Physics Fundamentals
Parameters

Beam

Fan angle

\( \alpha \)

\( = \alpha \)

\( 40^\circ = 12^\circ = 25^\circ \)

13LR + 55CM

Length

\( L \)

1400 0.557 2000 738 1300

850 0.557 2000 738 1300

409 0.557 2000 738 1300

425 0.278 977 184 815 - 1295 0.2 10.5 13LR25-S1000

698 0.278 973 184 815 - 1295 0.2 10.5 13LR40-S1000

201 0.278 977 184 815 - 1295 0.2 8 13LR12-S1000

217 0.139 496 46 415 - 815 0.3 8 13LR25-S500

357 0.139 492 46 415 - 815 0.3 10.5 13LR40-S500

103 0.139 496 46 415 - 815 0.3 8 13LR12-S500

109 0.077 249 12 205 - 415 0.7 8 13LR25-S250

180 0.077 245 12 205 - 415 0.7 10.5 13LR40-S250

52 0.077 248 12 205 - 415 0.7 8 13LR12-S250

55 0.042 119 2.9 100 - 205 1.4 10.5 13LR25-M125

26 0.042 120 2.9 105 - 205 1.4 10.5 13LR12-M125

0%

0%

0%

0%

0%

Power density

B

\[ \text{[mm]} \]

Power density

B

\[ \text{[mm]} \]

Power density

B

\[ \text{[mm]} \]

Power density

B

\[ \text{[mm]} \]

Laser Diode Characteristics

Laser Diodes, Divergence and Polarization,
Temperature and Power Dependence Astigmatism,
Coherence Wavelength Constancy, Lifetime and
Low Noise Operation

Laser Collimation, Collimating Lenses

Laser Diodes Overview

Structured Laser Illumination

Line Length and Line Width Extrapolation, Line Width,
Correction factor \( F \), Depth of Focus of a Laser Line,
Laser Speckle, Which Laser Line/Focus Generator:
Micro or Macro?

Micro and Macro Laser Lines or Spots

RS232 Interface for Laser Line and
Micro Focus Generators

Laser modules with RS232 interface, Features of the
RS232 interface, Integrated Electronics type, Pin-out
for electronics CS / PS, Attachment: Switchbox
SBS070701-USB

Low Noise Laser Diode Module

LNC-Series

Advantages of the low noise laser
diode beam source

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Pattern Generator

Order Example
Physics Fundamentals Laser Diode Characteristics

Laser Diodes

Laser Diodes are semiconductor lasers and are available in many different shapes and sizes with laser powers ranging from a few mW to hundreds of watts.

The emitted wavelength depends mainly on the semiconductor material of the laser diode cavity and laser diodes are produced to cover the full visible spectrum from blue to red, and even beyond, with some emitting in the infrared.

The laser diodes distributed by Schäfter+Kirchhoff cover the whole wavelength range from 370 nm to 2300 nm.

Temperature and Power Dependence

The emitted spectrum is influenced by the diode temperature and diode current, as well as the geometry of the laser cavity. The front face and the end face serve as a Fabry-Perot cavity allowing multiple longitudinal modes.

When operated just over the threshold, the diodes have a wavelength spectrum with equidistant peaks (longitudinally multimode). On increasing the diode current (to produce a higher power output), one of the longitudinal modes is usually favored and the diode emits in (longitudinally) singlemode.

Unfortunately, the gain profile and the refractive index of the semiconductor material are temperature dependent and, so, other longitudinal modes can be amplified and the output wavelength changes rapidly, by up to a few nanometers, resulting in mode hopping.

For a non-stabilized single-mode diode, mode hopping occurs stochastically and the emitted wavelength and output power can change erratically by as much as 3%.

Some diodes (e.g. VCSEL or Circular Laser) are designed to produce a circular beam profile.

The polarization of the emitted radiation is linear and typically is parallel to the active area of the diode. The degree of polarization varies with the diode current and is lowest at the threshold.

Divergence and Polarization

The microscopic cross-section of the laser diode active area of approx. 1 x 3 µm results in emitted radiation that is divergent. Most laser diodes have a cone of divergent radiation with an elliptical cross-section and an approximately Gaussian intensity distribution. The ellipticity can be overcome with the help of anamorphic optics.

Some diodes (e.g. VCSEL or Circular Laser) are designed to produce a circular beam profile.

The polarization of the emitted radiation is linear and typically is parallel to the active area of the diode. The degree of polarization varies with the diode current and is lowest at the threshold.

Temperature and Power Dependence (continued)

For a temperature range of 20 to 30°C, the center wavelength can drift by 2.5 – 3 nm (GaAs).

Since changing the diode current changes the diode temperature, the current/power output dependence of the laser diode is only nominal. When the laser power is increased from the threshold up to the nominal power then the wavelength increases by 2 – 4 nm.

Astigmatism

The non-uniform gain profile within the active layer of the laser diode means that some laser diodes show astigmatism. Here, the laser radiation emitted parallel and perpendicular to the active layer does not emerge from one point at the cavity end, but appears to be emerging from two different positions.

The distance between these is called the astigmatic difference ∆As and is between 3 – 40 µm. Astigmatism can be corrected by using anamorphic optics (5AN).

Coherence

The particular application determines whether a long coherence Lc (here given for a Gaussian spectrum) or a short coherence is desirable. Non-stabilized singlemode lasers with stochastic changes of the wavelength also exhibit stochastic changes in coherence behavior.

Superluminescent diodes use incoherent spontaneous emission to provide short coherence. For interferometry or spectroscopy, a long (or sufficient) coherence is essential, a feature of DFB, DBR VCSEL diodes with integrated or external thermo-electric cooling (TEC).

Wavelength Constancy

The emitted wavelength can be kept constant in a number of ways. External temperature control is possible using integrated or external Peltier elements and temperature sensors (see 48TE SOT). Most laser diodes also have an integrated monitor photodiode, providing feedback for control of the laser power.

The use of DFB (distributed feedback) or DBR diodes (distributed Bragg reflector) with their spectrally very narrow lines can be advantageous. With the help of a grid structure, only one longitudinal Fabry-Perot mode is amplified (stable singlemode) and mode hopping is suppressed.

VCSEL diodes use DBR structures to produce very narrow lines. The temperature dependence remains, however, and a constant wavelength can only be provided by using an integrated or external temperature control system with integrated monitoring photodiode.
Physics Fundamentals LD Characteristics and Laser Collimation

Laser Collimation (continued)

These differing definitions are responsible for the factor 1.7 in the equations above.

\[
\begin{align*}
\theta_+ & = 2 \cdot f \cdot \sin \left( \frac{1}{2} \theta_{\text{FWHM}} \cdot 1.7 \right) \\
\theta_- & = 2 \cdot f \cdot \sin \left( \frac{1}{2} \theta_{\text{FWHM}} \cdot 1.7 \right)
\end{align*}
\]

- \( f \) = focal length of collimating lens
- \( \theta_{\text{FWHM}} \) = laser diode beam divergence (50%-level)
- \( \theta_{\perp,\text{FWHM}} \) = laser diode beam divergence (13.5%-level)
- \( \theta_+ \) and \( \theta_- \) depend on the respective beam diameters at the collimator \( \Omega_+ \) and \( \Omega_- \), and on the wavelength \( \lambda \) of the emitted radiation.

Even a collimated beam exhibits minimal divergence, since the beam diameter varies (for large distances) with the distance \( A \) from the laser diode collimator.

The resulting beam divergences of the collimated beam \( \theta_+ \) and \( \theta_- \) depend on the respective beam diameters at the collimator \( \Omega_+ \) and \( \Omega_- \), and on the wavelength \( \lambda \) of the emitted radiation. For an ideal Gaussian beam (\( M^2 = 1 \)):

\[
\theta_\perp = \frac{2 \cdot \lambda}{\pi \cdot \Omega_+} \cdot \theta_{\perp,\text{FWHM}}
\]

- \( \theta_\perp \) = beam divergence of the collimated beam
- \( \theta_{\perp,\text{FWHM}} \) = beam diameter (13.5%-level)
- \( \lambda \) = wavelength

Collimating Lenses

The collimating lenses from Schäfter-Kirchhoff are manufactured from high quality glass. Beam collimation and beam shape are up to 30x more stable in comparison with plastic lenses, which exhibit variations in refractive index and shape with changes in temperature.

Bi-asphere lenses are used for collimating monochromatic radiation and exhibit the same correction and imaging quality as microscope lenses with three or four elements. The particular manufacturing process produces microstructures on the lens surface, which are manifest in the collimated beam but not in a focussed spot. Triplet lenses are three lens systems of spherical elements with high quality surfaces that provide a substantial level of spherical correction and a high numerical aperture.

In the wavelength range 370–2300 nm, lenses are provided with an individual anti-reflex coating that cover a few hundred nm of bandwidth.

Lifetime and Low Noise Operation

Laser diodes are very sensitive, especially when exposed to an electrostatic discharge. Surges in the current or voltage can damage a diode severely, making extremely stable power sources a necessity.

The life expectancy of the diode is increased at lower diode temperatures and power outputs, making it very important to operate the diode below its maximum current.

Faraday Isolators (48FI) can effectively prevent back-reflection into the diode. Back-reflections can cause mode hopping and instabilities in the diode wavelength as well as the power output that, in turn, result in faster degradation of the performance and disturbance of the polarization.

The beam can be characterized by the divergence \( \theta_{\perp} \times \theta_{\parallel} \) measured perpendicular and parallel to the active surface area at the 1/e²-level (= 13.5%).

Beam characteristics can also be described at the 50% intensity level and are then defined by the divergence

\[
\theta_{\perp,\text{FWHM}} \times \theta_{\parallel,\text{FWHM}}
\]

(FWHM: full-width at half-maximum).

For laser diodes, the parameters \( \theta_{\perp,\text{FWHM}} \times \theta_{\parallel,\text{FWHM}} \) are usually specified and for a collimated beam, a description at the 1/e²-level is more suitable.

Collimation optics transform a divergent beam with the divergence \( \theta_\perp \times \theta_\parallel \) into a collimated beam, retaining both its Gaussian intensity distribution and elliptical beam profile with diameters \( \Omega_\perp \times \Omega_\parallel \).

The beam diameter \( \Omega_\perp \) at the collimator is also given at the 1/e²-level and is defined by the focal length \( f \) of the collimating lens and the divergence \( \theta_{\perp,\text{FWHM}} \) of the laser diode.
Physics Fundamentals  Structured Laser Illumination

Laser lines are primarily characterized by their length and their working distance, with other parameters becoming relevant depending on the measuring task. The measurement resolution is determined by the line width and can be limited by speckle. A sufficient depth of focus has to be taken into account when measuring objects of variable height.

The Schäfter+Kirchhoff laser line generators were developed to satisfy these differing measurement requirements – providing laser micro lines for fine line widths and laser macro lines for extended depth of focus.

The fan angle can also be decisive in the choice of laser line and, for objects with glossy surfaces, Schäfter+Kirchhoff supplies laser line generators that are semi-telecentric. The Schäfter+Kirchhoff laser spot generators are also differentiated in the same manner, with micro focus generators producing small spot sizes and macro focus generators providing extended depth of focus.

The rule of propagation provides the equation for the extrapolation of line width and length. With the values \( L_1, B_1 \) and \( L_2, B_2 \) for two working distances \( A_1 \) and \( A_2 \) then the line length \( L \) and line width \( B \) for the desired working distance \( A \) can be calculated from:

\[
    L = L_1 + \frac{L_2 - L_1}{A_2 - A_1} (A - A_1)
\]

\[
    B = B_1 + \frac{B_2 - B_1}{A_2 - A_1} (A - A_1)
\]

Example:

Length \( L \) and Width \( B \) of 13LR25-S250 at \( A = 300 \text{ mm} \)
Look up values in Table 1.1a (Page 22):
\( A_1 = 248 \text{ mm} \quad A_2 = 496 \text{ mm} \quad L_1 = 109 \text{ mm}\)
\( L_2 = 217 \text{ mm} \quad B_1 = 0.063 \text{ mm}\)
\( B_2 = 0.126 \text{ mm}\) and insert into the formulas above
\( L = 132 \text{ mm}, B = 0.076 \text{ mm} \) at \( A = 300 \text{ mm} \) for 13LR25-S250

---

### Laser Diodes Overview

<table>
<thead>
<tr>
<th>Type of diode</th>
<th>Fabry Perot</th>
<th>DFB / DBR</th>
<th>Integrated TEC/NTC</th>
<th>VCSEL</th>
<th>Circular Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Ø9</td>
<td>Ø5.6</td>
<td>TO3</td>
<td>TO5</td>
<td>Ø9</td>
</tr>
<tr>
<td>Case type</td>
<td>without</td>
<td>with and without</td>
<td>without</td>
<td>with</td>
<td>with and without</td>
</tr>
<tr>
<td>Integrated TEC/NTC</td>
<td>without</td>
<td>with and without</td>
<td>with and without</td>
<td>without</td>
<td>with and without</td>
</tr>
<tr>
<td>Description</td>
<td>Fabry-Perot laser diodes possess a good price-performance ratio because they are one of the commonest types of laser diode and they have a simple edge-emitting structure.</td>
<td>Distributed feedback (DFB) laser diodes have an integrated grating within the active medium while the grating structure for DBR diodes is outside of the active area. The emission bandwidth is narrow since the emission wavelength can be tuned by modifying either the applied current or the diode temperature.</td>
<td>Superluminescent diodes are characterized by spontaneous emission, producing a larger emission bandwidth with lower coherence length.</td>
<td>Vertical cavity surface-emitting laser diodes are inexpensive to produce. The beam profile is circular and the emission bandwidth narrow.</td>
<td>Circular Laser diodes have integrated internal beam-correcting (anamorphic) optics that produce a circular beam profile.</td>
</tr>
<tr>
<td>Wavelengths</td>
<td>390 – 515 nm</td>
<td>x x</td>
<td>x x x x x x x x x</td>
<td>x</td>
<td>x x x x x x x x x</td>
</tr>
<tr>
<td>Emission bandwidth</td>
<td>narrow</td>
<td>narrow</td>
<td>very narrow</td>
<td>very narrow</td>
<td>broad</td>
</tr>
<tr>
<td>Coherence</td>
<td>varying</td>
<td>varying</td>
<td>long</td>
<td>long</td>
<td>short</td>
</tr>
<tr>
<td>Beam and spot profile</td>
<td>elliptical</td>
<td>elliptical</td>
<td>elliptical</td>
<td>elliptical</td>
<td>elliptical</td>
</tr>
</tbody>
</table>
Line Width

Ideally, a thin laser line is used in order to maximize the signal intensity at the sensor. Measurement accuracy can be improved by using sub-pixel algorithms with thicker laser lines, assuming any disturbances caused by laser speckle (see below) are small enough.

For both micro and macro line generators, the width of the laser line is proportional to the working distance and the power density decreases for deviations from the specified working distance and line width. The relationship between the square of the line width and depth of focus means that the depth of focus of a laser line required by an application effectively limits the minimum laser line width that can be used and, thereby, the signal intensity at the sensor.

Adjustment of the collimating lens generates a convergent beam. At distance \( A \) relative to the fiber collimator, a beam propagation with width \( B \) is formed.

\[
B = \frac{4 \cdot \lambda \cdot A}{\pi \cdot \varnothing_l^2}
\]

- \( B \) = line width [mm]
- \( A \) = working distance [mm]
- \( \lambda \) = wavelength of the laser emission [mm]
- \( \varnothing_l \) = cross-section [mm] of the collimated laser beam at the 1/e² level parallel to the active diode strip

Correction factor \( F \)

The beam properties of the laser line/focus generators are presented for a collimator using a diode example, the diode M26 with a wavelength of 660 nm and its distinct divergence angle; these diode characteristics determine the actual line width/spot size and Rayleigh range/depth of focus available for use.

Thus, for laser diode choices other than M26 with 660 nm the line width/spot size and Rayleigh range/depth of focus values must be recalculated using the correction factor \( F \) provided for each diode in the outmost right column of the right table. The other beam parameters remain the same.

For correction of:
- line width/spot size: multiply by \( F \)
- Rayleigh range:
- depth of focus: multiply by \( F^2 \cdot 660 / \lambda \) (in nm)

Depth of Focus of a Laser Line

The laser lines are focussed at a defined working distance and attempts at focussing outside of this narrow range produces line broadening and power density reductions. The range around the nominal working distance, in which the laser line does not increase by more than a factor 1.41, is usually specified as the depth of focus of that laser line and is specified differently for the two types of laser line generator.

Laser Speckle

Laser speckle is interference caused by stochastic lateral displacement of the coherent laser radiation upon reflection from a rough surface. Laser speckle disturbs the edge sharpness and homogeneity of the imaged laser line. The granularity of the laser speckle depends on the aperture setting of the objective used to image the laser line. With a small f-number / large aperture, the generated speckles have a high spatial frequency and produce a homogeneous image (see Figure 1B), whereas the speckles are more granular and particularly disturbing when using a larger f-number/smaller aperture (see Figure 1C).

The generation of laser speckle cannot be avoided as the principle of of laser light-sectioning relies upon the imaged surface being roughly textured and diffusely reflecting optically.

A substantial reduction in the speckle effect is achieved by:
- choosing large lens apertures/small aperture numbers for the objective, which improves depth discrimination but at the expense of depth of focus,
- altering the distance between the object and the sensor, which is most convenient when a scanning measurement is being performed anyway, such as profile measurement of railroad tracks while the train is moving,
- using a laser beam source with decreased coherence length, such as a superluminescent diode or laser of the LNC-Series (p. 49f).

Figure 1:

3D profiling by use of laser light sectioning

Improvement of laser speckling with larger aperture objectives

- Measured object with generated laser lines \( X_1 \) and \( X_2 \). at an incident angle of 60° and with an additional dome illumination of the object.
- Object imaged with a large aperture, f/# 2.8. The imaging lens acts as a spatial frequency filter, restricting the measurement to a shallower dissecting plane and minimizing the speckle effect.
- Object imaged with a small aperture, f/# 22, which increases speckle and granularity, bringing uncertainty in the contour of the line.

Which Laser Line/Focus Generator: Micro or Macro?

Micro lines/spots have a high power density close to their focus but the line width increases and the power density falls drastically when out of focus. In comparison, the power density of a macro line/spot is lower but does not change significantly over a larger range.

A compromise must be found for each application between either the benefits of a larger depth of focus, comparatively large line width/spot size with a lower power density, or narrower lines/smaller spots with a high power density and a smaller depth of focus.
Physics Fundamentals Micro and Macro Laser Lines or Spots

Laser Micro Line Generators and Laser Micro Focus Generators

- Narrow laser line widths or small laser spots
- High power density in the focal plane
- Gaussian intensity profile across the laser line or laser spot

Figure 2: Micro line intensity profile and line width characteristics

Laser Micro Line Generators (see Figure 2) produce narrow laser lines with a high power density and a Gaussian intensity profile across the laser line.

For a laser line with line width \( B \) (at the 13.5\% level) and wavelength \( \lambda \), the depth of focus is defined as the Rayleigh range \( 2z_R \).

Rayleigh range

\[
2z_R = \frac{\pi B^2}{2\lambda}.
\]

\( B \) = line width [mm]

\( \lambda \) = laser wavelength [nm]

Laser Micro Focus Generators produce laser spots with high power density and a Gaussian intensity profile. The line width \( B \) is replaced by the spot diameter in the formula to reveal the Rayleigh range.

Applications for Laser Micro Line/Focus Generators:
- Scattered light measurements
- Photometry
- Position sensing
- Machine vision
- Laser triangulation / 3D-Profiling: with narrow laser lines for detecting small changes within a small height range

Laser Macro Line Generators and Laser Macro Focus Generators

- Larger, almost constant laser line widths or spot sizes with lower power density
- Extended depth of focus (7 to 35-times greater)
- Approx. Gaussian intensity profile across the laser line or laser spot

Figure 3: Macro line intensity profile and line width characteristics

Laser Macro Line Generators generate laser lines with an extended depth of focus. Within the depth of the focus range, the intensity profile across the laser line is approximately Gaussian and the side lobes caused by diffraction remain below the 13.5\% intensity level within the depth of focus range (Figure 3).

For a laser line with line width \( B \) (at the 13.5\% level) and wavelength \( \lambda \), the depth of focus \( 2z_M \) is defined as:

Depth of Focus

\[
2z_M = 1.75 \frac{\pi B^2}{2\lambda}.
\]

For a particular line width \( B \), the depth of focus of a macro line is almost twice that of the equivalent micro line. At the same working distance \( L \), macro lines are 2 to 5-times wider and have a depth of focus 7 to 35-times larger than the equivalent micro line. The output power of a laser macro line generator is generally 50–60\% smaller than that of a laser micro line generator.

Laser Macro Focus Generators generate laser spots with lower power density and an extended depth of focus. The intensity profile is approximately Gaussian. The line width \( B \) is replaced by the spot diameter in the formula to reveal the depth of focus.

Applications for Laser Micro Line/Focus Generators:
- Machine vision
- Laser triangulation/3D profiling: with larger laser line widths for detecting over a large height measurement range
RS232 Interface for Laser Line and Micro Focus Generators

Schäfter+Kirchhoff now also offers laser line generators and micro focus generators with the RS232 interface, to improve access to the laser module, for control of laser power, or to read and store critical data. By knowing the hours of operation and the current consumption, for example, the degradation of the laser diode can be anticipated and maintenance planned.

Features include:
- Laser wavelengths 405 to 940 nm
- Variety of beam-shaping optics, including lasers with defined fan angle, semi-telecentric laser lines, micro focus generators and collimators
- RS232 interface for laser control and data readout
- USB interface using the Switchbox SBS070701-USB
- Integrated power control <5–100 %
- External modulation: TTL up to 250 kHz and analog up to 1 Hz
- Supply Voltage: 5 V DC

Laser modules with RS232 interface

Lasers with fan angle:
- 13L... + 55CM and 13LR... + 55CM ............ page 34f
- 5L... + 55CM and 5L...M + 55CM ............ page 36f
- 13LN... + 90CM and 13LN...M + 90CM ............ page 40f

Semi-telecentric lines:
- 13LT... + 90CM and 13LT...M + 90CM ............ page 42f
- 5LT... + 55CM and 5LT...M + 55CM ............ page 44f

Micro focus generators:
- 13MC... + 95CM and 13MMC... + 95CM ............ page 48f
- 13M... + 55CM and 13MM... + 55CM ............ page 52f

Collimators:
- 55CM .................................... page 57

Please note that laser modules based on collimators 55CR, 90CR or 95CR cannot be provided with an RS232 interface.

Features of the RS232 interface

The RS232 interface (or the USB connection using the switchbox SBS 070701-USB) allows laser control and reading out of laser data:

Input parameters:
- laser power
- laser output power limit
- mode of operation
- laser ON/OFF

Output parameters:
- laser current (mA)
- photo diode current (µA)
- temperature
- laser output power (%)
- operating voltage
- hours of operation
- min./max. temperature

Integrated Electronics type

<table>
<thead>
<tr>
<th>Features</th>
<th>CS</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>+5 V ± 0.2 V</td>
<td>+5 V</td>
</tr>
<tr>
<td>Current consumption max</td>
<td>250 mA</td>
<td>250 mA</td>
</tr>
<tr>
<td>Max. modulation analog frequency</td>
<td>&lt;1 Hz</td>
<td>&lt;1 Hz</td>
</tr>
<tr>
<td>Laser power output potentiometer</td>
<td>&lt;1–100 %</td>
<td>&lt;5–100 %</td>
</tr>
<tr>
<td>TTL modulation logic</td>
<td>TTL high</td>
<td>Laser ON</td>
</tr>
<tr>
<td>TTL or analog input</td>
<td>open or low</td>
<td>Laser OFF</td>
</tr>
<tr>
<td>Analog control voltage</td>
<td>P_{min} to P_{max}</td>
<td>0 ... 2.5 V</td>
</tr>
<tr>
<td>Input resistance</td>
<td>9k</td>
<td>9k</td>
</tr>
<tr>
<td>Cable type</td>
<td>6xAWG 26CUL 0.14 mm²</td>
<td>6xAWG 26CUL 0.14 mm²</td>
</tr>
</tbody>
</table>

Pin-out for electronics CS / PS

Circular connector Lumberg SV70 (IEC-60130-9) for power supply and external modulation (pin U_{mod}) and RS232 interface. Cable shielding and casing are connected and are galvanically decoupled from the laser diode and from the electronics.

<table>
<thead>
<tr>
<th>Pinout CS/PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Conn.</td>
</tr>
<tr>
<td>black 1 GND</td>
</tr>
<tr>
<td>red 2 +5 V</td>
</tr>
<tr>
<td>brown 3 U_{las} analog</td>
</tr>
<tr>
<td>orange 4 U_{max} TTL</td>
</tr>
<tr>
<td>yellow 5 RS232Tx</td>
</tr>
<tr>
<td>green 6 RS232 Rx</td>
</tr>
<tr>
<td>7 n.c.</td>
</tr>
<tr>
<td>shield case</td>
</tr>
</tbody>
</table>

Attachment: Switchbox SBS070701-USB

The switchbox is the interface between the power supply and laser diode beam source.

Switchbox SBS 070701-USB for laser diode beam sources with 5 V power supply and RS232 interface (electronics type CS/PS).

Recommended power supply module PS051007E.

Features:
- Suitable for lasers with RS232 interface
- Mini USB 2.0 connection for laser control and reading out of laser data, e.g. hours of operation
- Reverse voltage protection
- Dimensions: L 56 mm x H 30 mm x D 60 mm

For more information please see page 85
Low noise laser diode beam sources

Physics Fundamentals  Low Noise Laser Diode Modules LNC-Series

Low noise laser diode modules in comparison with standard laser diode beam sources

The notable benefits of RF-modulated laser diodes become more evident when compared with the undesirable characteristics of a standard laser diode. The noise, spectrum, laser speckle as well as interference behavior are all improved for the low noise laser diode module, Fig. 4, in comparison with a standard laser diode, Fig. 5.

Low Noise

In Fig. 4A and 5A, the noise profiles (bandwidth of 1 MHz, period of 60 minutes) of the two diodes are compared. Peak noise values exceed 1 % for a standard laser diode while the RF-modulation of the low noise laser diode module reduces noise to <0.1 %, a value close to the limit of detection.

No Mode Hopping

Without RF-modulation, the laser jumps stochastically between several emitting modes (Fig. 5B, different colors). Upon RF-modulation, numerous modes are excited within the gain profile of the resonator (Fig. 4B), producing a broad spectrum with about 1.5 nm FWHM (full-width at half-maximum).

Reduced Laser Speckle

The corresponding laser speckle behavior, a frequent problem in optical metrology, is shown in Fig. 4C and 5C. Speckle arises from multiple interference, e.g. diffuse reflection of laser radiation on optically rough surfaces (> λ/4). The speckle contrast and size generally depends on the spot size and the size of the aperture of the optics as well as the measurement geometry.

For thicker laser lines and larger laser spots when using a fully coherent laser source, the laser speckle contrast is 1 and there are areas of zero intensity within a laser spot. The emission from multiple laser modes results in the coherence length of a low noise laser diode being reduced, to <300 µm, and the speckle contrast and size are also less (compare Fig. 4C with Fig. 5C). This benefit is less relevant for thinner laser lines and smaller laser spots.

Less Interference

Another effect of a reduced coherence length can be observed in Fig. 4D and 5D. The recording of a collimated laser beam reveals a disturbing interference pattern when using a standard laser diode (Fig. 5D), as a result of internal reflection within the protective glass window of the detector in a CCD area scan camera.

Since the coherence length of a low noise laser diode module is less than the thickness of the glass then the interference is eliminated (Fig. 5D).

Low noise laser diode modules

- Low noise laser module (<0.1% RMS, bandwidth 1 MHz)
- Reduced coherence
- Mode hopping free laser operation
- Internal RF-modulation

For details of the low noise laser diode module LNC-Series, see page 63f.

Low noise laser diode beam sources

Conventional single-mode laser diodes are semiconductor lasers and usually operate on one favored longitudinal mode. However, the semiconductor laser material exhibits a temperature dependency, which alters the gain profile and refractive index so that the diode jumps between different longitudinal modes. This mode hopping causes the output wavelength to jump rapidly by a few picometers. For single-mode diodes that are not stabilized, the output power can change erratically by as much as 3%.

The undesirable features of power noise and mode hopping are eliminated in the low noise laser diode module LNC-series (p. 49) by modulating the current of the laser diodes at a frequency around 0.3 GHz. This RF-modulation excites numerous longitudinal modes of emission while simultaneously lowering signal noise significantly, to <0.1 % RMS.

This induced broadening of the spectrum, in a controlled and stable way, has the added advantage of considerably reducing the coherence length of the laser beam which, in turn, reduces laser speckle contrast and prevents interference patterns.
A standard laser diode module produces a laser spot with speckle. Note that speckle contrast and size generally depend on factors such as spot size and the aperture of the optics.

The laser spot recorded directly using a camera sensor, with its protection window generating a disturbing pattern of interference.

Power noise from a laser diode module. Mode hopping increases the power noise.

Mode hopping: temporal jumps between modes. The short-term coherence of individual modes is $\gtrsim 1\,\text{m}$, but effective coherence length is smaller.

A standard laser diode module produces a laser spot with speckle. Note that speckle contrast and size generally depend on factors such as spot size and the aperture of the optics.

Reduced laser speckle

Intensity distribution of a laser spot at a camera sensor. No interference patterns, despite the camera sensor protection window.

Variable noise

Broad stable spectrum

Low speckle contrast due to reduced coherence length. Note that speckle contrast and size generally depend on factors such as spot size and the aperture of the optics.

Reduced laser speckle

Low noise

The RF-modulation results in a constant mean laser power. Power noise $<0.1\%$ RMS ($<1\text{MHz}$).

Broadened spectrum ($\sim 1.5\,\text{nm FWHM}$) with reduced coherence length ($\sim 0.3\,\text{mm}$) as a result of using RF-modulation.

Shifting narrow Spectrum

Low noise, spectral broadening, reduced laser speckle and less interference can constrain the optical resolution.

High noise, mode hopping, laser speckle and unwanted interference can constrain the optical resolution.