Photonik
Ingenieurbüro
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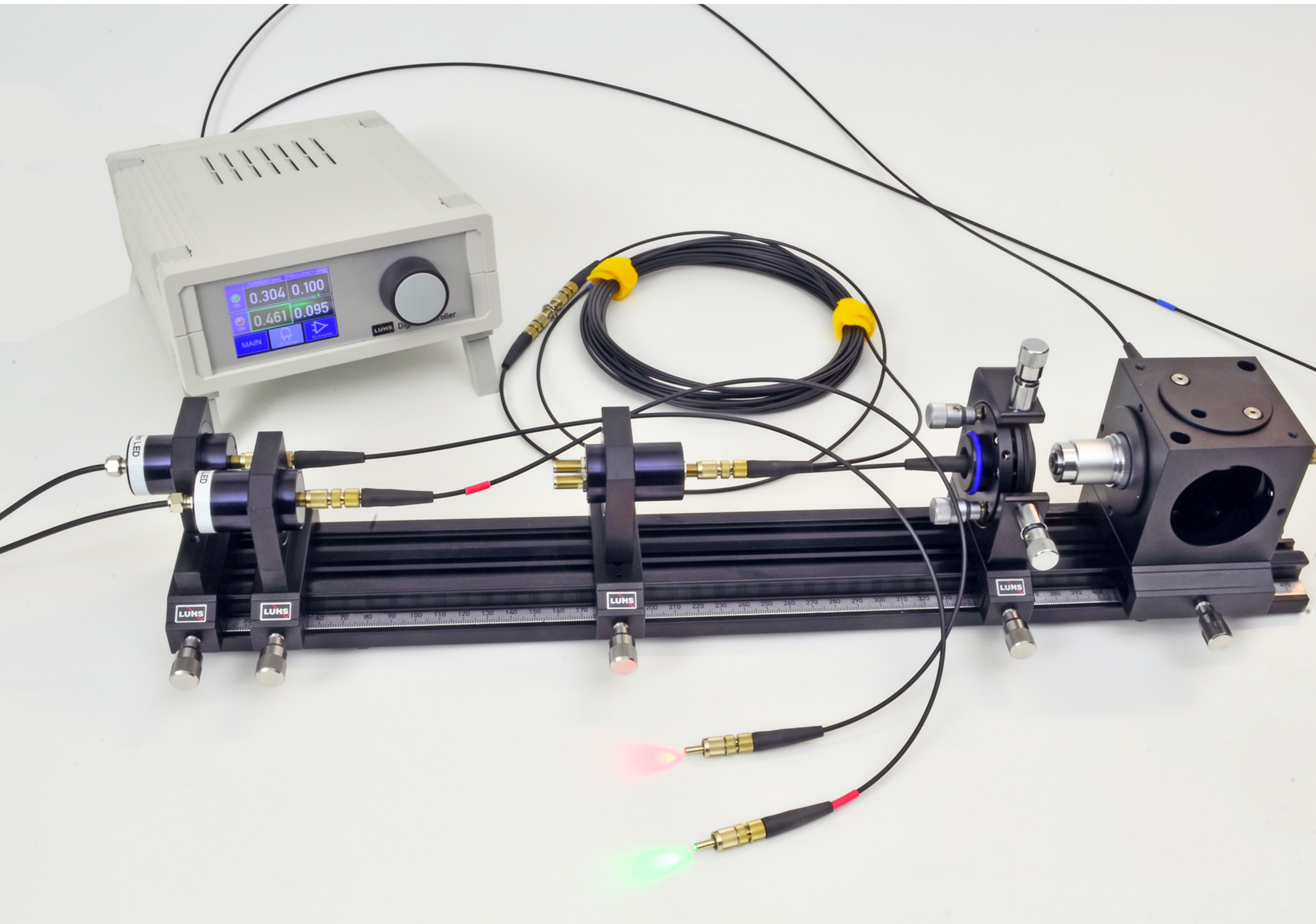
UM-LT01 Manual Plastic Fibre Optics



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1.0 Introduction

There is hardly any book in optics which does not contain the experiment of Colladon (1841) on total reflection of light. Most of us may have enjoyed it during the basic physics course.

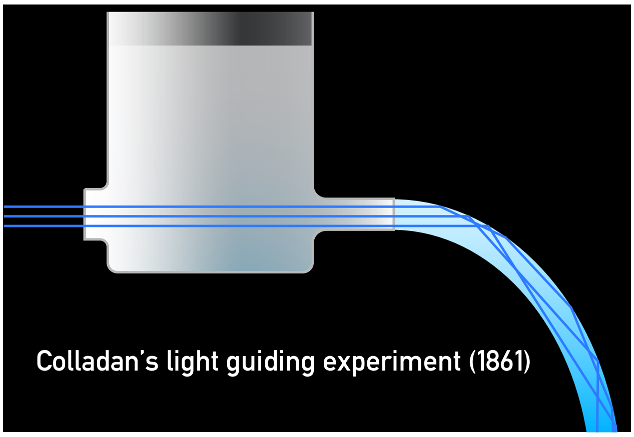


Fig. 1: Colladon's (1841) experiment for the demonstration of the total reflection of light

An intensive light beam is introduced into the axis of an out flowing water jet. Because of repeated total reflections the light can not leave the jet and it is forced to follow the water jet. It is expected that the jet remains completely darken unless the surface contains small disturbances. This leads to a certain loss of light and it appears illuminated all along its way. Effects of light created in this way are also known as „Fontaines lumineuses". They please generally the onlookers of water games. This historical experiment already shows the physical phenomena which are basic in fibre optics or in more general optical wave guides. Such devices are able to guide light waves and are used in many applications. One of the first known applications of using the idea of Colladon was in 1930 when Heinrich Lamm, than a medical student, published a paper reporting the transmission of the image of a light bulb filament through a short bundle of optical glass fibres. His goal was to look inside inaccessible parts of the human body. In his publication „The optical analogy of ultra short wavelength guides" H. Buchholz expressed in 1939 the idea to guide light signals along light conducting material and to use them for data transmission. But only with the development of the semiconductor laser in 1962 Buchholz' idea was materialising by using just these lasers and fibres as light transmitting medium. Suddenly simple and powerful light sources for the generation and modulation of light were available. Today the transmission of signals using laser diodes and fibres has become an indispensable technology and the ongoing development in this area is one of the most important within this century. Following the achievements of communication technology the development of fibre optical sensors began in 1977. Here the laser gyroscope for navigation has to be emphasised in particular. This new technology is based on well known fundamentals in a way that no new understanding has to be created. Still, there is a challenge with respect to the technical realisation keeping in mind that the light has to be guided within fibres of 5 µm diameter only. Appropriate fibres had to be developed and mechanical components of high precision to be disposed for coupling the light to the conductor (fibre) and for the installation of the fibres. Further goals are the reduction of transmission losses, optical amplification within the fibre as replacement of the electronic amplifiers and laser diodes of small band width to increase the transmission speed of signals. One of the most driving power for the development of fast optical networks is the steadily growing Internet in connection with worldwide data transfer. Nowadays the only so called WAN (Wide Area Networks) are equipped with high speed optical glass fibres whereas the LAN's (Local Area Networks) are still using copper wires. The reasons still for this are mainly the comparably high costs and specific installation requirements for the glass fibres. But on the other hand the demand for an all optical data transfer is more and more increasing since this technology has two major advantages. Firstly the interception security of sensitive data can be guaranteed to a much more higher degree and secondly all ground loop problems and electromagnetic interference (EMI) can be neglected. The alternative to take advantage of pure optical data transfer at low costs are the plastic optical fibre.

"Sooner or later, everything is made out of plastic" one can read on the Internet home page of one of the greatest plastic optical fibre manufacturer Boston Optical (www.bostonoptical.com).

This is a simple but nevertheless remarkable statement describing perfectly the past and probably also holds for the future. Indeed plastic optical fibre (POF) are making their way and it can bee seen that this technology will substitute the copper wire in local area networks. It is hard to say if they ever will be able to compete with optical glass fibres. The most significant disadvantage is the high attenuation of 200 dB/km versus 0.2-0.5 dB/km for glass fibres. But one should recall that in 1960 the first glass fibres had an attenuation of 1 dB per metre (!) and it is due to Dr. Charles K. Kao, an engineer born in Shanghai, who recognised that the attenuation of the glass fibre to that times is due to impurities not to silica glass itself that the optical glass fibres could make their way. In the April 1966 issue of the "Laser Focus" magazine one can read:

„At the IEE meeting in London last month, Dr. C. K. Kao observed that short distance runs have shown that the experimental optical wave guide developed by Standard Telecommunications Laboratories has an information carrying capacity ... of one gigacycle, or equivalent to about 200 TV channels or more than 200,000 telephone channels. He described STL's device as consisting of a glass core about three or four microns in diameter, clad with a coaxial layer of another glass having a refractive index about one percent smaller than that of the core. Total diameter of the wave guide is between 300 and 400 microns. Surface optical waves are propagated along the interface between the two types of glass."

"According to Dr. Kao, the fibre is relatively strong and can be easily supported. Also, the guidance surface is protected from external influences. ... the wave guide has a mechanical bending radius low enough to make the fibre almost completely flexible. Despite the fact that the best readily available low loss material has a loss of about 1000 dB/km, STL believes that materials having losses of only tens of decibels per kilometre will eventually be developed."

Nowadays optical glass fibres with an attenuation below 0.5 dB/km at 1.5 µm wavelength are state of the art. So, based on this history, taking roughly 30 years dropping down the attenuation of glass fibres to usable values, maybe one can

predict a similar development for the plastic optical fibre. But nevertheless already today these fibres play an important role in local area networks, as well as in industry for signal transfer, EMI free audio application in cars, air planes and home, medicinal and technical endoscopes, as light tubes for illumination of control panels and so on.
The goal of this experimental kit is to get familiar with plastic optical fibre and some of their application to become an expert to take share in this exiting technology. There are worldwide no other fields with such a high annual growing rate and investment like the multimedia and telecommunication technology.

1.1 Refraction and reflection

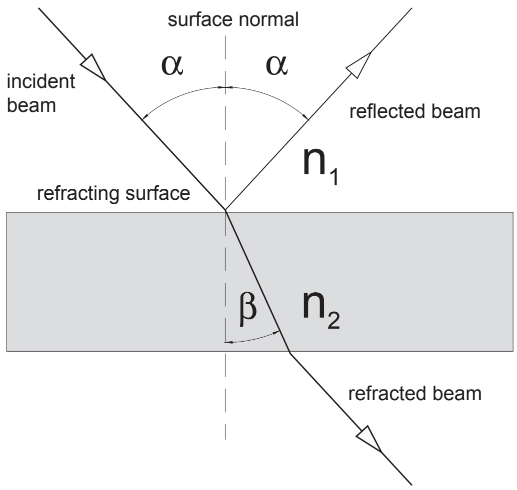


Fig. 2: Reflection and refraction of a light beam

Concededly it was a long way to obtain these simple results. But on the other hand we are now able to solve optical problems much more easier. This is especially true when we want to know the intensity of the reflected beam. For this case the traditional geometrical consideration will fail and one has to make use of the Maxwell's equations. To understand the concept of plastic optical fibre we only need to know the basics of reflection and refraction. But as soon as we reduce the diameter of a fibre towards optical glass fibre for monomode transmission it is absolutely necessary to use this formalism. The main phenomena exploited for plastic optical fibre is the total reflection at a surface. Without celebrating the entire derivation by solving the wave equation we simply interpret the law of refraction. When we are in a situation where $n_1 > n_2$ it may happen that sinβ is required to be >1. Since this violates mathematical rules, it has been presumed that such a situation will not exist and instead of refraction the total reflection will take place.

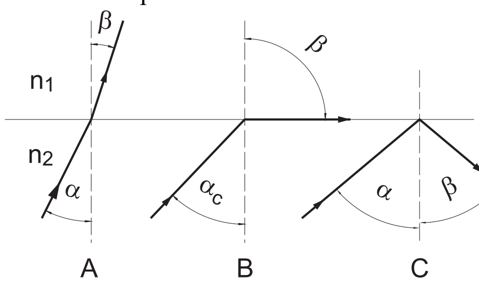


Fig. 3: From refraction to total reflection

The figure above shows three different cases for the propagation of a light beam from a medium with index of refraction n_2 neighboured to a material with n1 whereby $n_2 > n_1$. The case A shows the regular behaviour whereas in case B the incident angle reached the critical value of:

$$\sin\beta = \frac{n_2}{n_1}\cdot\sin\alpha_c = 1$$

The example has been drawn assuming a transition between vacuum (or air) with $n_1=1$ and BK7 glass with $n_2=1.45$ yielding the critical value for $\alpha_c=46.4°$. Case C shows the situation of total reflection when the value of $\alpha > \alpha_c$ and as we know from the law of reflection α=β.
Now we have collected all necessary knowledge to discuss the concept of plastic optical fibre. It should be mentioned that the results will also be valid for glass fibre as far as the dimension of the wave guiding material large compared to the wavelength used e.g. for multimode fibre.

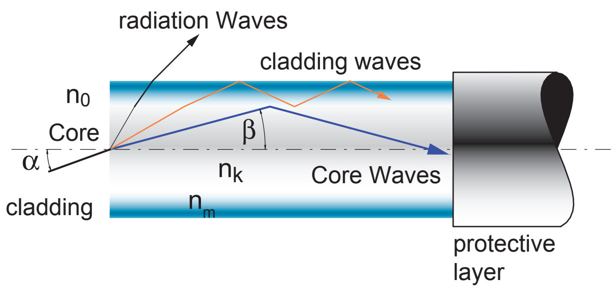


Fig. 4: Structure of an optical fibre

Glass or plastic fibres as wave conductors have a circular cross section. They consist of a core of refractive index n_k. The core is surrounded by a cladding of refractive index n_m slightly lower than n_k. Generally the refractive index of the core as well as the refractive index of the cladding are considered homogeneously distributed. Between core and cladding there is the boundary as described in the previous chapter. The final direction of the beam is defined by the angle α under which the beam enters the fibre. Unintended but not always avoidable radiation and cladding waves are generated in this way. For reasons of mechanical protection and absorption of the radiation waves the fibre is surrounded by a protective layer sometimes also termed as secondary cladding. Fig. 2.4 reveals some basic facts which can be seen without having solved Maxwell's equations. Taking off from geometrical considerations we can state that there must be a limiting angle β_c for total reflection at the boundary between cladding and core.

$$\cos(\beta_c) = \frac{n_m}{n_k} \qquad 16.$$

For the angle of incidence of the fibre we apply the law of refraction:

$$\frac{\sin(\alpha_c)}{\sin(\beta_c)} = \frac{n_k}{n_0}$$

and we get:

$$\alpha_c = \arcsin\left(\frac{n_k}{n_0}\cdot\sin\beta_c\right).$$

Using equation (16.) and with $n_o \cong 1$ for air we finally get:

$$\alpha_c = \arcsin\left(\sqrt{n_k^2 - n_m^2}\right)$$

The limiting angle α_c represents half the opening angle of a cone. All beams entering within this cone will be guided in the core by total reflection. As usual in optics here, too, we can define a numerical aperture A:

$$A = \sin \alpha_c = \sqrt{n_k^2 - n_m^2}$$

Depending under which angle the beams enter the cylindrical core through the cone they propagate screw like or helix like. This becomes evident if we project the beam displacement onto the XY- plane of the fibre. The direction along the fibre is considered as the direction of the z-axis. A periodical pattern is recognised. It can be interpreted as standing waves in the XY- plane.

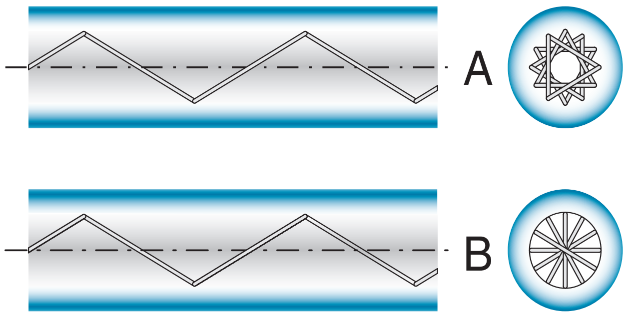


Fig. 5: Helix (A) and Meridional beam (B)

In this context the standing waves are called oscillating modes or simply modes. Since these modes are built up in the XY- plane, e.g. perpendicularly to the z-axis, they are also called transversal modes. Modes built up along the z-axis are called longitudinal modes. For a deeper understanding of the mode generation and their properties one has going to solve the Maxwell equations under respect of the fibre boundary conditions. But in case of plastic optical fibre with commonly a diameter of 1 mm the mode structure is of less interest as in glass fibre.

Before we will only focus on plastic fibre a brief comparison of both fibres shall be given. As already mentioned in the introduction the intended use of plastic fibre is the short haul transmission of optical signals whereas the optical glass fibre are preferentially used for long distance communication due to their excellent low attenuation. But the glass fibre technology has its price starting by the production process and ending up in the required high precision mechanical installation and handling components like connectors with precise sub micrometer ferrules, special fibre cutter and splicing units. However glass fibre are the best and only choice for high speed and long distance optical communication. Local area networks not exceeding 50 -100 m, are the domain of plastic fibre. The production process is less expensive and the handling is quite easy since as cutting tools simple razor blades can be used. The core diameter of 1 mm allows the usage of cheap light emitting diodes (LED) and also the precision requirements of the connectors are much more less stringent.

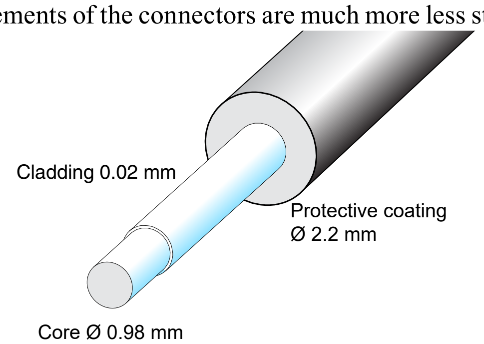


Fig. 6: Dimensions of common PMMA optical Fibre

The core of modern plastic fibre are made from PMMA (PolyMethylMethAcrylat) also known as plexiglass. It is a brittle but nevertheless ductile material which can be produced with outstanding optical properties and has an index of refraction of 1.492. The actual light tunnel, the core, has a diameter of 0.98 mm and is surrounded by a cladding made from fluoridated PMMA with a thickness of 0.02 mm. The index of refraction with 1.456 is slightly lower than that of the core to keep as much light inside the fibre. With these data of the index of refraction of the core and cladding the numerical aperture we calculate to 0.1 corresponding to a full angle of 12°. A second cladding or protective coating with an outer diameter of 2.2 mm and is used to absorb light which may leave the fibre as well as to guard the fibre against environmental stress. The next Fig. 7 shows the attenuation of such a PMMA fibre.

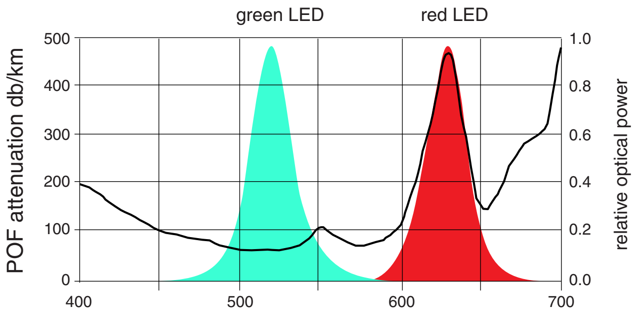


Fig. 7: Attenuation versus wavelength of a PMMA fibre

The curve clearly shows two distinct minima, one at 635 nm and the other one around 520 nm whereby the "green" area has the lowest attenuation. Whereas in the past mainly 660 nm light emitting diodes have been used nowadays more and more so called blue green LED's with an emission wavelength of 525 nm are used to take advantage of the significant lower attenuation. These LED's have become available very recently with optical power of some candela. More information on this new development will be given in the next chapter and it should be mentioned that we are going to use both a blue green and red LED within the experimental setup. Within this project we are going to use light emitting diodes (LED) as well as photodiodes. Both components exploit the properties of semi conducting solid state material to convert electrical current directly into light and vice versa.

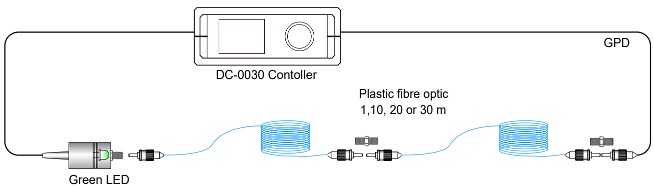


Fig. 8: Setup for the measurement of a single fibre

With the setup of Fig. 8 only one LED, the green one or the red is used to measure the attenuation of the plastic optical fibre.

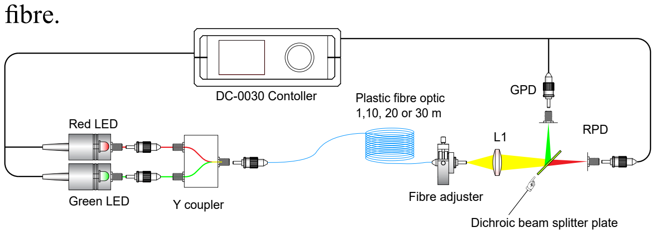


Fig. 9: Setup with dual transmission

The setup of Fig. 9 uses both simultaneously by using a wavelength multiplexer or simple Y-coupler.

2.0 Description of the components

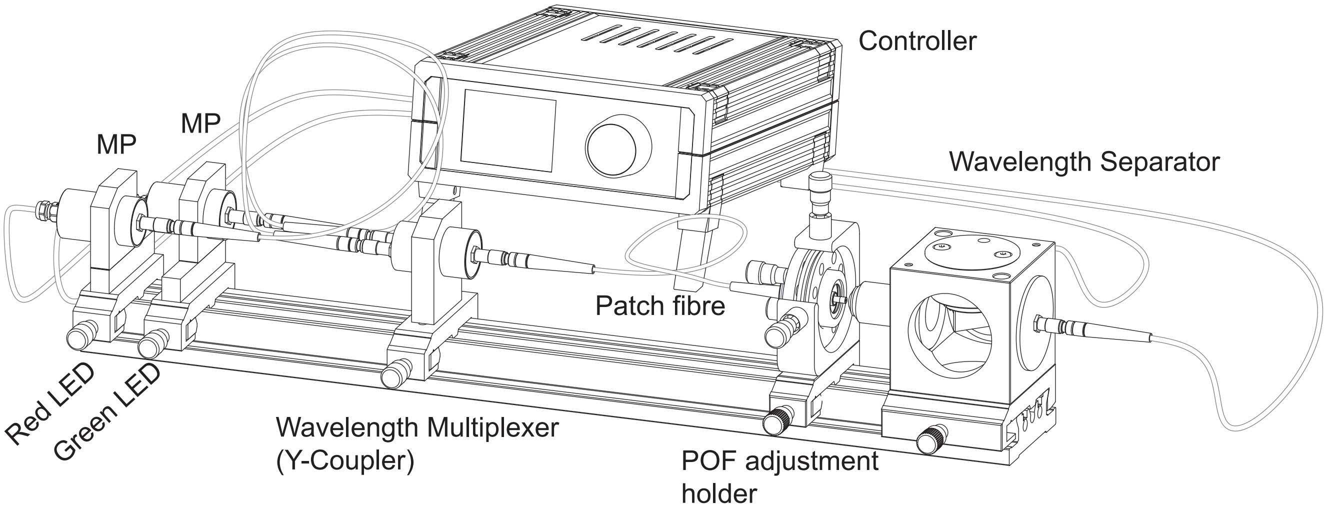


Fig. 10: Plastic Optical Fibre Setup

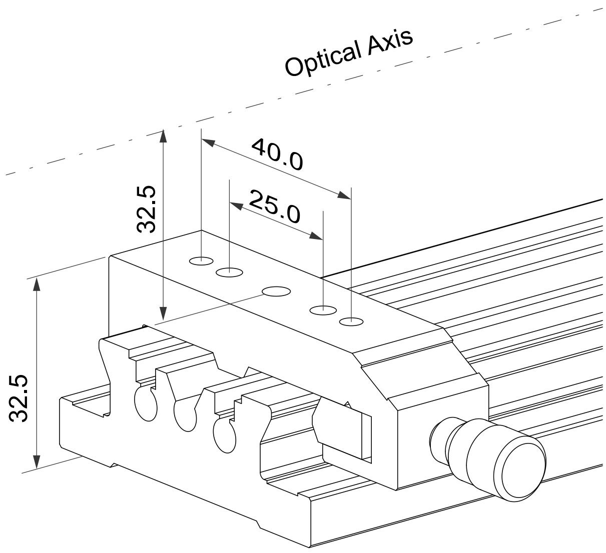


Fig. 11: Rail and carrier system

The rail and carrier system provides a high degree of integral structural stiffness and accuracy. Due to this structure it is a further development optimised for daily laboratory use. The optical height of the optical axis is chosen to be 65 mm above the table surface. The optical height of 32.5 mm above the carrier surface is compatible with all other systems like from MEOS, LUHS, MICOS, OWIS and LD Didactic. Consequently a high degree of system compatibility is achieved.

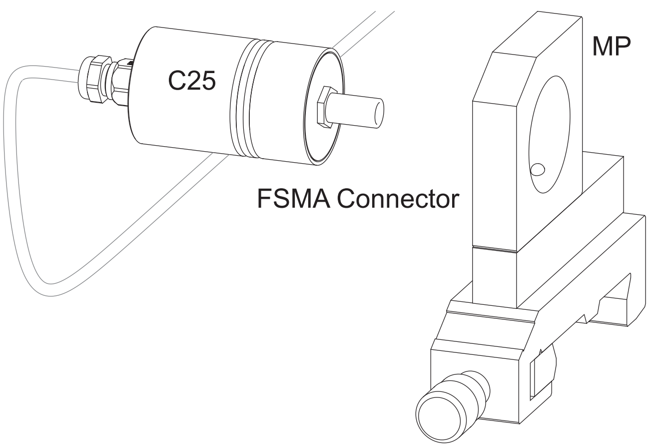


Fig. 12: Red / green LED

A high power LED is mounted into a C25 housing which has two groves. Ones inserted into the mounting plate (MP) the spring loaded balls keep the housing in position. In front of the LED a F-SMA jack is located which serves as connector for the plastic optical fibre.

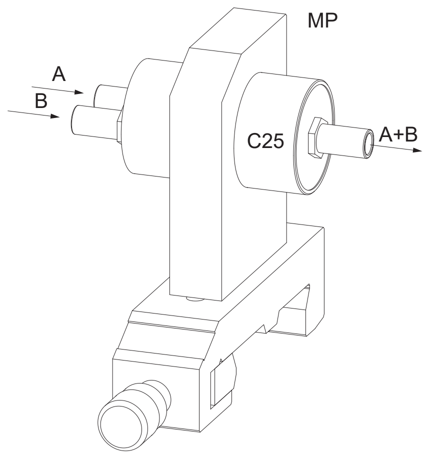


Fig. 13: Wavelength multiplexer (Y-coupler)

A simple Y-coupler made from plastic optical fibres is built into a C25 housing and the entrance and exit fibres are connected to F-SMA jacks. The coupler is mounted into a mounting plate and is kept in position by the spring loaded steel balls of the mounting plate.

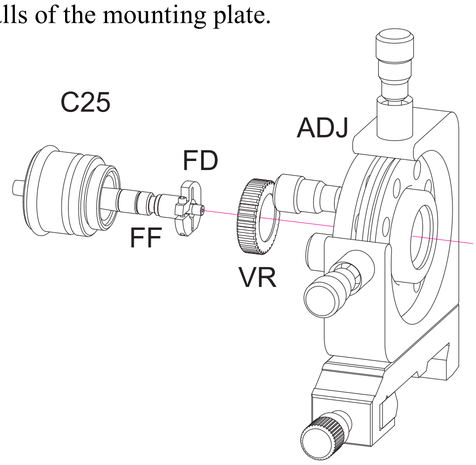


Fig. 14: POF Adjustment holder

The ferrule (FF) of one end of the fibre patch cable is clamped into a disk which is set into the C25 holder and fixed by the threaded cap. The arrangement is inserted into the 4 axis adjustment holder (ADJ). This assembly allows the alignment of the fibre exit with respect to the collimating lens of the wavelength separator.

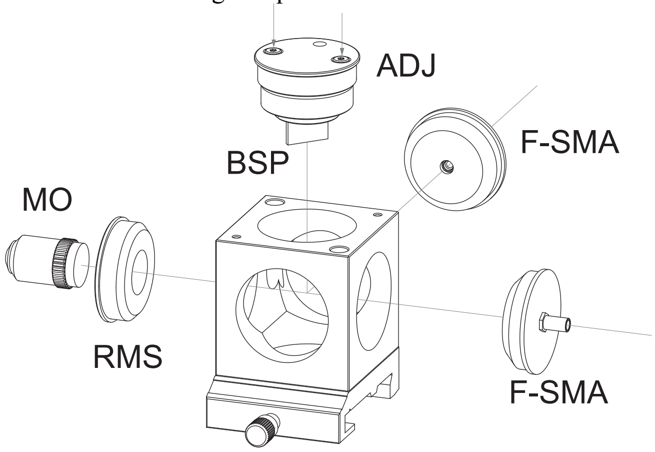


Fig. 15: Wavelength separator

This unit serves as separator of the light leaving from the optical fibre having two different wavelengths at 525 and 635 nm. The heart of the assembly is a so called dichroic mirror, which has the property that it reflects the "green" light and transmits the "red" light.

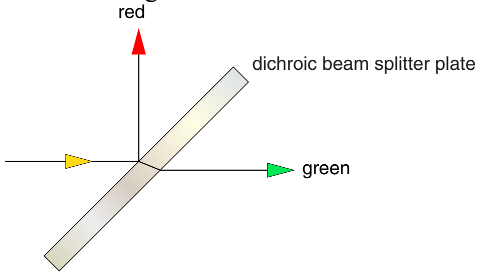


Fig. 16: Dichroic mirror

The front face of the plate as shown in Fig. 16 is coated with a specially designed layer system to obtain the required wavelength selection. To avoid unwanted "green" light reflected from the back face of the plate and refracted towards the "green" direction, it is necessary to cover this side with a high quality anti reflection coating.
The dichroic mirror (BSP) is mounted under 45° with respect to the vertical axis into an adjustment holder and can be tilted by means of the adjustment screws of holder (ADJ). The assembly comes already mounted and preset along with the necessary tools should the occasion arise for a re-adjustment. On the left side of Fig. 15 a microscope objective (MO) is shown and serves as collimator for the light which is leaving the fibre. The objective is already mounted to the assembly. For the detection of the varying intensity of the separated light two F-SMA connectors to which two POF patch cables are connected to guide the light to Si-PIN photodiodes located inside the controller DC-0030.

Fig. 17: POF coil terminated with F-SMA connectors

The experimental set-up comes with a set of 3 plastic optical fibres (10, 20 and 30 m) each terminated with F-SMA connectors.

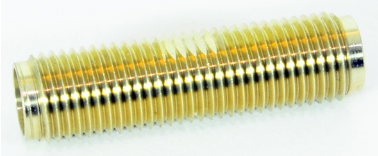


Fig. 18: F-SMA connector sleeve to connect two fibres to each other

By means of the provided F-SMA connector sleeves combinations of different fibre lengths can be arranged. In this way fibre lengths of 10, 20, 30, 40, 50 and 60 m can be obtained. Using the 30 m fibre and in addition a combination of 10 and 20 metre, the insertion and coupling losses of the fibre can be determined.

Fig. 19: DC-0030 Dual channel LED transmitter

This microprocessor operated device contains a dual LED current controller and a dual photodiode amplifier. A touch panel display allows in conjunction with the digital knob the selection and setting of the parameter for the attached LED. The two channel photodiode amplifiers are converting the photo current of the connected photodiode into a voltage. The gain of the amplifier can be selected and the photo voltage is available on the respective BNC connector on the back panel.

Fig. 20: Back panel of the DC-0030 Dual channel LED transmitter

The DC-0030 is powered from a 12V wall plug power supply which is connected via a 5.5/2.1 mm plug to the controller. The red or green LED is connected either to the "LED A" or "LED B". Each LED is provided with a15 pin male SubD connector into which an EEPROM is integrated. Connected to the device, the relevant parameters like wavelength, maximum current and optical power are read. The controller contains two independent transimpedance amplifier. To reduce the noise due to environmental radiation, the photodetectors are built into F-SMA jacks attached at the back panel (Receiver A IN and B IN) of the controller. Two internal modulators are used to modulate the current of each LED independently. The modulation signal is available at the "REF A" or the "REF B" phone jack. To connect the signal to the oscilloscope a suitable phone/BNC cable is provided.

Introduction

Fig. 21: Start screen

After switching on the device the start screen appears. After touching the screen, the main menu appears.

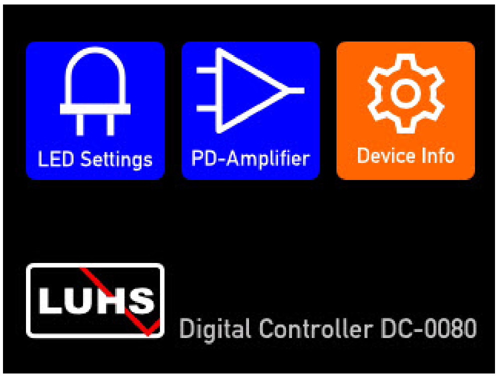


Fig. 22: Main Menu

Touching one of the buttons brings up the selected screen.

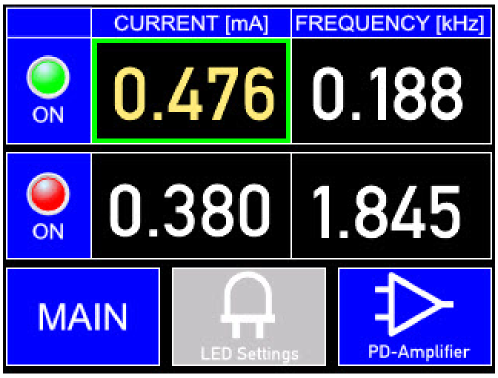


Fig. 23: LED setting screen

To switch an LED ON or OFF tap the LED button on the screen. Touching the numerical display, for instance the current, it is highlighted and the value can be change by turning the settings knob of the controller. Touching the field again deactivates it. The current cannot set be higher as it is stored in the EEPROM of the individual LED.

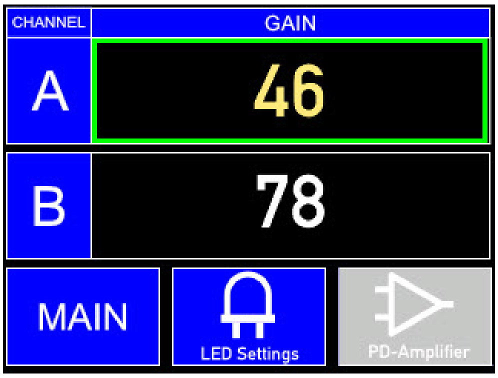


Fig. 24: Gain setting of the photo amplifier

The gain can be set from 1 to 100, which is not the real gain factor. This value will be determined within the experiments.

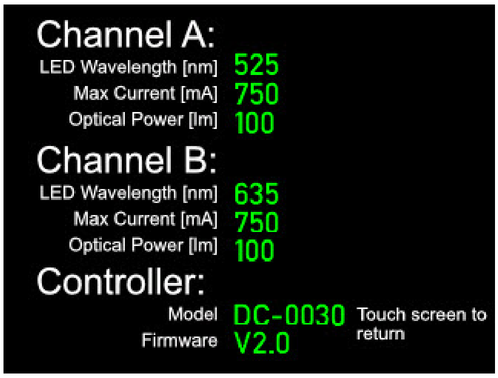
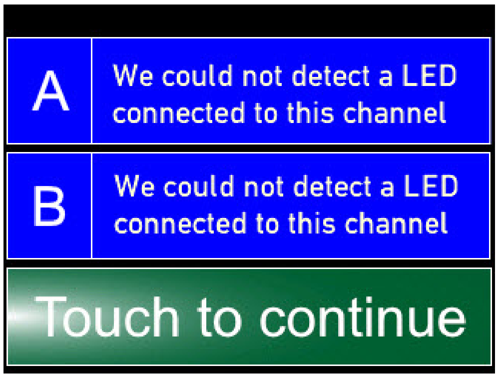


Fig. 25: Info screen



Error screen

If the controller cannot contact the EEPROM it issues this error page. In the above shown case, none of the two LED are present. However, touching the green button, one can continue working. The photo amplifier section is active whereas the reported missing LEDs are deactivated.

3.0 Preparing the fibre

Although the set-up comes with already terminated and polished fibres, a set of tools is added to get experienced to prepare the fibre to be connected and polished. Since the F-SMA connectors can be removed easily from the fibre it can be left to the students at the beginning to configure at least one fibre

3.1 F-SMA Connector

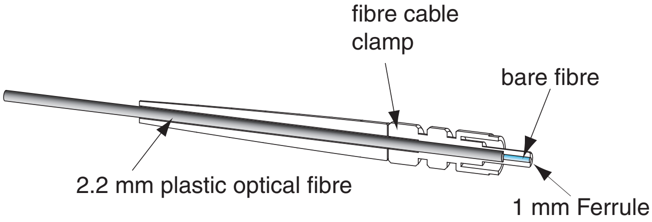


Fig. 26: Cut through of an F-SMA connector with attached POF

Before the fibre can be terminated with a connector the protective cover has to be removed at a length of app. 15 mm. This will be done with a special tool as explained in chapter 3.2. After that the fibre cable clamp is released and the fibre inserted into the connector in such a way that the bare fibre stands out approximately 2-5 mm from the ferrule. Subsequently the stand out bare fibre will be ground down with the provided polishing tools as explained in chapter3.4.

3.2 Stripping the fibre

Insert the fibre into the 1 mm slot of the stripping tool.

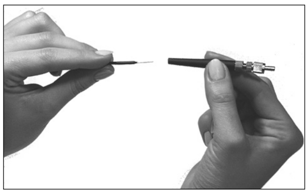
Slightly press the grips, the cladding will be removed automatically. Release the grips and remove the readily stripped fibre from the tool. Make sure that the bare fibre stands out app. 12 mm apart from the protective coating.

Ready stripped fibre

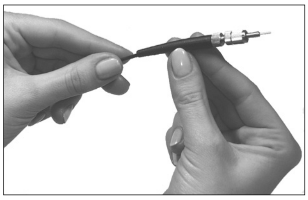
Fig. 27: Removing the protective plastic cover with the provided tool

3.3 Cutting the fibre

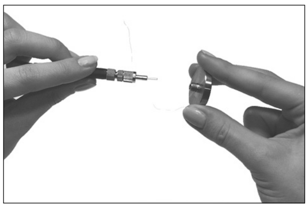
The fibre clamp of the F-SMA connector must be released Fig. 26 and the stripped fibre is inserted as far as it will go. The fibre clamp is fastened again.



The core stands out for a few mm.



Insert the plug into the polishing support and screw the cap of the fibre connector to the polishing disk.



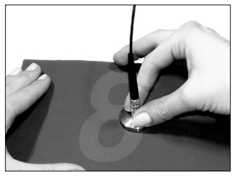
Now cut the core down the outstanding fibre to about 1 mm by means of the provided side cutting pliers.

Fig. 28: Shortening of the out standing bare fibre

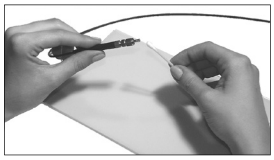
3.4 Grinding and Polishing

After cutting off the out standing bare fibre the process starts with grinding the residual bare fibre down to the surface of the plane of the polishing tool by using the 1000 grade graininess grinding paper. This takes about 10-20 seconds. Subsequently the grinding dust should be blown away from the fibre and the final polishing carried out with the yellow polishing film. After 20 to 30 seconds the fibre face should be look glossy when inspecting by eye or even better with a magnifying glass. To avoid that scratches can be built up one should move the polishing tool following the shape of an imaginary eight.

Grinding down the core following the shape of an imaginary eight.



After each grinding or polishing process the face of the fibre should be cleaned by means of a cotton swap.



Final process of polishing using the fine polishing film following the shape of an imaginary eight.

