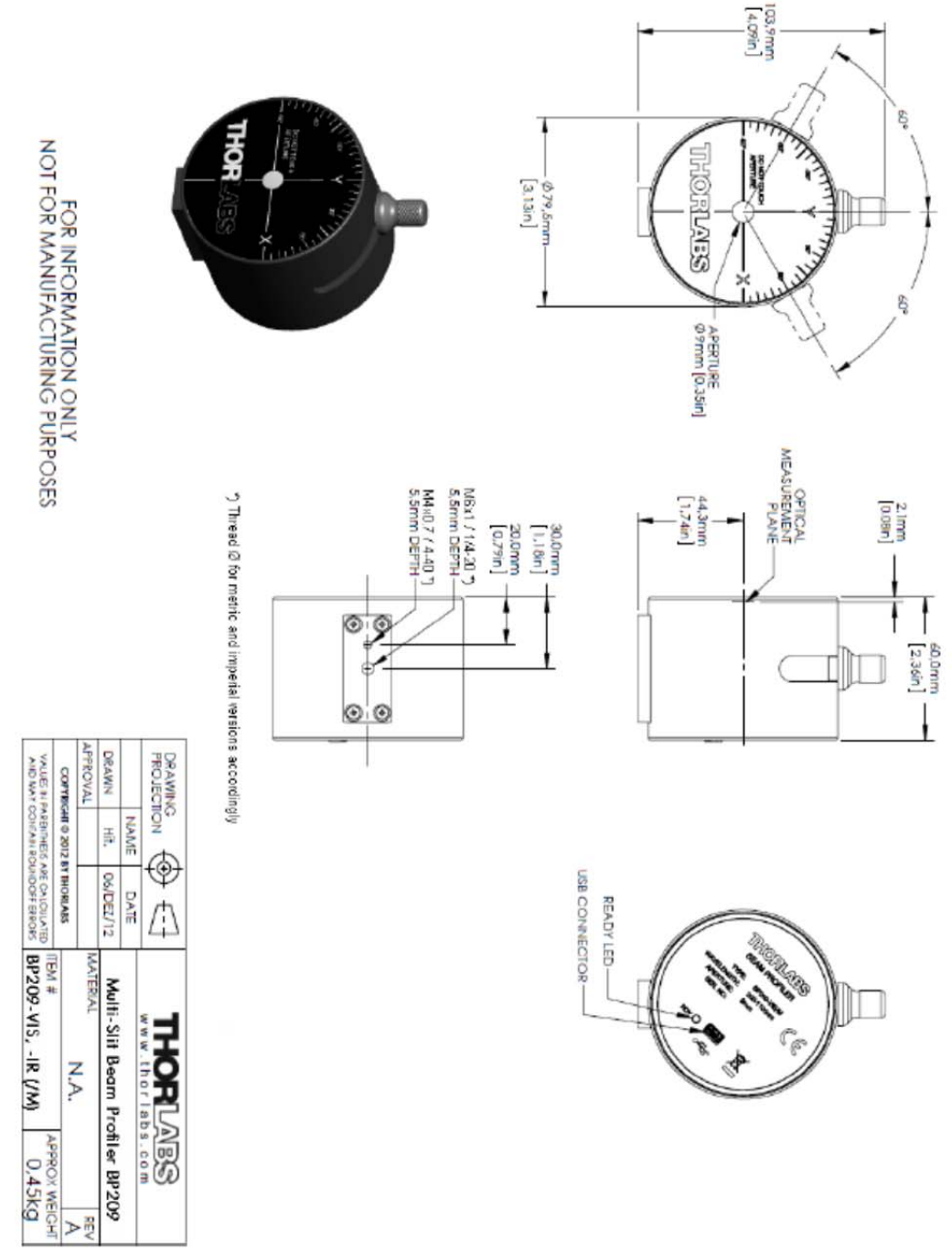
9.2 Typical Photodiode Response Curves

The following diagrams show typical response curves of UV-enhanced Silicon photodiodes used in BP209-VIS and extended wavelength Indium Gallium Arsenide (x-InGaAs) photodiodes used in BP209-IR:



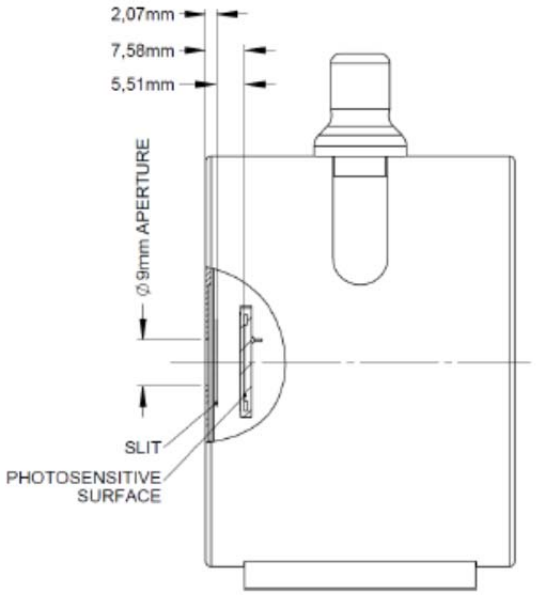


9.3 BP209



9.4 Slit and Photodiode Position

Especially for highly divergent beams it is required that the entire beam power enters the entrance aperture, is scanned by the slit and is detected by the photodiode. To check for this condition the operator needs to know the positions and distances of these elements.



BP209-IR uses an aspheric collimating lens between the slit and the photodiode: