PHYSICS

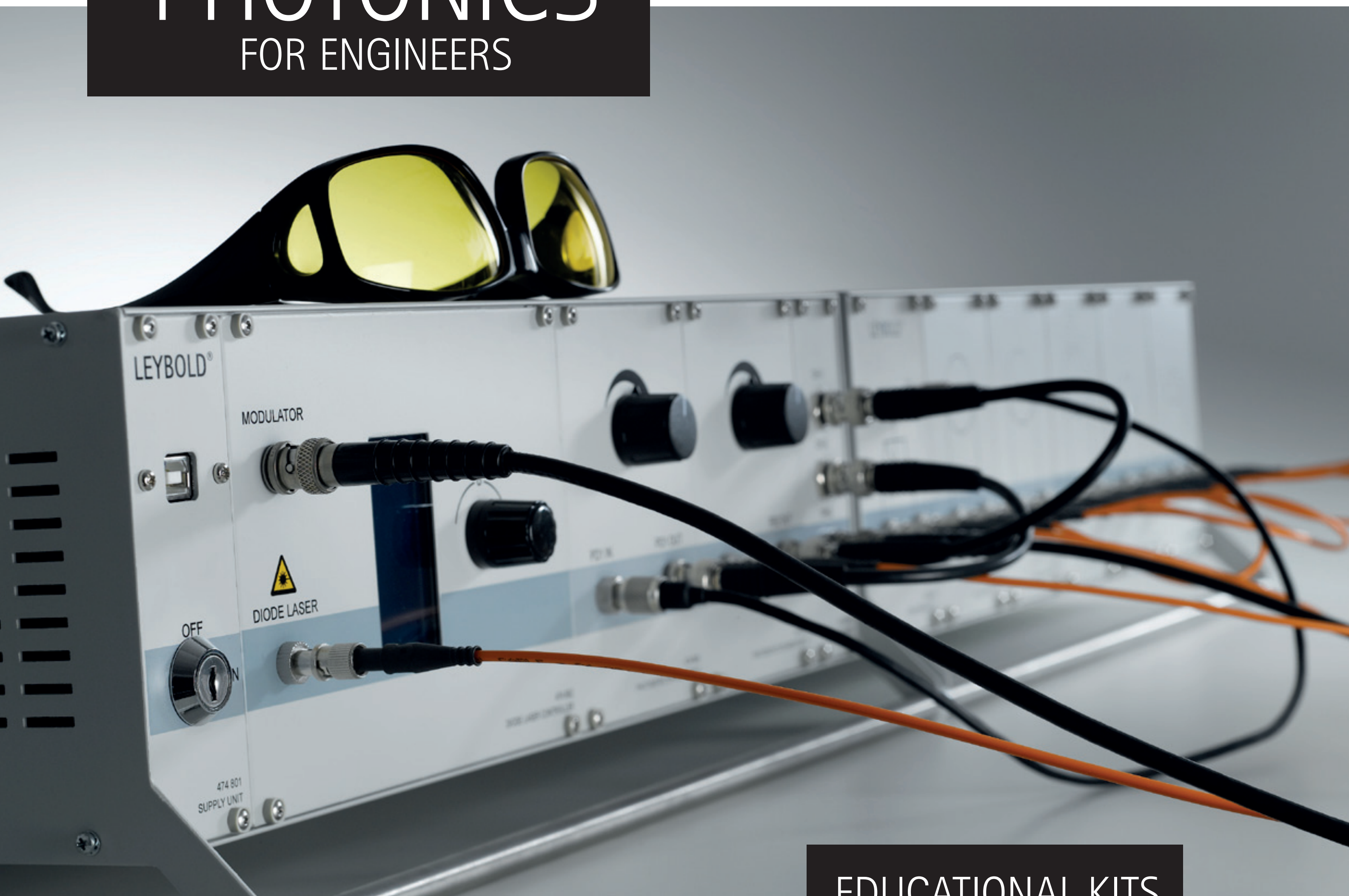
CHEMISTRY BIOLOGY

ENGINEERING

LD DIDACTIC

PHOTONICS

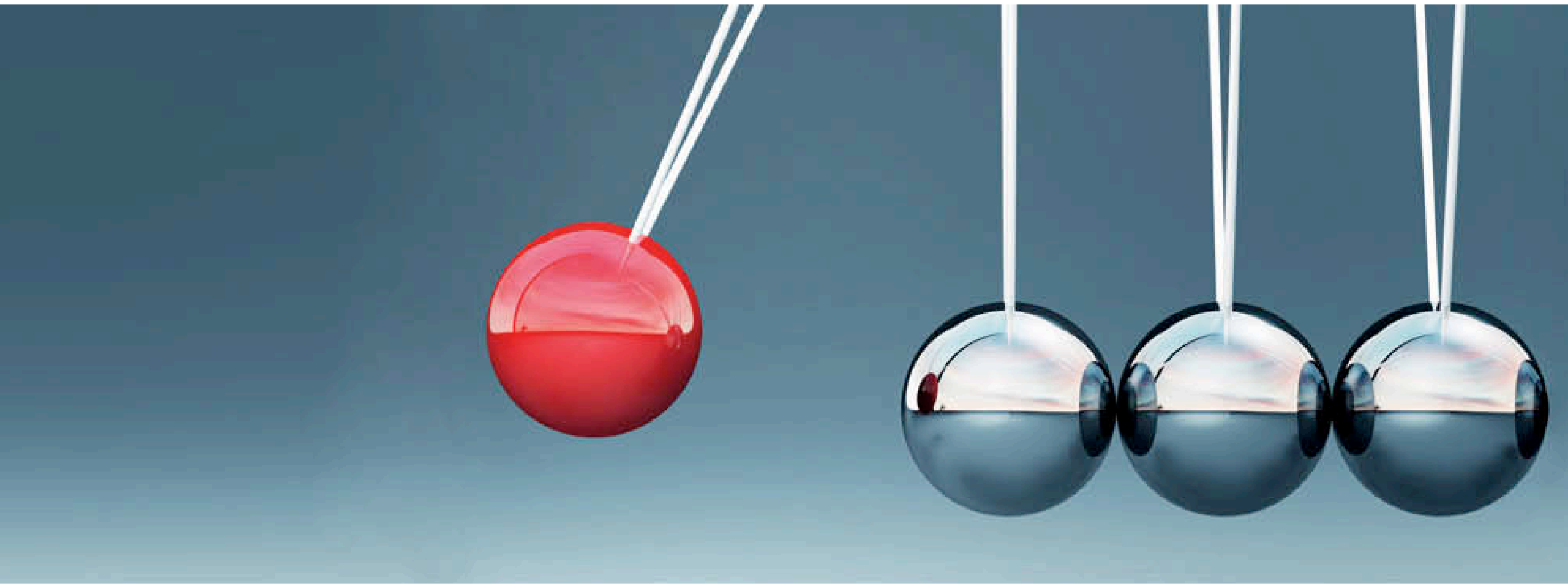
FOR ENGINEERS



EDUCATIONAL KITS

LEYBOLD®

PHOTONICS EXPERIMENTS
FOR ENGINEERS



The science of photonics covers all technical applications of light including generation, emission, transmission, modulation, signal processing, switching, amplification, detection and sensing.

This catalogue presents the LEYBOLD range of experiments – especially designed for the education of engineers – covering topics from basic optics for fibres up to quite sophisticated set-ups in laser and technical applications.

With the introduction of this new optical rack based module concept (OMC) LD Didactic sets a milestone for modern practise and multimedia oriented experimental systems in Photonics education.

The OMC concept provides a variety of photonic and electronic plug-in modules which are inserted into standard 19" base housings.
The ingenious OMC connects and merges Photonics and Electronics and serves the more application oriented education for engineers.

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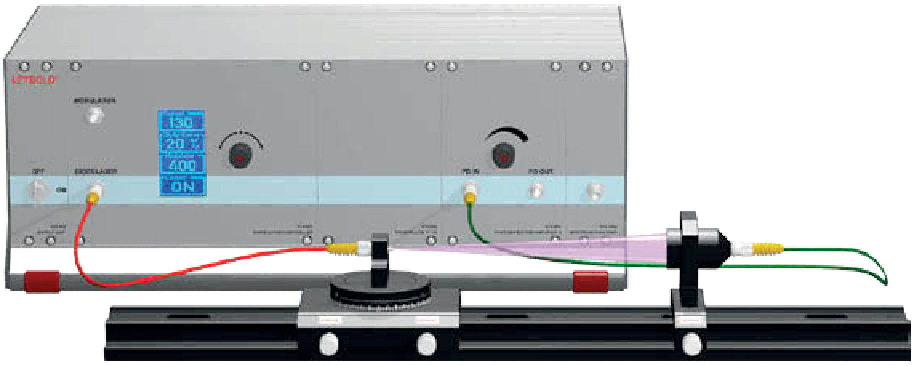
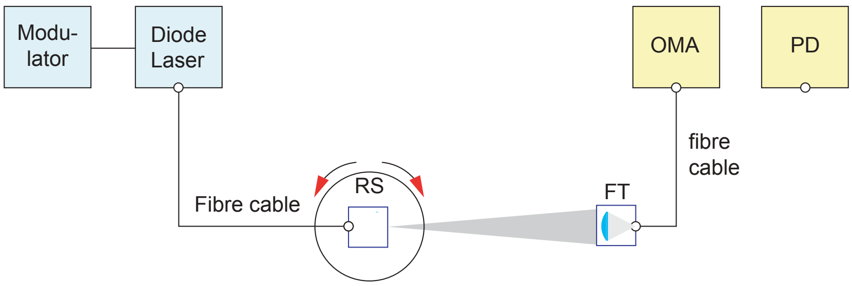
E5.2.7 LASER BASICS

E5.2.7.1 FIBRE COUPLED DIODE LASER

- ✓ Principle of Diode Laser
- ✓ Beam Collimation
- ✓ "Fibre Pig Tail"
- ✓ Output Power
- ✓ Beam Properties
- ✓ Spatial Beam Distribution



Principle of operation



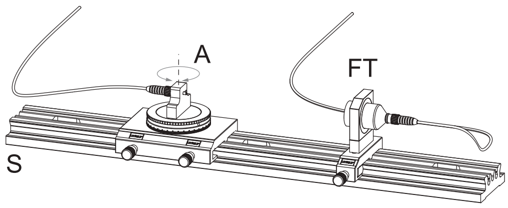
Diode lasers differ from most "classical" lasers in two distinct ways:
First they do not posses an inherently defined wavelength. Instead of two defined energy levels, the lasing transition occurs between two energy bands. Further, the pn junction defines the lasing volume, instead of the resonator in a classical laser. The experiment introduces the laser diode and investigates the variation of the emitted laser wavelength versus temperature and current.
The diode laser is mounted inside the slot-in module and provides an optical fibre output which terminates on the front panel of the slot-in module. By means of a fibre patch cable, it is connected to a rotational stage (RS) which allows the rotation perpendicular to the beam propagation to measure the spatial distribution of the emitted laser light. Via a second fibre patch cable, the detected light is guided to the photodetector module or to the optical spectrum analyser. The integrated frequency modulator is used to study the modulation capabilities of the laser diode with respect to its characteristic curve. Furthermore, it is used to modulate the laser diodwe with a rectangular signal in order to eliminate disturbing environmental light enhancing the sensitivity of the angle resolved intensity distribution of the used fibre patch cable.

Examples of investigation and measurement

General setup

The set-up consists of a digital slot-in module with a 40 mW pig-tailed laser diode and integrated Peltier cooler (3). The change in wavelength by varying the temperature of the laser diode is measured by means of an optical spectrum analyser (5). The typical shift is approx. 0.25 nm per °C. The temperature range of the diode laser controller can be varied from 10 to 40° C, which results in a shift of 7.5 nm. The relative laser power is measured with a photodetector integrated into (4). The supply unit (2) provides the safety key switch and the USB connection for computer control.
The use of an oscilloscope is recommended. To prevent the influence of other light sources the measurements are carried out with modulated diode laser light.

The diode laser is connected via the fibre patch cable to the fibre holder of the module A. It can be turned horizontally and the beam intensity distribution is measured. The angle dependent intensity is collected by the fibre telescope (FT) and transferred optically to the photodetector amplifier. The output of the amplifier is measured either with a digital voltmeter or by the optional oscilloscope. The optical rail (S) provides a ruler with millimetre ticks and can be used to verify the $1/r^2$ law.



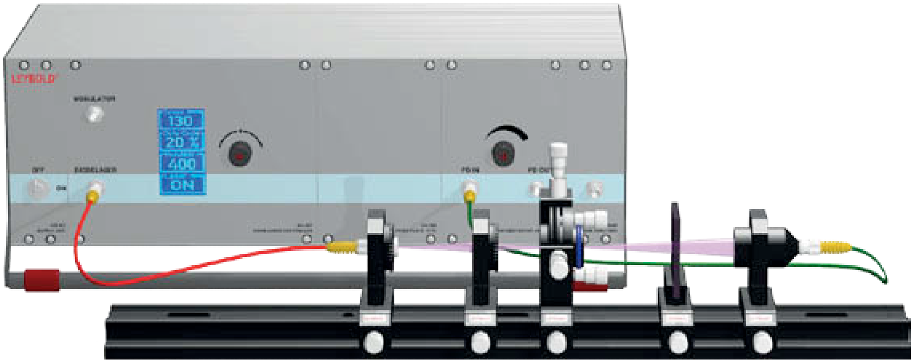
E5.2.7.1 Fibre Coupled Diode Laser consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 40 mW TEC
4	1	Photodetector Module Si Optical
5	1	Optical Spectrum Analyser VIS, USB
6	1	Optical Rail 500 mm
7	1	Rotational Stage with Fibre Holder

Item	Qty	Description
8	1	Mounting Plate 25 with Carrier
9	1	ST Fibre Telescope VIS
10	2	Fibre Patch Cable MM, 1 m
		Options:
	1	USB Oscilloscope 40 MHz, USB
	1	Control Software TACOON
	1	Spectrum Analysis Software

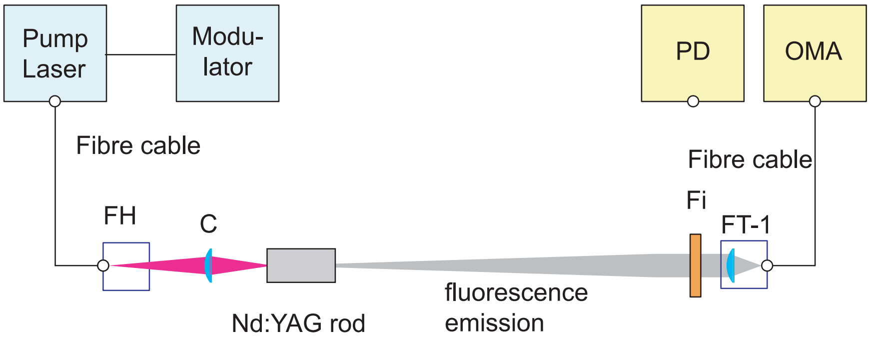
E5.2.7.2 EMISSION AND ABSORPTION

- ✓ Principle of Diode Laser
- ✓ Pig Tailed Diode Laser
- ✓ Temperature Control
- ✓ Nd:YAG Crystal
- ✓ Absorption Spectrum
- ✓ Emission Spectrum
- ✓ Spectrum Analyser
- ✓ Computer Control



Principle of operation

A 40 mW fibre pig-tailed laser diode with a thermoelectric cooler is used as a pump light source. The controller and the laser diode is accommodated inside a slot-in module. The diode laser radiation is transferred by means of a fibre patch cable to the fibre holder (FH). The lens (C) focuses the radiation into the Nd:YAG rod. The generated emission passes the filter (Fi) to remove residual pump power and is transferred via the fibre telescope (FT1) either to the photodetector module for measurements in the time domain or to the spectrum analyser for the spectral analysis.

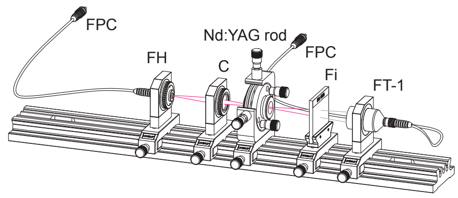


Examples of investigation and measurement

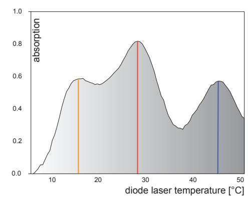
General setup

The temperature and current stabilising of the laser diode to vary the parameters of the laser diode is done by the module (3). By means of the integrated frequency generator, the output power of the laser diode can be modulated. The measurements and settings can be performed either in local mode or through computer control via the USB connection of the supply unit (2) built into base housing (1). The relative laser power as well as created fluorescence light is measured with a photodetector integrated into the module (4). The module (5) provides a fibre coupled spectrum analyser with a USB bus allowing the monitoring and recording of the emission of the diode laser.

The light of the diode laser is guided via the fibre patch cable to the external experiment. It terminates at the fibre holder (FH) where the cable is plugged to the respective mount. The divergent light emerging from the fibre is focused by means of the focusing lens (C) into the Nd:YAG rod. The rod is mounted into an adjustment holder to align the rod with respect to the focus of the diode laser light. The excitation or pumping of the Nd:YAG material causes spectral absorption of the pump light as well as induced and spontaneous emission which is part of the measurements.
A two channel oscilloscope for displaying the time resolved signals is necessary.



In a first set-up the characteristic parameters of the laser diode are measured. The full digitally controller (3) sets and maintains the value for injection current, temperature and modulation frequency of the diode laser. The transmission or absorption spectra of the laser diode radiation is measured by changing the temperature and therewith the emission wavelength. By means of the well known absorption lines the emission wavelength of the laser diode can be determined exactly. Adding the filter RG1000 (Fi) in front of the detector blocks the pump radiation and the fluorescence is measured. The modulation of the diode laser is activated and the timely response displayed on an oscilloscope. From this curve the mean life time of the exited laser state of the Nd:YAG material is measured which inverse value represents the important Einstein coefficient for spontaneous emission.



Absorption Spectra

Fluorescence Decay

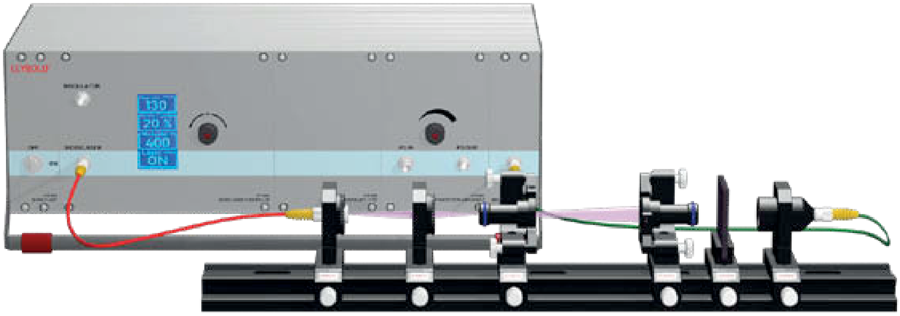
E5.2.7.2 Emission and Absorption consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 40 mW TEC
4	1	Photodetector Module Si Optical
5	1	Optical Spectrum Analyser VIS, USB
6	1	Optical Rail 500 mm
6	3	Mounting Plate 25 with Carrier
7	1	Filter Plate Holder
8	1	Fibre Connector Jacket in C25 Mount

Item	Qty	Description
9		Focusing Lens f=60 mm in C25 Mount
10	1	Nd:YAG Rod in 5 Axes Adjustment Holder
11	1	Coloured Glass Filter RG1000
12	1	ST Fibre Telescope VIS
13	2	Fibre Patch Cable MM, 1 Metre
		Options:
	1	USB Oscilloscope 40 MHz, USB
	1	Control Software TACOON
	1	Spectrum Analysis Software

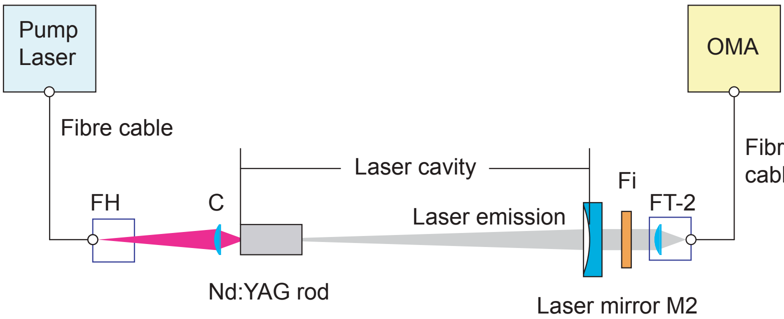
E5.2.7.3 DIODE PUMPED SOLID STATE LASER (DPSSL)

- ✓ Optical Pumping
- ✓ Nd:YAG Crystal
- ✓ Pig-Tailed Diode Laser
- ✓ Absorption Spectrum
- ✓ Emission Spectrum
- ✓ Laser Operation
- ✓ Dynamic Laser Behaviour
- ✓ Computer Control



Principle of operation

The light of the pump laser is transferred via a fibre cable to the fibre holder (FH). The lens (C) focuses the radiation into the Nd:YAG rod. The generated laser emission passes the filter (Fi) and the residual pump light is blocked. The laser emission can be transferred by means of the fibre telescope (FT-2) either to the optical spectrum analyser (OMA) or to the photodetector.
This set-up is ideally suited to demonstrate the fundamental behaviour of a solid state laser system, its excitation process as well as its spectroscopic characteristics.

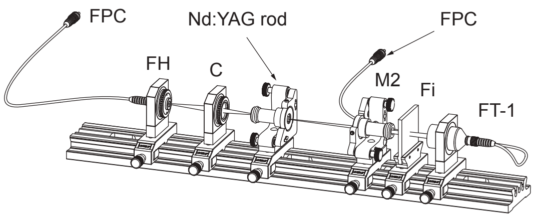


Examples of investigation and measurement

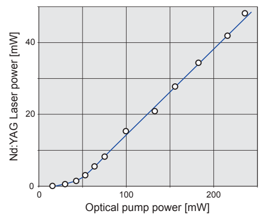
General setup

The set-up consists of a digital slot-in module with a 500 mW pig-tailed laser diode and integrated Peltier cooler (3). The change in wavelength by varying the temperature of the laser diode is measured by means of an optical spectrum analyser (5). The typical shift is approx. 0.25 nm per °C. The temperature range of the diode laser controller can be varied from 10 to 40° C, which results in a shift of 7.5 nm. The relative laser power is measured with a photodetector integrated into (4). The supply unit (2) provides the safety key switch and the USB connection for computer control.

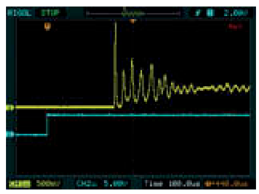
When the laser mirror (M2) is removed, the excitation spectra can be recorded by means of the spectrum analyser(5). By varying the temperature of the laser diode its wavelength will change. This effect can be studied first and then used to obtain the absorption spectrum of the Nd:YAG crystal. By modulating the pump laser, the time resolved emission spectrum allows the measurement of life-time of the excited state and the dynamic behaviour of the Nd:YAG laser. The measurements can be performed either in local mode or through computer control via the USB connection of the base housing.



Adding the second cavity mirror (M2) to the set-up and aligning it properly laser oscillation at the wavelength of 1064 nm is obtained. The optimum laser parameters with respect to pump power and wavelength are ascertained. The laser threshold and efficiency are determined and by modulating the pump laser diode the so called spiking effect is demonstrated. By changing the length of the laser cavity the stability criterion is verified.



Static Laser behaviour



Dynamic behaviour (spiking)

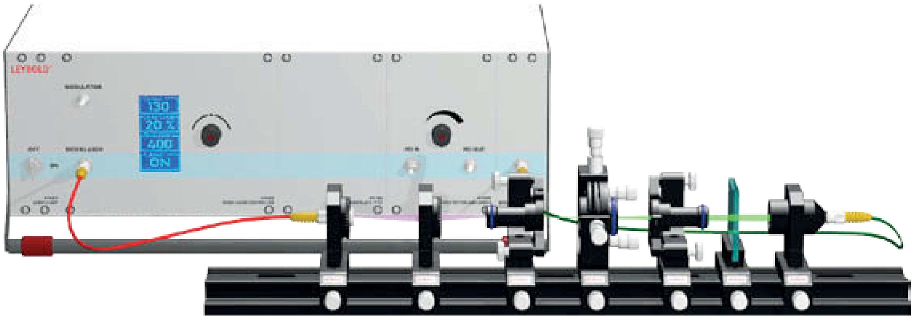
E5.2.7.3 Diode Pumped Solid State Laser (DPSSL) consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 500 mW TEC
4	1	Photodetector Module Si Optical
5	1	Optical Spectrum Analyser VIS, USB
6	1	Optical Rail 500 mm
7	3	Mounting Plate 25 with Carrier
8	1	Fibre Connector Jacket in C25 Mount
9	1	Focusing Lens f=60 mm in C25 Mount
10	1	Mirror Adjustment Holder Left
11	1	Mirror Adjustment Holder Right

Item	Qty	Description
12	1	Nd:YAG Rod 1064 nm, M16 Mount
13	1	Laser Mirror HR 1064, R100, M16 Mount
14	1	Filter Plate Holder
15	1	Coloured Glass Filter RG1000
16	1	ST Fibre Telescope VIS
17	2	Fibre Patch Cable MM, 1 m
		Options:
	1	Laser Mirror T=2% @ 1064, R100, M16 Mount
	1	USB Oscilloscope 40 MHz, USB
	1	Control Software TACOON
	1	Spectrum Analysis Software

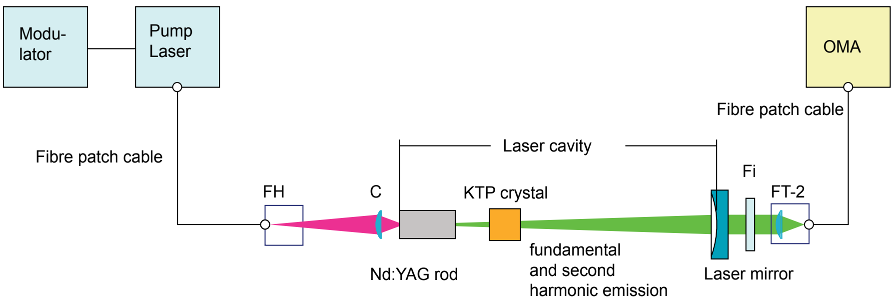
E5.2.7.4 SECOND HARMONIC GENERATION

- ✓ Fibre Coupled Pump Laser
- ✓ Optical Pumping
- ✓ Nd:YAG Laser
- ✓ Frequency Doubling
- ✓ Spectrum Analyser
- ✓ Emission Spectrum
- ✓ Computer Control



Principle of operation

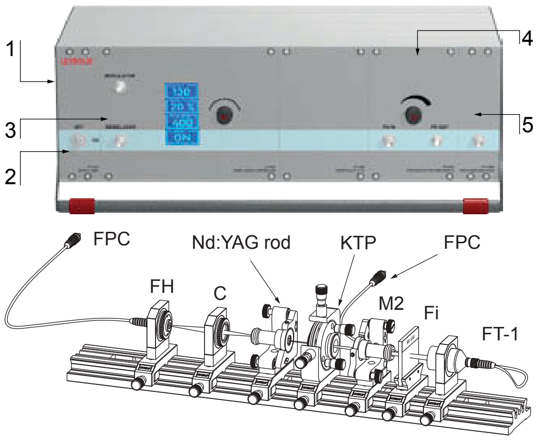
By inserting the KTP crystal inside the cavity immediately second harmonic generation takes place. Green laser light is emitted. The subsequent measurements can be performed either in local mode or through computer control via the USB connection of the base housing. This set-up is ideally suited to demonstrate the fundamental behaviour of a solid state laser system, its excitation process as well as its spectroscopic characteristics. Furthermore, the non-linear optic is impressively introduced by converting invisible laser radiation into visible green radiation.



Examples of investigation and measurement

General setup

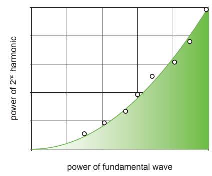
The set-up consists of a digital slot-in module with a 500 mW pig-tailed laser diode and integrated Peltier cooler (3). The change in wavelength by varying the temperature of the laser diode is measured by means of an optical spectrum analyser (5). The typical shift is approx. 0.25 nm per °C. The temperature range of the diode laser controller can be varied from 10 to 40° C, which results in a shift of 7.5 nm. The relative laser power is measured with a photodetector integrated into (4). The supply unit (2) provides the safety key switch and the USB connection for computer control.



The light of the pump diode laser of module (3) is brought via a fibre patch cable to the external set-up. It is kept in the holder (FH). The lens (C) is focusing the light into the Nd:YAG rod. The coating of the left side of the rod and the laser mirror (M2) are forming the optical cavity. The KTP is mounted into an adjustment holder with 5 degrees of alignment freedom to adjust for best phase matching. The created green radiation is guided via a filter (Fi) which blocks the pump as well as laser radiation to the fibre telescope. Via the second fibre patch panel this light is brought either to the photodetector unit (4) or to the spectrum analyser.

The KTP crystal assembly is inserted inside the aligned cavity It can be turned inside the adjustment holder for best phase matching indicated by highest green output power. The intensity of the second harmonic is measured as function of the fundamental power and the injection current of the pump laser respectively. The evaluation of the data will show the expected quadratic behaviour.
Due to the high gain of the Nd:YAG material a lot of transverse modes are generated and are visible due to their wavelength of 532 nm. By placing the adjustable iris into the cavity close to the right mirror the number of transverse modes can be reduced significantly down to pure TEM_{00}. This can be observed on a wall or white sheet of paper when the photodetector is removed.


Second Harmonic Generation



Quadratic relation

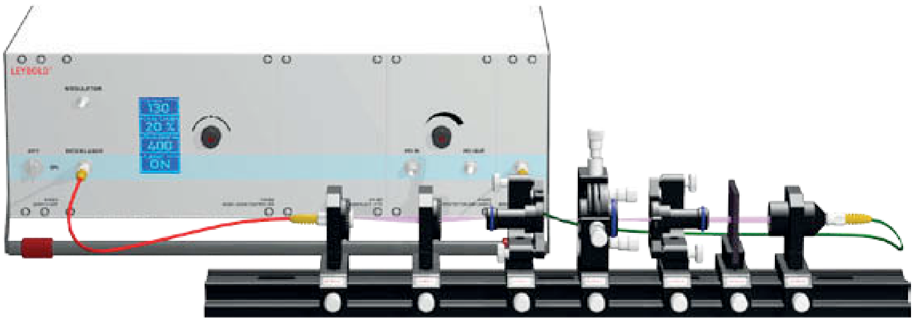
E5.2.7.4 Second Harmonic Generation consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 500 mW TEC
4	1	Photodetector Module Si Optical
5	1	Optical Spectrum Analyser VIS, USB
6	1	Optical Rail 500 mm
7	3	Mounting Plate 25 with Carrier
8	1	Fibre Connector Jacket in C25 Mount
9	1	Focusing Lens f=60 mm in C25 Mount
10	1	Mirror Adjustment Holder Left
11	1	Nd:YAG Rod 1064 nm, M16 Mount
12	1	Mirror Adjustment Holder Right
13	1	Laser Mirror HR 1064, R100, M16 Mount

Item	Qty	Description
14	1	KTP Crystal in 5 Axes Adjustment Holder
15	1	Filter Plate Holder
16	1	Coloured Glass Filter RG39
17	1	Coloured Glass Filter RG1000
18	1	ST Fibre Telescope VIS
19	2	Fibre Patch Cable MM, 1 Metre
		Options:
	1	Adjustable Iris in C25 Mount
	1	Upgrade SHG 1.32 µm to 0.66 µm
	1	USB Oscilloscope 40 MHz, USB
	1	Spectrum Analysis Software
	1	Control Software TACOON

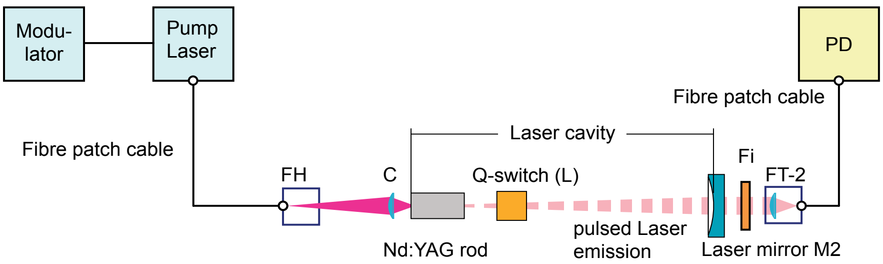
E5.2.7.5 GENERATION OF SHORT PULSES (Q-SWITCH)

- ✓ Fibre Coupled Pump Laser
- ✓ Optical Pumping
- ✓ Nd:YAG Laser
- ✓ Q-switching
- ✓ Pockels Cell
- ✓ Generation of Short Pulses
- ✓ Computer Control



Principle of operation

The basic set-up of the diode pumped Nd:YAG laser is enhanced by the saturable absorber module L which is placed into the laser cavity formed by mirror M1 and M2. The initial absorption prevents the laser oscillation. By increasing induced emission due to the optical pump process the absorption decreases below the threshold of the laser resulting in a giant laser pulse.

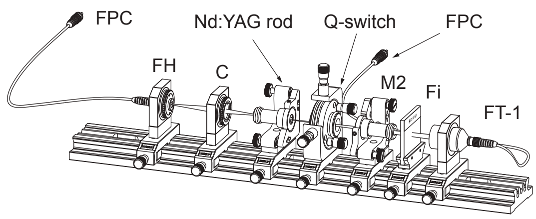


Examples of investigation and measurement

General setup

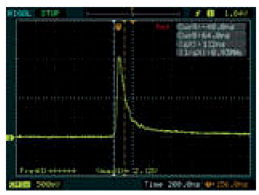
The set-up consists of a digital slot-in module with a 500 mW pig-tailed laser diode and integrated Peltier cooler (3). The change in wavelength by varying the temperature of the laser diode is measured by means of an optical spectrum analyser (5). The typical shift is approx. 0.25 nm per °C. The temperature range of the diode laser controller can be varied from 10 to 40° C, which results in a shift of 7.5 nm. The relative laser power is measured with a photodetector integrated into (4). The supply unit (2) provides the safety key switch and the USB connection for computer control.

The light of the pump diode laser of module (3) is brought via a fibre patch cable to the external set-up. It is kept in the holder (FH). The lens (C) is focusing the light into the Nd:YAG rod. The coating of the left side of the rod and the laser mirror (M2) are forming the optical cavity. The passive q-switch is mounted into an adjustment holder with 5 degrees of alignment freedom to adjust for best operation. The created pulsed radiation is guided via a filter (Fi) which blocks the pump radiation to the fibre telescope. Via the second fibre patch panel this light is brought either to the photodetector unit (4) or to the spectrum analyser.



By inserting the active or passive q-switch inside cavity the laser starts to operate in pulsed mode. The repetition rate depends on the quality of the cavity as well as on the pump power and lies in the range of a couple kHz. This rate as well as the pulse width are measured and recorded.

Passive Q-Switch



Single Q-Switch Pulse

E5.2.7.5 Generation of short Pulses (Q-switch) consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 500 mW TEC
4	1	Photodetector Module Si Optical
5	1	Optical Spectrum Analyser VIS, USB
6	1	Optical Rail 500 mm
7	3	Mounting Plate 25 with Carrier
8	1	Fibre Connector Jacket in C25 Mount
9	1	Focusing Lens f=60 mm in C25 Mount
10	1	Mirror Adjustment Holder Left
11	1	Nd:YAG Rod 1064 nm, M16 Mount
12	1	Mirror Adjustment Holder Right
13	1	Laser Mirror HR 1064, R100, M16 Mount

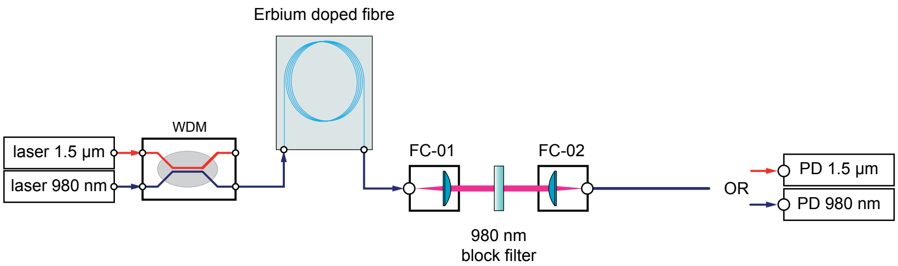
Item	Qty	Description
14	1	Passive Q-Switch in 5 Axes Adjustment Holder
15	1	Filter Plate Holder
17	1	Coloured Glass Filter RG1000
17	1	ST Fibre Telescope VIS
18	2	Fibre Patch Cable MM, 1 Metre
		Options:
	1	Laser Mirror T=2% @ 1064, R100, M16 Mount
	1	Active Q-Switch with Pockels Cell
	1	USB Oscilloscope 40 MHz, USB
	1	Spectrum Analysis Software
	1	Control Software TACOON

E5.2.7.6 ERBIUM DOPED FIBRE AMPLIFIER (EDFA)

- ✓ Fibre Coupled Diode Laser
- ✓ 980 nm and 1.550 nm
- ✓ Optical Pumping
- ✓ Optical Gain
- ✓ Fibre Laser
- ✓ Computer Control

Principle of operation

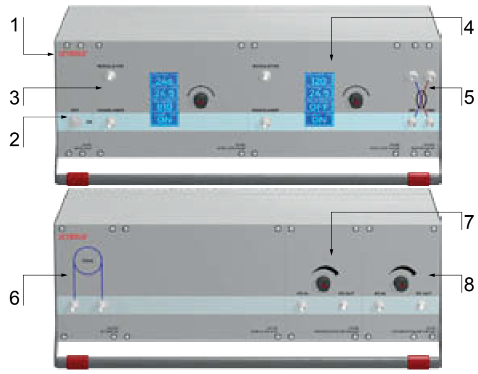
An Erbium doped fibre is optically pumped by a laser diode emitting at a wavelength of 980 nm. Due to the pump process a population inversion is created between two states with an energy difference corresponding to a wavelength around 1.5 µm. Signals having this wavelength will be amplified when passing the fibre. Such a signal is generated by a laser diode emitting a radiation of 1.5 µm. For combining both emissions a WDM is used.



Examples of investigation and measurement

General setup

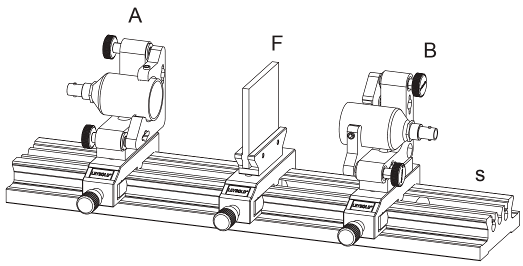
The individual modules are accommodated by the SMC base unit (1) with a capacity for 84 TE (1 TE = 5.08 mm) according to the standard for 19" racks. The switch panel (2) provides a safety key switch and the connections for the 12 V supply of the modules. Each diode laser module (3 and 4) contains a temperature controlled fibre coupled diode laser. The control of injection current, temperature, modulation and display is done by a microprocessor. The connection of the diode laser to the WDM (5) is accomplished by the provided fibre patch cables. The modules (7 and 8) are fibre coupled dual photodetector unit. One photodetector is a Si PIN type for the detection of the 980 nm radiation and the other one a GaAs type for the detection of the 1.5 µm radiation. The gain of each channel can be set by means of a one knob on the respective front panel. The analogue output of each channel is available at BNC connectors at the front panel.



Beam handling module

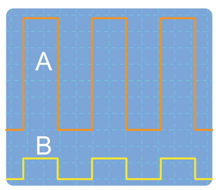
To separate the pump radiation of 980 nm and the signal radiation of 1.5 µm the beam handling module is used. It consists of two precise adjustment holder (A and B) and a filter plate (F) which blocks the pump radiation. This unit is used to make the radiation accessible travels inside the fibre. To demonstrate and measure the spiking of the fibre laser the pump radiation needs to be blocked.

The output of the Erbium doped fibre (6) is connected to the fibre adapter of the adjustment holder (A). A lens inside the fibre adapter collimates the light to an almost parallel beam. The adjustment holder (B) has the same fibre adapter and will be connected to the photodetector amplifier by means of a fibre patch cable.

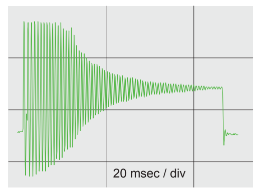


Optical amplification

Once the pump radiation has been launched to the fibre via the WDM, the signal radiation needs to be fed to the erbium doped fibre as well. Once the signal radiation passes the fibre, the pump radiation (B) is modulated, the signal radiation (A) not. As soon as amplification takes place the amplitude of the signal radiation is measured for different pump power and signal power levels. By increasing the pump power the amplifier can be turned into a laser. Due to the high gain laser operation is achieved even with the uncoated fibre faces.



Optical amplification measured with an oscilloscope



Spiking of the fibre laser operating at 1.5 µm

E5.2.7.6 Erbium Doped Fibre amplifier (EDFA) consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 980 nm 300 mW TEC
4	1	Laser Diode Module CW 1550 nm 10 mW TEC
5	1	Photodetector Module Si Optical
6	1	Photodetector Module InGaAs Optical
7	1	WDM 980 / 1550 nm SM
8	1	Erbium doped Fibre 8 m
9	1	Optical Rail 300 mm
10	1	Mirror Adjustment Holder Left
11	1	Mirror Adjustment Holder Right
12	1	Filter Plate Holder

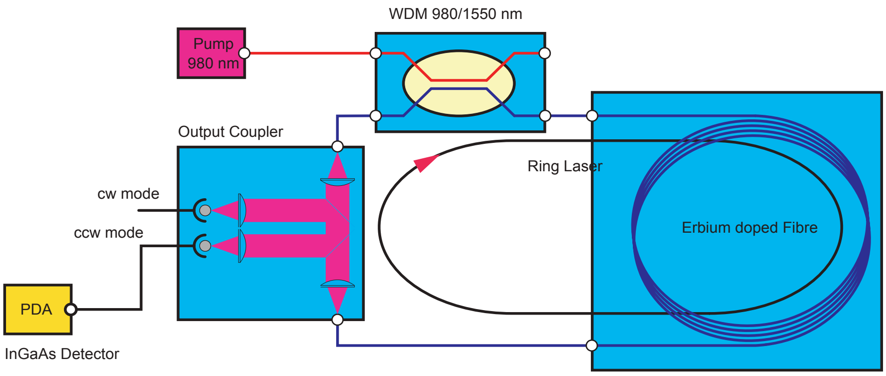
Item	Qty	Description
13	1	Coloured Glass Filter RG1000
14	2	ST Fibre Telescope NIR
15	3	Fibre Patch Cable SM, 0.5 Metre
16	2	Fibre Patch Cable SM, 1 Metre
		Options:
	1	Optical Spectrum Analyser NIR, USB
	1	USB Oscilloscope 40 MHz, USB
	1	Spectrum Analysis Software
	1	Control Software TACOON

E5.2.7.7 ERBIUM DOPED FIBRE LASER

- ✓ Fibre Coupled Diode Laser
- ✓ Optical Pumping
- ✓ ASE Spectrum
- ✓ Optical Gain
- ✓ Spectrum Analyser
- ✓ Emission Spectrum
- ✓ Fibre Laser
- ✓ Computer Control

Principle of operation

An Erbium doped fibre is used as active material. To form a ring laser a WDM is used to couple the pump light into the fibre and to close the ring structure. The ring is opened where thin glass plates couple a small fraction of the clockwise (cw) and counter clockwise (ccw) laser modes. By means of a SiPIN photodetector the radiation of the pump laser of 980 nm is detected and a InGaAs photodiode is used for the laser oscillation of 1.5 µm.

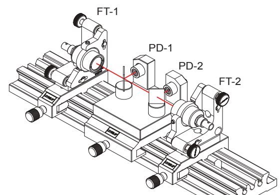


Examples of investigation and measurement

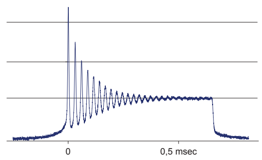
General setup

The individual modules are accommodated by the SMC base unit (1) with a capacity for 84 TE (1 TE = 5.08 mm) according to the standard for 19" racks. The switch panel (2) provides a safety key switch and the connections for the 12 V supply of the modules. The diode laser module (3) contains a temperature controlled fibre coupled diode laser emitting 300 mW at a wavelength of 980 nm. The control of injection current, temperature, modulation and display is done by a microprocessor. The connection of the diode laser to the WDM (4) is accomplished by the provided fibre patch cables. The module (6) is a photodetector amplifier unit. The gain can be set by means of a one knob on the respective front panel. The analogue output of each channel is available at BNC connectors at the front panel.

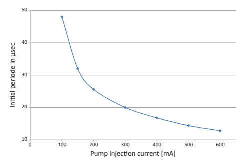
The output coupling assembly is placed onto the rail. Due to the high gain the adjustment is not critical and laser oscillation is obtained once the fibre collimator are aligned to each other. The alignment is monitored on an oscilloscope using the signal of the photodetector amplifier (6). The assembly is equipped with two photodetectors, PD-1 and PD-2. By means of a SiPIN photodetector the radiation of the pump laser of 980 nm is detected and a InGaAs photodiode is used for the laser oscillation of 1.5 µm. Two thin glass plates couple a small fraction of the ring laser emission to the respective photodetector. Without using the assembly the set-up can also be operated as linear laser.



Once Laser oscillation has been obtained, a variety of measurements can be performed. Static measurements yield the output power versus the pump power from which the slope efficiency and laser threshold is determined. One example for the dynamic be-haviour is shown on the right - the initial spiking - which is very dominant due to the long life time of the excited state in the range of some milliseconds.



Spiking of the fibre laser



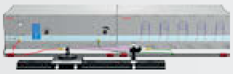
Spiking periodicity

E5.2.7.7 Erbium Doped Fibre Laser consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 980 nm 300 mW TEC
4	1	Photodetector Module InGaAs Optical
5	1	WDM 980 / 1550 nm SM
6	1	Erbium doped Fibre 8 m
7	1	Optical Rail 300 mm
8	1	Mirror Adjustment Holder Left
9	1	Mirror Adjustment Holder Right
10	2	ST Fibre Telescope NIR

Item	Qty	Description
11	1	Ringlaser Output Coupler
12	2	Fibre Patch Cable SM, 0.5 m
13	2	Fibre Patch Cable SM, 1 m
		Options:
	1	Optical Spectrum Analyser NIR, USB
	1	USB Oscilloscope 40 MHz, USB
	1	Spectrum Analysis Software
	1	Control Software TACOON

E5.2.8 Fibre Optics

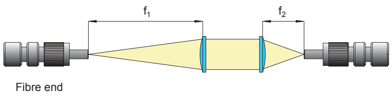


E5.2.8.1 FIBRE OPTICAL COMPONENTS

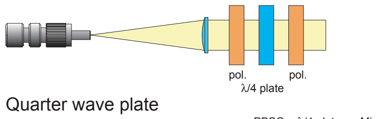
- ✓ Optics for Fibres
- ✓ Focusing Lenses
- ✓ Beam Expander
- ✓ Beam Splitting Cubes
- ✓ Quarter Wave Plates
- ✓ Polariser
- ✓ Optical Diode

Principle of operation

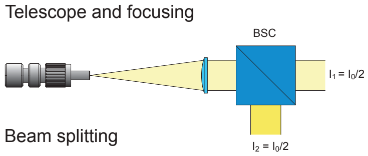
Optical glass fibres are ideal transportation media for light. Not only telecommunications benefit from this fact; a lot of other applications also apply this idea. At the beginning and at the end of transportation via the fibre, the light needs to be conditioned. This is done through elements we know from classical optics. Besides others, the following techniques are commonly applied.



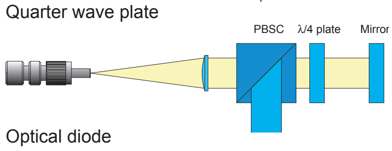
Telescope and focusing



Quarter wave plate



Beam splitting



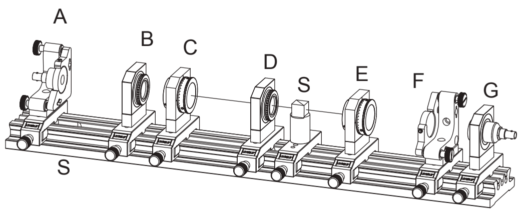
Optical diode

Examples of investigation and measurement

General setup

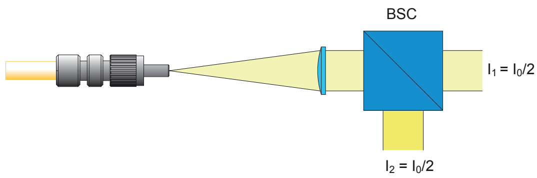
Optical glass fibres are ideal transportation media for light. Not only telecommunications benefit from this fact; a lot of other applications also apply this idea. At the beginning and at the end of transportation via the fibre, the light needs to be conditioned. This is done through elements we know from classical optics. As fibre coupled probe a diode laser emitting 40 mW is used (3). The injection current, temperature and modulation frequency are controlled either by means of the one knob interaction or by a PC tablet connected to the USB hub of the supply unit (3). A 1000 m long optical fibre (4) serves as test link. Optical signals are detected by the photodetector of the unit (5).

The diode laser is connected to the external components mounted on an optical rail (S) via the adjustment holder A. The module B and D are containing focusing lenses to setup a fibre telescope with subsequent back focusing to the fibre. Module C and E are mounting plates with rotator to accommodate either polariser or the quarter wave plate. The module S provides a beam splitter cube. A mirror for defined back reflections is mounted into a mirror adjustment holder (F). The module G is used to guide the laser light to the photodetector unit (5).



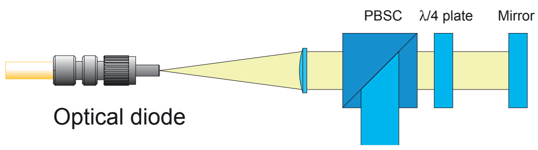
Beam splitting

For this task, either beam splitter plates or cubes are used. Beam splitter cubes (BSC) have the advantage that no beam displacement occurs, as is the case when using plates. The incident light is split into two fractions. The splitting ratio depends on the coating design of the beam splitting cube. Commonly, this ratio is 1:1. This means that both beams have half the incident intensity. Furthermore, the direction of one beam is changed by 90° with respect to the other.



Optical diode

The combination of a quarter wave plate and a polarising beam splitter cube can be used as a so-called optical diode. This means that light can pass only in one direction via this combination. To verify this within the experiment, a mirror is used to change the direction of the light. If the quarter wave plate is turned into the position where it changes the polarisation direction of the back coming light by 90°, then it will be reflected at the polarising beam splitter cube.



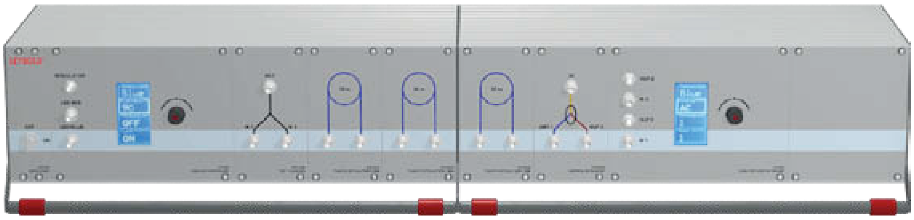
E5.2.8.1 Fibre Optical Components consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 40 mW TEC
4	1	Multimode Fibre 50/125, 1000 m
5	1	Photodetector Module Si Optical
6	1	Optical Rail 500 mm
7	3	Mounting Plate 25 with Carrier
8	1	Focusing Lens f=40 mm in C25 Mount
9	1	Focusing Lens f=60 mm in C25 Mount

Item	Qty	Description
10	2	Mounting Plate 25 with Rotator
11	1	Quarter Wave Plate in C25 Mount
12	2	Polariser in C25 Mount
13	1	Polarising Beam Splitter Cube Assembly
14	1	Mirror Adjustment Holder Left
15	1	Mirror Adjustment Holder Right
16	1	Front Surface Mirror 25.4 mm
17	2	ST Fibre Telescope VIS
19	3	Fibre Patch Cable MM, 1 m

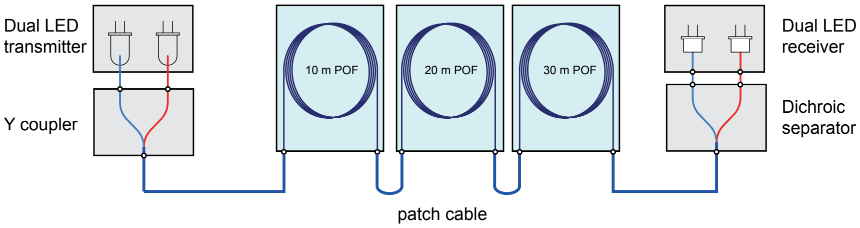
E5.2.8.2 PLASTIC FIBRE OPTICS

- ✓ LED Transmitter
- ✓ Si Photo Detector Receiver
- ✓ Dichroic Separator
- ✓ LED Modulation
- ✓ Y Coupler
- ✓ Data Transmission
- ✓ Losses in Plastic Fibre



Principle of operation

The goal of this experiment is to introduce the capabilities of optical plastic fibres demonstrated with a two channel transmission via one fibre. A plastic fibre is an equivalent to optical multi-mode glass fibres. Whereas glass fibres are used for long distance and high speed data transmission, plastic fibres are commonly used for local area networks for data and signal transmission.

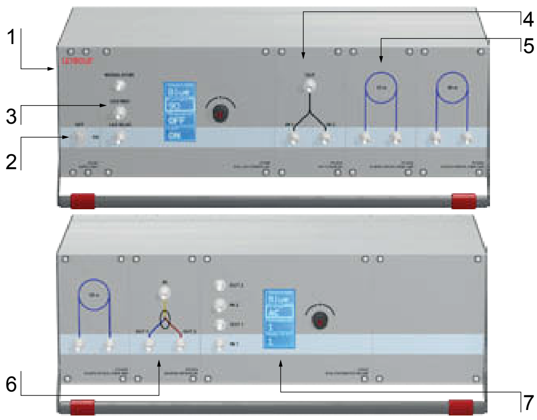


The transmission losses with 12 dB / 50 m of these fibres are significantly higher than those of the glass fibres. A lot of effort is undertaken to remove this disadvantage, since the manufacturing and installation costs of plastic fibres are comparably low. For signal transfer at short distances, optical plastic fibres play an important role. Especially in difficult environments, for example, in high voltage power stations, signal transfer via light and plastic fibre can be performed almost free of noise. The light transfer in all plastic optical fibres (POF) is achieved using a plastic core which is coated with a material to obtain a step index profile. Typical diameters are 1 mm for the core, which simplifies the coupling of light compared to glass fibres significantly. Also the preparation process, e.g. the cutting of the fibre can be done with a simple cutter blade instead of using special cleaving tools as in the case for glass fibres.

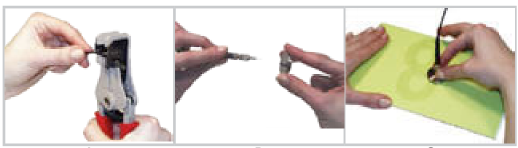
Examples of investigation and measurement

General setup

Two independent LED (3), one emitting in the blue and the other one in the red spectral range are attached to the input of a Y - coupler (4) in such a way that both emissions are coupled into one optical fibre. This arrangement is built into one housing (1) having F-SMA fibre connectors. The dual channel transmitter (3) allows the individual control of injection current and modulation of each LED. The aim of this measurement is the characterization of the LED, demonstration of a WDM (wavelength division multiplexing) and WDDM (wavelength division de-multiplexing).
The output of the selected fibre (5) is measured for the provided three different length of the plastic optical fibre. From the recorded values the attenuation of the individual fibre is determined. In addition two or three fibres can be coupled together by means of the provided F-SMA fibre patch cable and also the losses of the connectors determined. In additional measurements the crosstalk of the setup is determined and the component causing the crosstalk is identified.



The experimental kit provides all tools and materials to train the preparation of the plastic optical fibre like cutting, stripping (A), assembling the F-SMA connector (B) and polishing support as well as polishing (C). For the polishing fine grinding and polishing paper are provided. A comprehensive explanation on professional grinding and polishing of plastic optical fibre is given inside the manual which comes along with the kit.



A B C

E5.2.8.2 Plastic Fibre Optics consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Dual LED Transmitter, Blue, Red POF Coupler
4	1	Plastic Optical Y Coupler
5	1	Plastic Optical Fibre Module 10 m
6	1	Plastic Optical Fibre Module 20 m
7	1	Plastic Optical Fibre Module 30 m
8	1	POF Dichroic Separator
9	1	Dual Photodetector Amplifier, POF Coupler

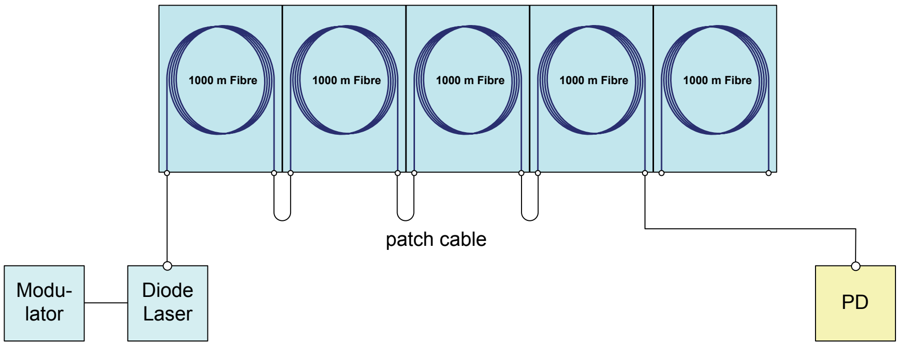
Item	Qty	Description
10	6	POF Patch Cable 0.5 m
11	2	POF Patch Cable 1 m
12	1	Tool Set for connectorizing POF

E5.2.8.3 GLASS FIBRE OPTICS

- ✓ Guiding of Light in Fibres
- ✓ Multimode Fibre
- ✓ Single Mode Fibre
- ✓ Characterization of Fibres
- ✓ Fibre Coupled Laser Diode
- ✓ Fibre Coupled Photo Detectors
- ✓ Speed of Light Measurement
- ✓ Communication via Fibres

Principle of operation

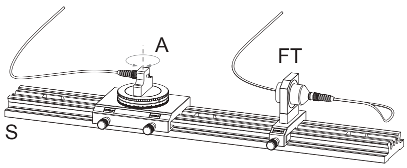
The field of fibre optics is still expanding and is of high common interest. Therefore, this experiment is a valuable contribution for students entering this technology. The tremendous success of optical fibre communication, combined with high mass production, makes it possible to make use of sophisticated components even for single mode devices and fibres. Consequently, this experiment makes comprehensive approach to commercial parts completely removing difficult alignment tasks. Within this experiment, no alignment is required; all connections are done with fibre patch cables.



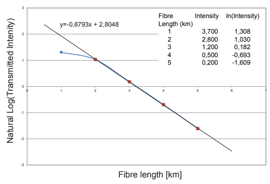
Examples of investigation and measurement

General setup

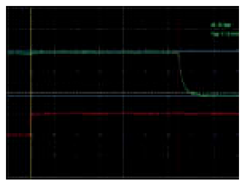
The laser diode slot-in module (2) provides an optical output for the laser radiation. A variety of measurements concerning the diode laser itself are performed by connecting the output to the rotational stage (A). For experiments with optical fibres, 5 modules (5) comprises in total of 5 km of either multi or single mode fibre. By modulating the diode laser, time resolved measurements are carried out allowing to measure e.g. the speed of light inside the fibre. Due to the arrangement of 5 segments, the attenuation of the fibre can be measured without the need to cut the fibre. A photodetector module (4) provides accurate results. Although it is fibre coupled, it can also be used for external measurements using the provided fibre telescope (FT).



For each fibre length starting with 5000 m, the transmitted power is taken and the natural logarithm of the transmitted light is plotted against the fibre length in kilometres. We estimate the slope as 0.88 and calculate the attenuation as 3.8 dB/km which is in good approximation of the value for the wavelength of 830 nm of 2.8 dB/km for 850 nm given by the manufacturer. Within the same set-up the speed of light is measured. For this purpose the diode laser is switched on and off periodically and at the end of the fibre the respective time delay is measured.



Virtual fibre cut back method



Time of flight for 5 km fibre

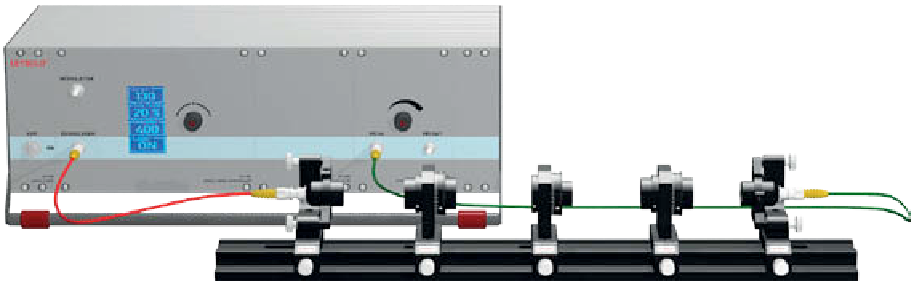
E5.2.8.3 Glass Fibre Optics consisting of:

Item	Qty	Description
1	2	Base Housing 84 TE
2	1	Laser Diode Module CW 808 nm 40 mW TEC
3	5	Multimode Fibre 50/125, 1000 m
4	1	Photodetector Module Si Optical
5	1	Optical Rail 500 mm
6	1	Rotational Stage with Fibre Holder
7	1	Mounting Plate 25 with Carrier

Item	Qty	Description
8	1	ST Fibre Telescope VIS
9	4	Fibre Patch Cable MM, 0.5 m
10	2	Fibre Patch Cable MM, 1 m
		Options:
	1	USB Oscilloscope 40 MHz, USB
	1	Spectrum Analysis Software
	1	Control Software TACOON

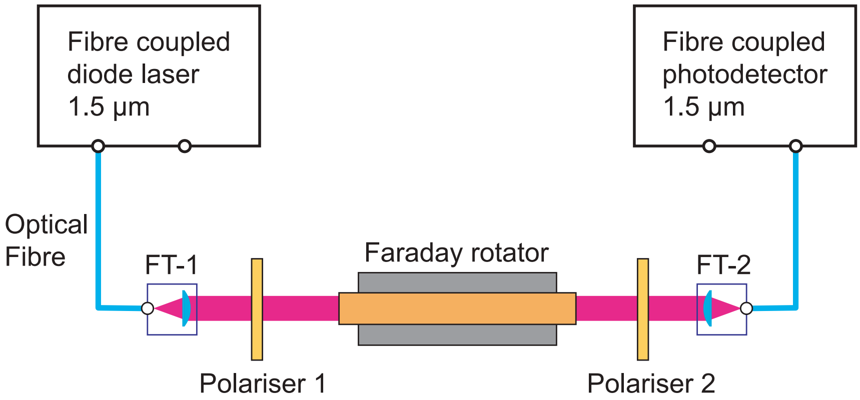
E5.2.8.4 OPTICAL ISOLATOR

- ✓ Basic Concepts
- ✓ Optical Diode
- ✓ Beam Splitting Cube
- ✓ Quarter Wave Plate
- ✓ Faraday Rotator



Principle of operation

The carrier of information in optical fibre telecommunications is laser light which is generated by separate highly stabilised laser sources. For each of the optical channels, such a source must be provided to deliver a stable wavelength. It is a well known phenomena that the stabilisation process is severely disturbed when even very small fractions of laser light is coupled back to the source. However, along a fibre optical transmission line many reflecting surfaces, like connectors or other optical components exist. Therefore it is necessary to protect the laser sources against back reflected light by optical isolators. The most commonly used isolator is a combination of a Faraday rotator operated between two polarisers based on the magneto-optical effect.

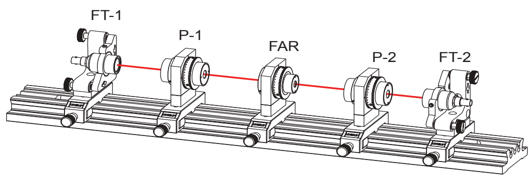


Examples of investigation and measurement

General setup

The concept of using optical diodes formed by a polarising beamsplitter and a quarter wave plate will be treated within the theoretical part of this experiment, since it is not applied to such an extent as the magneto optical isolators. Therefore, the experiment focuses on optical isolators with their operational wavelengths in the 1.30-1.55 µm range used widely in optical fibre communication. The basics of operation, its structures, mechanisms, and applications will be demonstrated. To understand the concept of optical data transmission the set-up provides a free space Faraday isolator in connection with a 1.5 µm diode laser.

The light of the laser diode leaves the fibre telescope (FT-1) almost parallel. The polariser (P-1 and P-2) as well as the Faraday rotator)FAR), are mounted in rotational holders with a 360° scale. The light which passes the optical isolator is collimated by the fibre telescope (FT-2). The task of the experiment is to find the best settings for maximum suppression and transmission. Especially for low intensities, it is recommended to modulate the diode laser and monitor the AC signal of the photodiode amplifier (4) using an oscilloscope.

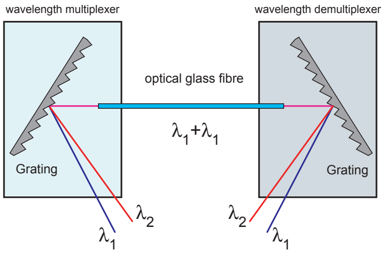


E5.2.8.4 Optical Isolator consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 1550 nm 10 mW TEC
4	1	Photodetector Module InGaAs Optical
5	1	Optical Rail 500 mm
6	1	Mirror Adjustment Holder Left
7	1	Mirror Adjustment Holder Right
8	2	ST Fibre Telescope NIR
9	2	Fibre Patch Cable MM, 1 m
10	2	Rotatable Polariser Assembly 1.5 µm
11	1	Rotatable Faraday Rotator 1.5 µm

E5.2.8.5 WAVELENGTH DIVISION MULTIPLEXER (WDM)

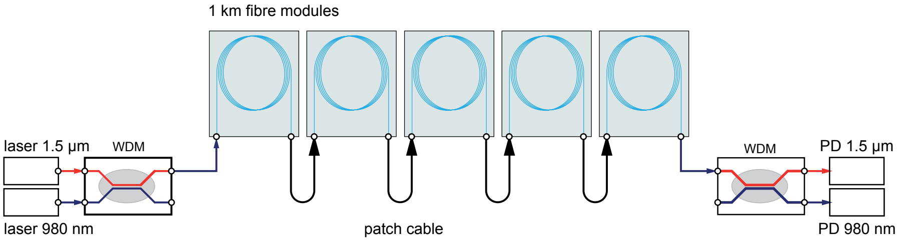
- ✓ Fibre Coupled Diode Laser
- ✓ Wavelength 980 and 1550 nm
- ✓ Coupling Efficiency
- ✓ Optical Multiplexer
- ✓ Optical Demultiplexer
- ✓ Data Transmission
- ✓ Fibre Losses
- ✓ Speed of Light



Principle of operation

The basic idea of the wavelength division multiplexer WDM makes use of an optical grating. It is well known that such a grating can separate an incoming light beam into its fundamental wavelengths. The reverse process, combining two beams with wavelengths, for example, λ_1 and λ_2 into one beam is the fundamental idea of the WDM. Of course also many other beams with different wavelengths can be combined to one beam and transported via one optical fibre. In telecommunication for each transmission channel a specific laser with a specific wavelength is required. The digital or analogue modulated laser beams are combined and travel through the transmission fibre and at the destination they are separated by means of a demultiplexer which works in the same way as the multiplexer.

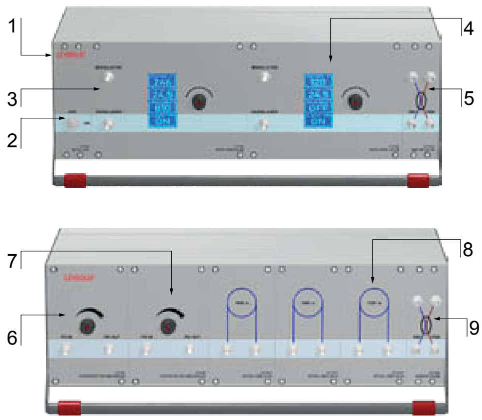
Within this setup two laser modules are used, one for the wavelength of 980 nm and the other for 1.5 µm. Each laser can be modulated by its own integrated modulator. The two laser are connected via fibre patch cables to the first WDM. The output of the WDM is connected to the fibre transmission line which consists of 3 modules with 1000 m fibre. The end of the transmission line the second WDM separates both wavelengths which are connected to the dual photodetector module.



Examples of investigation and measurement

General setup

The individual modules are accommodated by the base unit (1) with a capacity for 84 TE (1 TE = 5.08 mm) according to the standard for 19" racks. The switch panel (2) provides a safety key switch and the connections for the 12 V supply of the modules. Each diode laser module (3 and 4) contains a temperature controlled fibre coupled diode laser. The optical output is available at ST jacks at the front panel of each module. The control of injection current, temperature, modulation and display is done by a microprocessor. The USB bus allows the connection and control via a PC which allows with the provided software also the collection of data.
The first WDM (5) is placed into the first base unit. The connection of the diode laser to the WDM is accomplished by the provided fibre patch cables.
The module (6) is a fibre coupled photodetector unit. The optical signal is fed via the ST connector to the photodetector. One photodetector module is a Si PIN type for the detection of the 980 nm radiation and the other one a GaAs type for the detection of the 1.5 µm radiation.
The gain of each channel can be set by means of a knob. The analogue output of each channel is available at BNC connectors at the front panel and are used as input signals for the oscilloscope.
The fibre transmission line consists of 3 fibre modules (8) each having a fibre length of 1000 metres and are built along with the second WDM (9) into the second base unit. Beside the demonstration and characterization of the wavelength multiplexing the fibre losses can be measured for two wavelengths namely 980 nm and 1.5 µm. Due to the modulation facilities of the diode laser the speed of light can also be measured and the dispersion of the fibre determined.



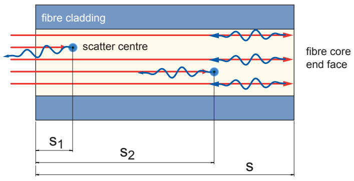
E5.2.8.5 Wavelength Division Multiplexer (WDM) consisting of:

Item	Qty	Description
1	2	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 980 nm 300 mW TEC
4	1	Laser Diode Module CW 1550 nm 10 mW TEC
5	1	WDM 980 / 1550 nm SM
6	3	Monomode Fibre 9/125, 1000 m
7	1	Photodetector Module Si Optical
8	1	Photodetector Module InGaAs Optical
9	9	Fibre Patch Cable SM, 0.5 m

E.5.2.9 Optical Fibre Instruments

E5.2.9.1 OPTICAL TIME DOMAIN REFLECTOMETRY (OTDR)

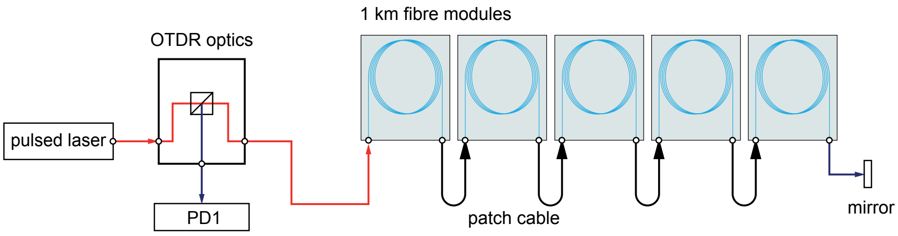
- ✓ Fibre coupled laser diode
- ✓ Pulsed and cw operation
- ✓ Optical fibre, 5 km
- ✓ Losses of fibre and connectors
- ✓ Fibre coupled photo detector
- ✓ Light echoes, speed of light



Principle of operation

There are two main reasons for the origination of scattered light. One is the back scattering at imperfections of the fibre so called scatter centre and the other one the faces of the fibre. According to the Fresnel laws a part of the incident light intensity is reflected back to the fibre entry and causes a peak which is related to the distance of the reflecting face. The back scattered light caused by the scatter centres provides the information of the attenuation of the fibre. The time resolved intensity of the back scattered light is either taken by an oscilloscope or the provided software.

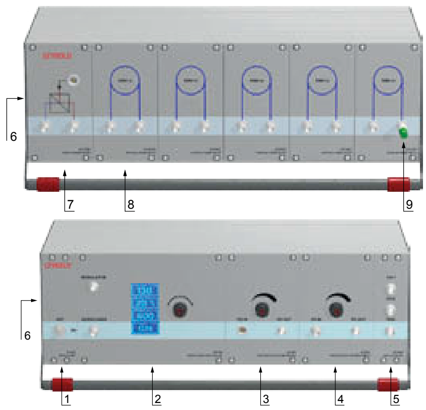
The output of a pulsed laser is connected via a fibre patch cable to the OTDR optics which consists of a polarised beam splitter cube. The laser light passes the optics and is connected via a fibre patch cable to the fibre modules. Each of them has a length of 1.0 km. The back scattered light is diverted at the beam splitter cube in such a way that it is detected by a fast photodetector (PD1).



Examples of investigation and measurement

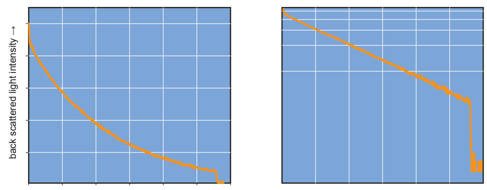
General setup

The individual modules are accommodated by the base unit (6) with a capacity for 84 TE (1 TE = 5.08 mm) according to the standard for 19" racks. The switch panel (1) provides a safety key switch and the connections for the 12 V supply of the modules. The diode laser controller (2) is operated fully digital by a microprocessor and provides an USB bus. By means of a one knob interface all parameters can be set like injection current, duty cycle and modulation frequency. The laser light is transferred via the OTDR optics (7) to the optical fibre modules (8) which are accommodated in a separate housing. The back scattered light is detected by a photodiode which is attached to the OTDR optics (7). By means of a shielded cable it is connected to the photodetector amplifier (3). The additional amplifier (4) has a fibre coupled detector which can be connected to the fibre ends to measure the emergent light intensity. The photodetector amplifier is also controlled by a microprocessor and the parameter like gain, offset and impedance can be set by the one knob control. A mirror (9) which is integrated inside a fibre connector serves as strong reflecting face.



OTDR measurements

With the completed setup as already shown in the general setup the OTDR measurements performed using the optical multimode fibre having a length of 1000 m. Thus approximate time of flight is 2 x 5 µs which can be monitored with a 40 MHz oscilloscope. The figure on the right shows the exponential decay of the back scattered light. This is related to the losses along the fibre. Therefore the exponential part of the curve contains the information about these losses. From the slope of the logarithmic intensity curve the attenuation can be calculated.

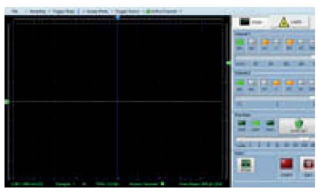


Exponential decay of back scattered light

Logarithmic intensity scale

Control software

The diode laser as well as the photodetector controller are equipped with an USB interface and can be connected to a computer. The provided software allows the control of the injection current, duty cycle and modulation of the diode laser. In addition the parameters like gain, offset and impedance of the photodiode controller can be set. The software initiates a series of laser pulses and records the time resolved intensity of the back scattered light. The number of pulses, accumulation and averaging of the recorded values can be set according to the fibre length and information of interest.



Control, recording and analysing software

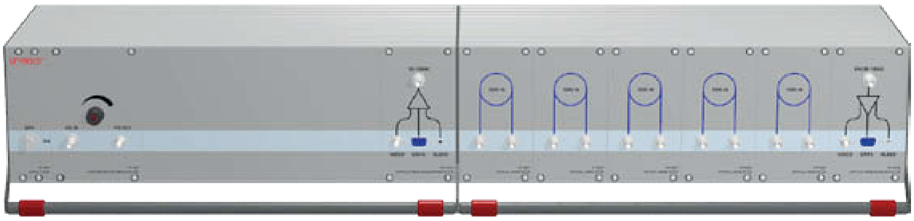
E5.2.9.1 Optical Time Domain Reflectometry (OTDR) consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 808 nm 500 mW TEC
4	1	OTDR Transceiver Optics
5	1	Multimode Fibre 50/125, 1000 m
6	1	Photodetector Module Electronic
7	1	Photodetector Module Si Optical

Item	Qty	Description
8	1	Back Reflection Pigtail
9	4	Fibre Patch Cable MM, 0.5 m
10	3	Fibre Patch Cable MM, 1 m
11	1	USB Oscilloscope 40 MHz, USB
12	1	Spectrum Analysis Software
13	1	OTDR Software

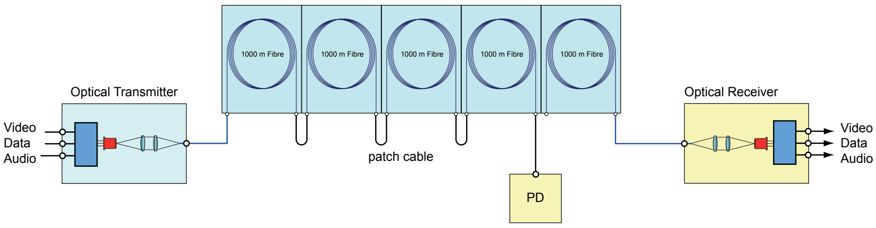
E5.2.9.2 OPTICAL TRANSMITTER AND RECEIVER

- ✓ Optical Fibre Transmitter
- ✓ Optical Fibre Receiver
- ✓ Optical Glass Fibre, 5 km
- ✓ CCD Camera
- ✓ Video & Audio Transfer
- ✓ Optical Fibre
- ✓ Optical Signal Detection
- ✓ Fibre Coupled Photodetector
- ✓ Communication via Fibres



Principle of operation

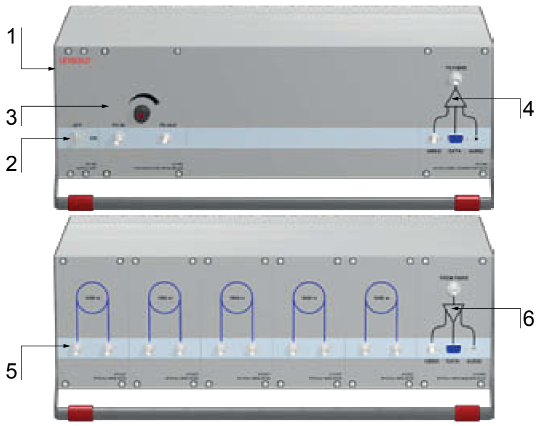
Within this project, a data transmission segment will be set-up with a total fibre length of 5 km and the transmission of video and audio signals are studied. The project starts with the connection of the fibres to the transmitter and receiver. In the next step, the electronic connections are done. The set-up can operate with a colour CCD video camera, a CD-player as an audio source, a TV screen as a monitor as well as serial RS232 data devices. This project demonstrates in an impressive way the new exiting telecommunication via optical glass fibre.



Examples of investigation and measurement

General setup

The set-up consists of the base unit housing (1) which provides all further slot-in modules with the required electrical power. The data transmission line consists of 5 segments of optical single mode fibres (5) each having a length of 1 km. The electronic signal (video, audio or data) are fed into the optical transmitter (4) where the conversion to laser light takes place. The optical output of the transmitter with a wavelength of 1.3 µm is connected via a fibre patch cable to the desired glass fibre segment. Depending on the goal of the investigation, the 5 fibre segments can be inter-connected also via fibre patch cables. A maximum distance of 5 km is achieved when all segments are connected in series which each other. The end of the fibre line is either patched to the provided InGaAs fibre coupled photodetector (3) in order to measure or monitor the optical signal or it is connected to the optical receiver (6). The back conversion to electronic signals takes place there and the individual video, data or audio signal can be connected to a monitor, computer or audio system.
Due to the fact that a combination of 5 different lengths of the fibre line is available, reliable measurements of the attenuation can be carried out. For this purpose, the use of a frequency generator connected to the audio channel is recommended to provide a steady signal.



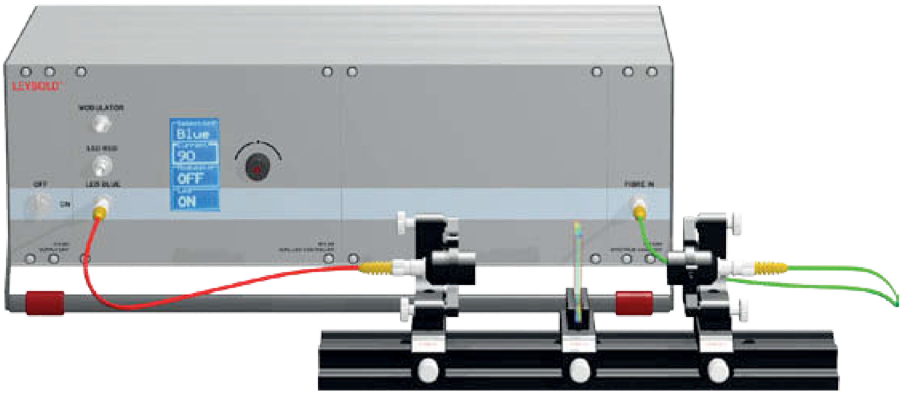
5.2.9.2 Optical Transmitter and Receiver consisting of:

Item	Qty	Description
1	2	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Optical Fibre Transmitter MM
4	5	Multimode Fibre 50/125, 1000 m

Item	Qty	Description
5	1	Optical Fibre Receiver MM
6	1	Photodetector Module InGaAs Optical
7	5	Fibre Patch Cable SM, 0.5 m
8	1	Fibre Patch Cable MM, 1 m

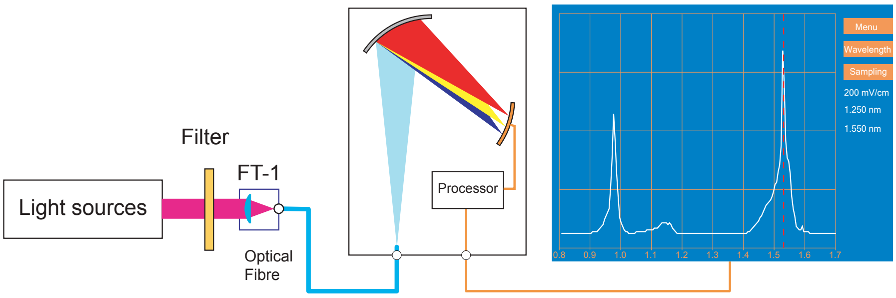
E5.2.9.3 FIBRE OPTICAL SPECTRUM ANALYSER

- ✓ Spectrum Analyser
- ✓ Fibre Coupled Laser Diode
- ✓ Nd:YAG Excitation Spectrum
- ✓ Environmental Light Spectrum
- ✓ Wavelength Calibration
- ✓ Second Order Spectrum
- ✓ Computer Control



Principle of operation

Optical spectrum analysers are an indispensable tool for research, development and maintenance. The number of semiconductor light sources like diode lasers or light emitting diodes (LED), is steadily growing and their spectral characteristics are of great importance for scientists and engineers. Due to this rapid development, miniaturized fibre coupled devices are also common in the size of a match box. This kind of spectrometer is easy to use and handle, since no settings and reading of the grating are needed.



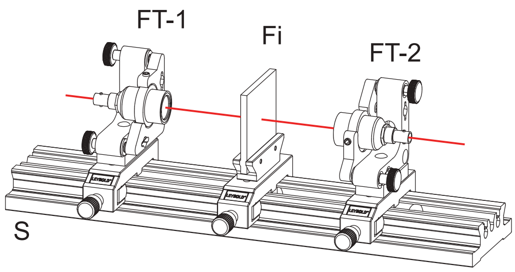
Instead of an exit slit, high resolving linear CCD arrays are used. Microprocessors control the device and deliver the full spectrum covered by the grating. Each pixel of the linear sensor, or a couple of them, represents a "slit" or channel. Based on the position of the pixel and the illumination intensity, the processor constructs the spectrum. Such devices are also termed optical multi-channel analysers or in short OMA.

Examples of investigation and measurement

General setup

The optical multi-channel analyser and the spectrometer are integrated into one module. A fibre telescope is used to enhance the incoming light level. As light sources to be investigated, two LED light sources emitting in the blue (450 nm) and red (670 nm) are provided (3). Furthermore, a spectral lamp is provided optionally emitting a variety of fixed emission lines for calibrating purposes. Due to the USB connection, all functions are remote controlled by a computer or tablet PC using the spectrum analyser software.

In order to connect the individual light sources directly to the spectrum analyser ST and F-SMA adapter for the plastic optical fibre connection of the LED module (3) are provided. Two filters (Fi) complete the equipment. One filter is an RG1000 type, which blocks visible radiation below 1000 nm and the other BG39 blocks radiation above 750 nm. Furthermore, it is possible to analyse environmental light by simply directing the fibre telescope (FT) into the position of the emitting source.



E5.2.9.3 Fibre Optical Spectrum Analyser consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Dual LED Transmitter, Blue, Red POF Coupler
4	1	Optical Spectrum Analyser VIS, USB
5	1	Optical Rail 300 mm
6	1	Mirror Adjustment Holder Left
7	1	Mirror Adjustment Holder Right
8	1	ST Fibre Telescope VIS

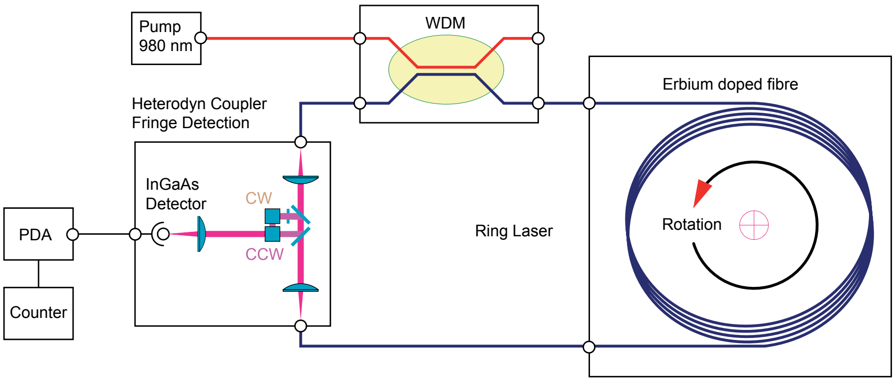
Item	Qty	Description
9	1	POF Fibre Telescope
10	1	Filter Plate Holder
11	1	Set of 2 Coloured Glass Filter
12	1	PC Tablet, Win 7 or higher
13	1	Spectrum Analysis Software

E5.2.9.4 FIBRE LASER GYROSCOPE

- ✓ Sagnac Effect
- ✓ Fibre Ring Laser
- ✓ Ring Laser Modes
- ✓ Interference
- ✓ Fringe Detection
- ✓ Mode Lock-in
- ✓ Precision Angle Measurement
- ✓ WDM Coupler

Principle of operation

Air planes are equipped with laser gyros for navigation. Beside their high precision, they have shown reliability, long term stability, and a long lifetime.
Within this experimental set-up, the basics of the laser gyro are explained and practically studied at the system, which allows full access to all components. The experimental laser gyroscope (gyro) consists of a sturdy turntable on which the fibre ring laser is mounted. By means of a motorised rotational stage, the angular motion of the turntable is performed. The ring laser consists of an Erbium Doped Fibre (EDF) and is coiled up onto a drum. The point of rotation lies well within the centre of the drum.

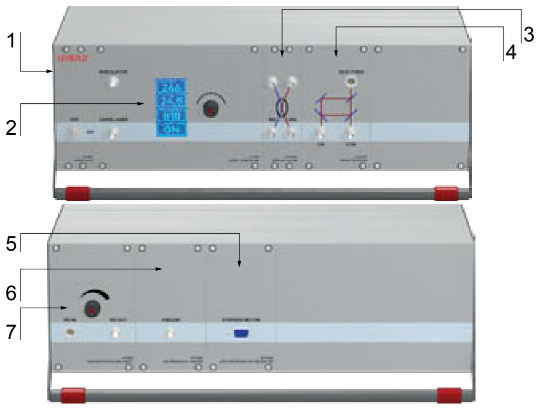


The fibre ring laser is composed out of the erbium doped fibre and a neutral fibre. The ring laser is optically pumped by a 980 nm laser diode via the WDM coupler. To necessary single mode operation of the ring laser is achieved by extending the resonator length by means of a neutral fibre. In this case a clockwise (cw) and counter clockwise mode is travelling inside the fibre ring laser. A small amount of the cw and ccw mode is reflected by the glass plates to the InGaAs photodetector.

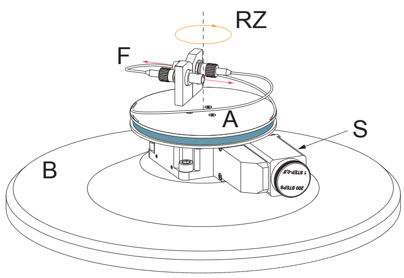
Examples of investigation and measurement

General setup

The laser diode which provides the pump light is part of the module (2). The injection current and temperature is controlled by a microprocessor and the settings are done either by the one knob interface or by software. The pump light is connected via a ST fibre patch panel to the WDM coupler (3) and subsequently to the fibre coil which is mounted to the rotation stage (A). The fibre ring is completed by connecting the fringe detection optics (4).
Once the ring laser is operative, measurements can be performed using the photodetector signal which is present at (4). By modulating the pump laser diode also the dynamic behaviour of the laser like life time of excited state or spiking of the Erbium ring laser can be studied.



Once the setup of the ring laser is done, the beat frequency is measured with the photodetector differential amplifier (2). For this purpose the turn table (A) is used. On a sturdy base plate (B) a stepper motor driven turntable (S) carries the fibre coil (F) which is centred to the rotation axis (RZ). The stepper motor is operated by the controller (5) which is connected via its USB bus to an external tablet PC.
Even for low speeds the beat frequency is already in the kHz range and can determined by the frequency counter (6). While rotating the turntable the beat frequency signal is observed. By using the provided tablet PC and the software different angular speeds can be set and the resulting beat frequency is measured. In this way the lock-in threshold is determined and the Sagnac relation verified.



E5.2.9.4 Fibre Laser Gyroscope consisting of:

Item	Qty	Description
1	2	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Diode Module CW 980 nm 300 mW TEC
4	1	WDM 980 / 1550 nm SM
5	1	Fringe Detector
6	1	Photodetector Differential Amplifier

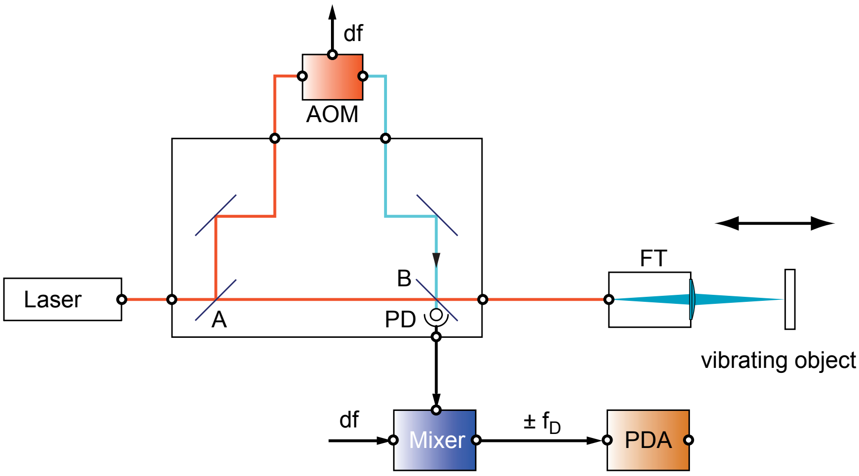
Item	Qty	Description
7	1	USB Frequency Counter
8	1	USB Stepper Motor Controller
9	1	Fibre Gyro Assembly
10	1	PC Tablet, Win 7 or higher
11	1	Laser Gyroscope Software
12	1	USB Oscilloscope 40 MHz, USB

E5.2.9.5 FIBRE LASER VIBROMETER

- ✓ Dual Beam Interference
- ✓ Mach-Zehnder Interferometer
- ✓ Doppler Effect
- ✓ Acoustooptic Modulator
- ✓ Frequency Shift
- ✓ Heterodyne Interferometer
- ✓ Frequency Mixing
- ✓ Vibration Measurement

Principle of operation

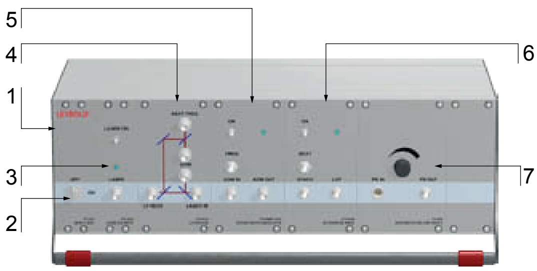
The laser vibrometer allows the high precision and contactless measurement of the movement of a target. For a common interferometer, a mirror must be attached to the target which reflects the light back into the interferometer. The outstanding property of the laser vibrometer is the fact that it directly focuses the laser beam to the target. It therefore belongs to the important class of contactless operating measuring instruments. The heart of the set-up is formed by a Mach-Zehnder interferometer. The frequency of one of the two beams is shifted by an acoustooptic modulator in order to apply the heterodyne fringe detection technique. Contrary to the homodyne technique, the subsequent signal amplifiers are AC coupled allowing a much higher gain in a simpler way. Due to its contactless operation and high precision, the laser vibrometer has found a lot of applications in industrial applications.

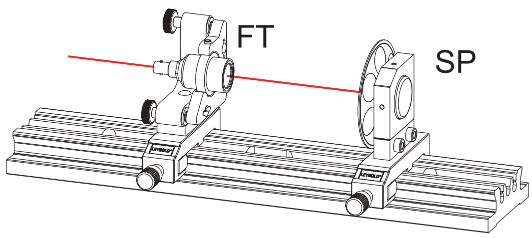


Examples of investigation and measurement

General setup

The beam of the laser (3) is divided into two beams at the beam splitter (A). One part is reflected and the other part is transmitted. Both beams have the same frequency, namely the one of the laser (fo). The reflected beam passes the acousto optic modulator (AOM, 5) whereby the laser frequency is changed to f_o+df. At the beam splitter B, this beam is directed back and finally hits the photodetector (PD). The beam which is transmitted at the beam splitter cube A also transmits the beam splitter cube B and is guided within a fibre to the telescope (FT). The focused beam hits the vibrating target (SP). The frequency of the back scattered beam is superimposed by the Doppler frequency, caused by the vibration of the object. The frequency of the returning radiation is therefore fo ± fD.
Both beams are combined at B and hit the photodetector (PD). Due to its non-linear characteristic, the photodetector produces the difference of both frequencies df ± fD. To obtain the desired Doppler frequency, which is proportional to the speed of the target, this frequency is mixed with the modulation frequency df of the AOM (5) by the mixer. The subsequent photo diode amplifier (PDA,7) conditions the signal in such a way that it fits the needs of further monitoring or recording. The amplitude of the Doppler frequency finally gives the time resolved translation and the frequency itself gives the speed of the target.





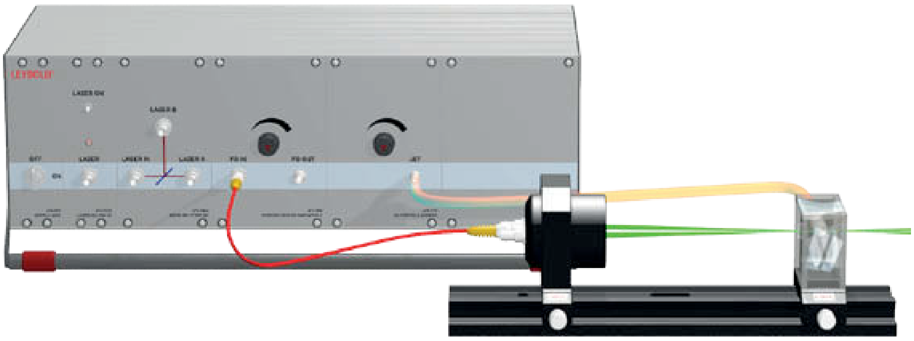
E5.2.9.5 Fibre Laser Vibrometer consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Module CW 532 nm 10 mW
4	1	Laser Vibrometer Coupler
5	1	Acoustooptic Modulator
6	1	Heterodyne Mixer
7	1	Photodetector Module Electronic
8	1	Optical Rail 300 mm

Item	Qty	Description
9	1	ST Fibre Telescope VIS
10	1	Mirror Adjustment Holder Left
11	1	Mounting Plate 25 with Speaker
12	3	Fibre Patch Cable SM, 0.5 m
13	1	Fibre Patch Cable SM, 1 m
		Option
	1	USB Oscilloscope 40 MHz, USB
	1	Control Software TACOON

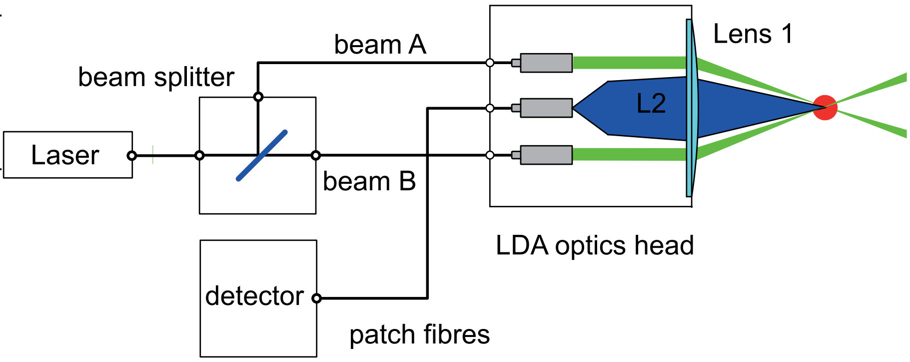
E5.2.9.6 FIBRE LASER DOPPLER ANEMOMETER

- ✓ Fibre Coupled Laser Diode
- ✓ Fibre Coupled Beam Delivery
- ✓ Dual Beam Interference
- ✓ Spatial Interference
- ✓ Doppler Effect
- ✓ Light Scattering
- ✓ Measuring Particle Speed
- ✓ Spatial Scattering
- ✓ Seeding Particles
- ✓ Fourier Transformation



Principle of operation

Anemos is a Greek word which means "wind". Consequently, a Laser Doppler Anemometer (LDA) is a "wind meter" using a laser based on the physical effect Christian Doppler discovered in 1842. However, the LDA cannot detect pure wind as a clean air stream; it needs to have particles moving with the wind. These particles move through two crossing laser beams. Due to the coherence of the laser, a spatial interference pattern appears within the crossing zone which look like Zebra stripes. When particles are moving through the stripes, they scatter the light in preferred directions.



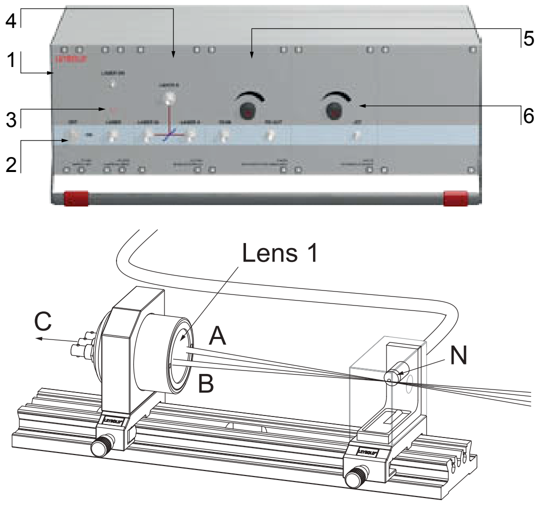
When children play by striking the vertical bars of a picket fence with a stick, it gives a characteristic burst-like noise. The faster they run the shorter the burst is, however, the frequency of the strikes is higher. Yeh and Cummins exploited the same principle in 1964 when they invented their laser Doppler anemometer. Instead of children playing, the set-up uses an ultra sonic particle seeder. An avalanche photodetector combined with a telescope is used to detect the scattered light. A storage oscilloscope is required to display and store the individual burst for subsequent analysis.

Examples of investigation and measurement

General setup

The beam of the laser (3) is transferred by means of an optical fibre to the beam splitter (4) where it is divided into two beams. Beam (A) is reflected and the other one (B) transmitted. Also with patch fibres (C), the output of the beam splitter unit is connected to the LDA optics head. Inside the head, both beams (A) and (B) are converted back to parallel beams. The main lens 1 bends and focuses the beams to a crossing point, producing the required spatial interference pattern. In addition the lens collects the back scattered light and focuses it to the fibre which is connected to the photodetector amplifier (5)

By means of an ultra sonic device (6), particles are generated streaming via the nozzle (N) passing the "Zebra" structure of the crossed beams. During their travel, they produce back scattered light which is collimated by lens 1 and imaged by lens 2 into the entrance of an optical fibre. This fibre is connected via a fibre patch cable to the SiPIN detector unit providing an fibre optical input. The optical signal is converted into an electronic one and subsequently conditioned and amplified to be displayed on an storage oscilloscope.
The nozzle N is covered with a acrylic cover to enclose the particle, mainly water, which condenses at the bottom where it is leaks via a hose into a small reservoir.

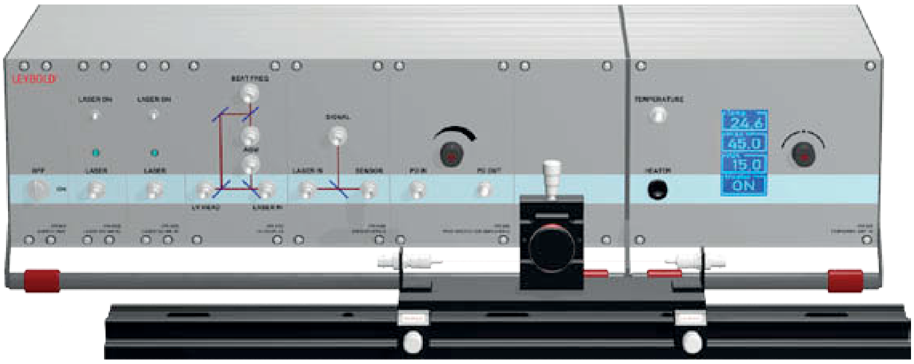


E5.2.9.6 Fibre Laser Doppler Anemometer consisting of:

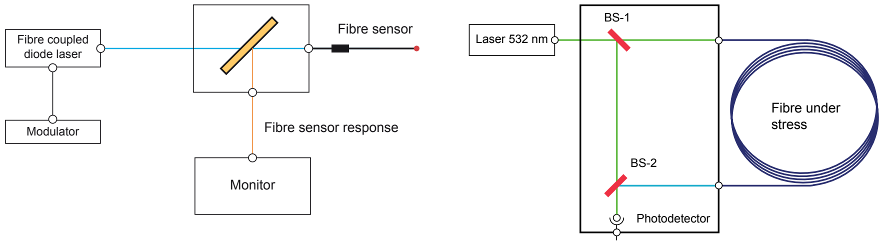
Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Module CW 532 nm 10 mW
4	1	Beam Splitter 523 nm
5	1	US Particle Seeder
6	1	Photodetector Module Si Optical
7	1	Optical Rail 300 mm
8	1	LDA Sensor Head
9	1	Particle Seeder Nozzle Assembly
10	2	Fibre Patch Cable SM, 1 m
11	1	Fibre Patch Cable MM, 1 m
		Options:
	1	USB Oscilloscope 40 MHz, USB
	1	PC Tablet, Win 7 or higher
	1	LDA Software with FFT

E5.2.9.7 FIBRE OPTICAL SENSORS

- ✓ Interferometric Sensors
- ✓ Intensity Sensors
- ✓ Mach-Zehnder Interferometer
- ✓ Temperature Sensor
- ✓ Stress and Pressure Sensor
- ✓ Current Sensor
- ✓ Computer Control



Principle of operation



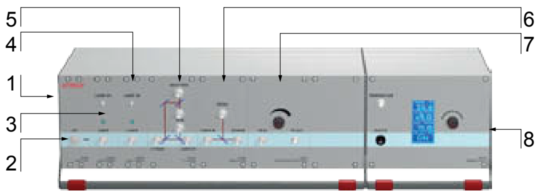
A. Intensity based fibre sensor

B. Interferometric based fibre sensor

The main reasons for the popularity of optical fibre based sensor systems are their small size, light weight and immunity to electromagnetic interference (EMI). Furthermore, the widespread use of optical fibre communication devices in the telecommunication industry has dropped the costs of optical fibre sensor. They have been developed for a variety of applications in industry, medicine, defence and research. Some of these applications include gyroscopes for navigation systems, for the measurement of various physical and electrical parameters like temperature, pressure, liquid level, acceleration and voltage in mains power plants. The response of all optical fibre sensors is a change in either polarization, phase, frequency, intensity or a combination of all. Optical fibre sensors can be classified according to their properties. Two major types exist: an intensity based and an interferometric based. The intensity based sensors require simple electronics. The interferometric based type requires advanced signal processing and has an extremely high sensitivity.

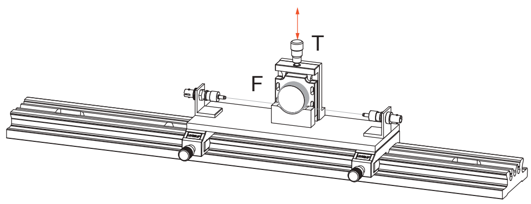
Examples of investigation and measurement

General setup



Within this experiment both types of sensors are applied. For the intensity based ones, a temperature sensor with a GaAs tip is selected. The response light of the sensor is monitored under varying temperatures. For this purpose the fibre sensor is placed into a small oven (8) which is operated by a Peltier's element in the range of 15° to 60°C. The attached temperature controller provides an accuracy of ± 1 °C. The sensor is operated either with a laser wavelength 532 nm (3) or 808 nm (4). The beam splitter (6) reflects the sensor affected light into a fibre which is connected to the photodiode amplifier (7).

The interferometric based sensor consists of a fibre coil (F) into which tension can be manually introduced (T). The sensor is connected to a Mach-Zehnder interferometer (5) and the fringes are either displayed on the optional oscilloscope or counted with the frequency counter.



E5.2.9.7 Fibre Optical Sensors consisting of:

Item	Qty	Description
1	1	Base Housing 84 TE
2	1	Supply Unit with USB Hub
3	1	Laser Module CW 532 nm 10 mW
4	1	Laser Module CW 808 nm 50 mW
5	1	Laser Vibrometer Coupler
6	1	Fibre Sensor Optics
7	1	Photodetector Module Si Optical
8	1	Tempering Unit HI, Heat and Cool 15°C to 70°C
9	1	Optical Rail 500 mm
10	1	Fibre Stress Assembly

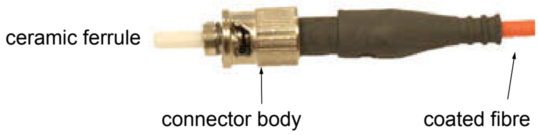
Item	Qty	Description
11	1	Fibre Temperature Sensor, ST
12	1	Fibre Patch Cable SM, 0.5 m
13	2	Fibre Patch Cable SM, 1 m
14	3	Fibre Patch Cable MM, 0.5 m
		Options
	1	USB Oscilloscope 40 MHz, USB
	1	USB Frequency Counter
	1	PC Tablet, Win 7 or higher
	1	Control Software TACOON

E.5.2.9.8 FIBRE OPTICS WORKSHOP

- ✓ Safety Rules
- ✓ Fibre Stripping
- ✓ Fibre Breaking
- ✓ Fibre Connections
- ✓ Fibre Polishing
- ✓ Fibre Inspection

Fibre handling and connectorizing

The main goal of this workshop is the connectoring of optical glass fibres with ST connectors. Although a variety of other fibre connectors exist the process of connectoring however remains the same.
Another major technology is the welded connection of bare fibres by means of the fusion splicing technology.

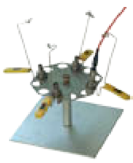


Connectoring optical fibre

It starts with the preparation of the fibre by stripping the plastic cladding from the fibre for at least 3-4 cm. Within this workshop so called hot melt connectors (8) are used. The connectors are already filled with a hot melt adhesive. As the name suggests, these adhesives melt and flow when heated to wet the substrates and bond quickly upon cooling. A connector is placed by means of a special holder into the oven (6) and remains there for about 1 minute. After that the fibre (5) is inserted into the hot connector until 1 to 2 cm of fibre protruding the connector. The hot connector with the fibre is placed into the cooling rack (9) for a couple of minutes until it cooled down and the adhesive is solidified. The protruding fibre is scratched by means of the provided cleaver and subsequently broken.

Fibre stripper (1)

Melting oven (6)



Cooling rack (9)

Polishing and inspection of the fibre connector

The so prepared connector is polished with the polishing machine (7) . For this purpose the fibre is fixed to the swivel arm of the unit. A polishing film (2) is placed onto the rotating disk. After one minute of polishing the fibre is ready for inspection using the handheld fibre inspection microscope (3).

Fibre connector polishing (7)

Connector inspection (3)

Fusion splicing of optical fibres

Another important technology is the connection of two bare fibre ends. It is important that the splicing should affect the optical transmission to lowest possible degree. Fusion splicing is a well established technology for connecting bare fibres.
Before the fusion takes place the plastic cover of the fibre ends must be removed and precisely perpendicular cut. This is done by a precision fibre cleaving and breaking tool (12). The so prepared fibre ends are placed into the fusion splicer where the fibre faces are automatically orientated to each other. The fibre ends are moved to close contact of the faces and the fusion which is a kind of welding is started. Based on the resulting geometry of the "welded" fibre ends the unit calculates already the transmission losses. Actually before the splicing process a splicing tube and a hot shrinking protective plastic cover is attached to one side. After the fusion process the splice is covered and protected by this tube.

Precision fibre cleaving and breaking (11)

Fibre fusion splicer (10)

E5.2.9.8 Fibre optics workshop consisting of:

Item	Qty	Description
1	1	Adjustable plastic cover stripper 103-S
2	1	Polishing film 2 µm / set of 50
3	1	Fibre inspection microscope, 200 x
4	1	Tungsten Carbide fibre cleaver
5	1	Multimode optical glass fibre 1000 m, 50/125 µm
6	1	Hotmelt oven
7	1	Hotmelt polishing unit

Item	Qty	Description
8	1	Hotmelt ST connector, set of 60
9	1	Cooling rack
		Options
10	1	Fusion splicer for SM and MM Fibres
11	1	High performance fibre cleaver and breaker
12	1	Splicing tubes set of 250

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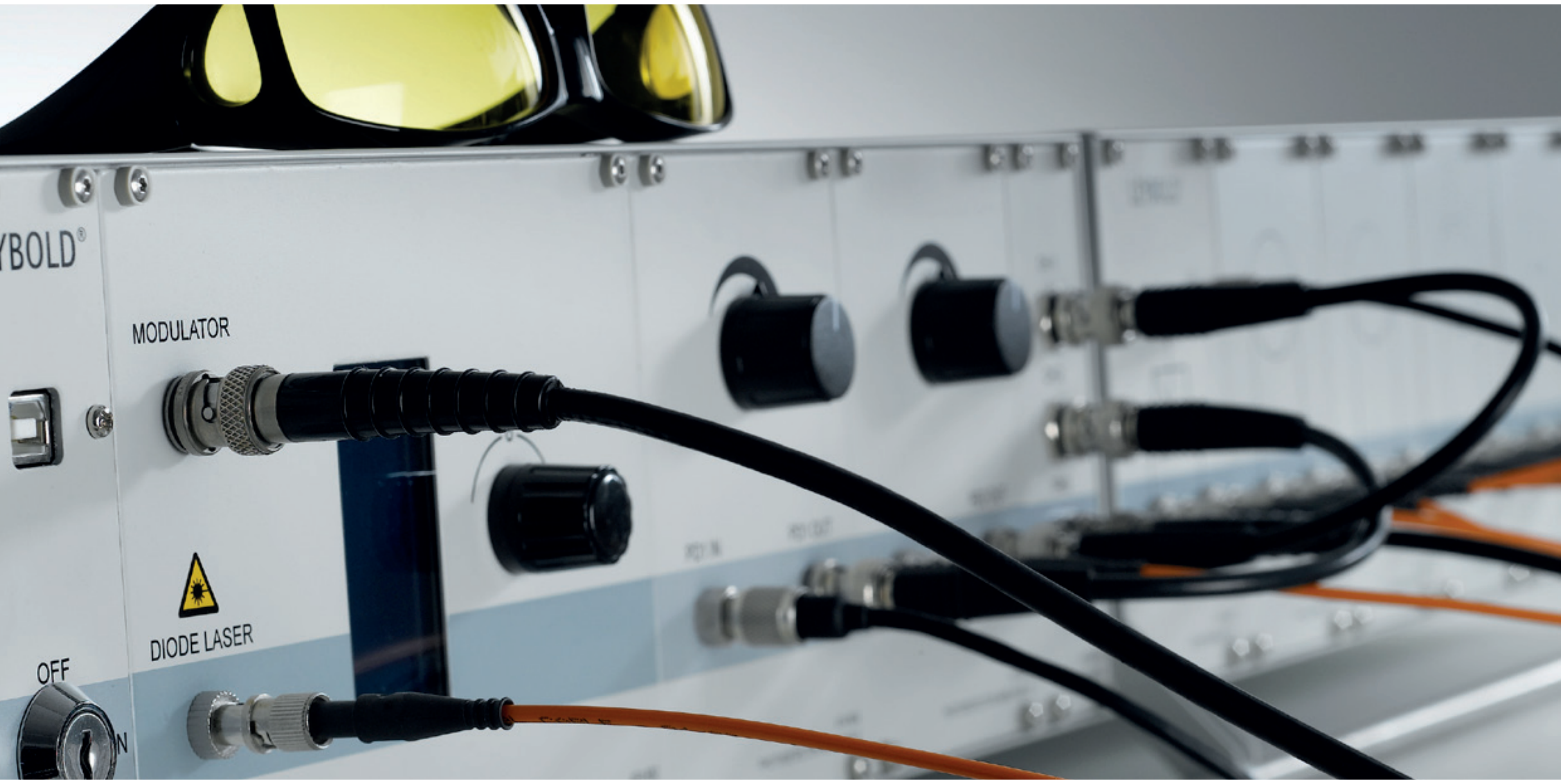

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