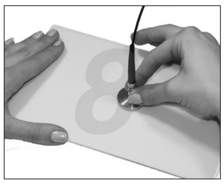


Fig. 29: Polishing the fibre following the shape of an eight

4.0 Setup and Measurements

4.1 Amplifier calibration

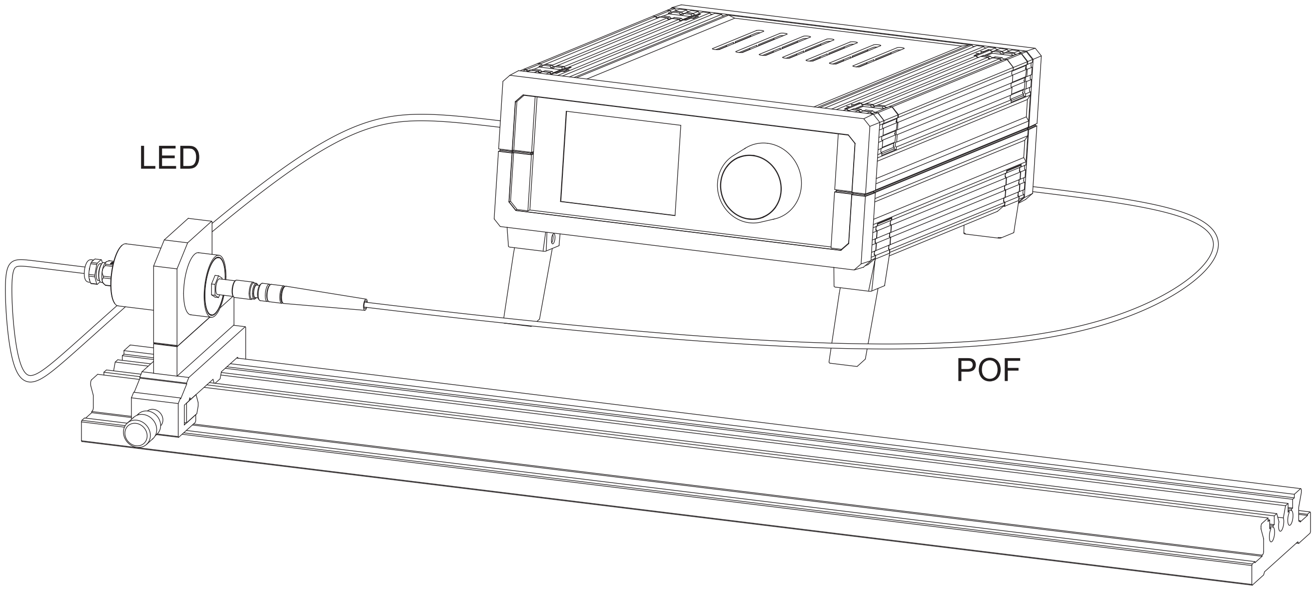


Fig. 30: Setup to calibrate the photo amplifier.

Set the mounting plate onto the rail and insert one of the LED. Connect a POF cable to the LED and a photo amplifier at the rear of the controller. Connect the output of the amplifier to the oscilloscope.

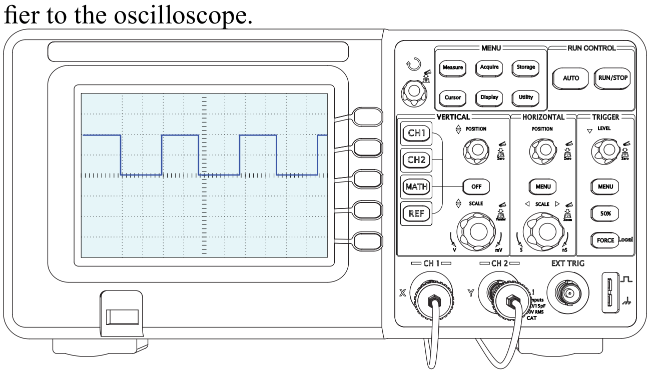


Fig. 31: Oscilloscope picture of the selected amplifier output

Select the power of the LED in such a way, that it will not saturate the photodetector or amplifier. Set the amplifier to 100 and check the signal, after that set the amplifier to 1 and check if s still a suitable signal is present. Carry out a series of measurements like:

Amplifier	Scope Amplitude	Gain
1	100 mV	1
10	380 mV	380/100=3.8
20	530 mV	530/100=5.5
100	2000 mV	2000/100=20

Please note, the above numbers are fictitious

4.2 Single wavelength channel plastic fibre

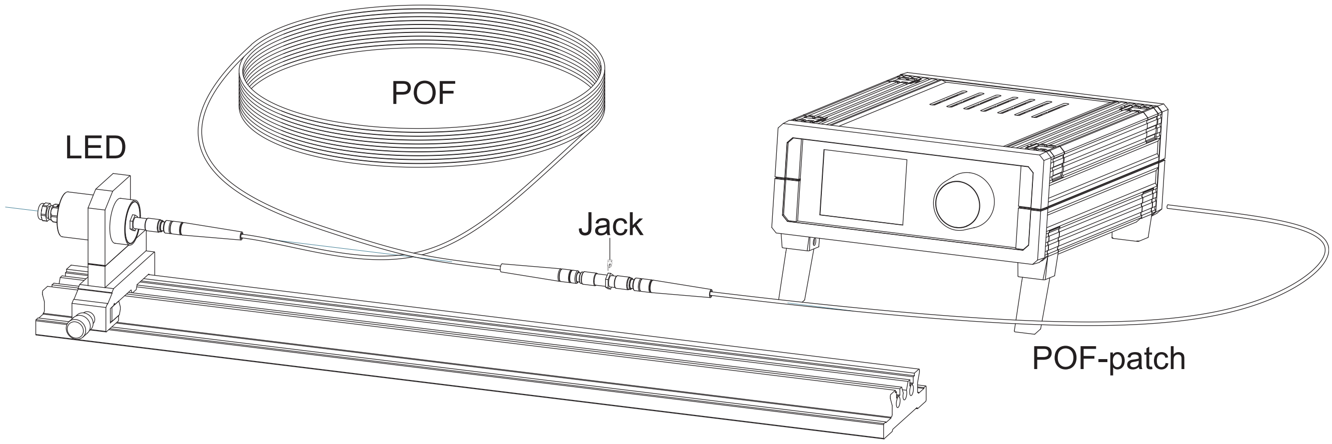


Fig. 32: Measurement of the POF attenuation.

These measurements are carried out to measure the attenuation of the plastic optical fibre for two different wavelength. A mounting plate with LED is placed onto the rail. The POF is connected with one side directly to the LED, while the other side is connected by means of the F-SMA jack (or sleeve) to the POF patch cable which is connected to one of the amplifier inputs. The respective output is connected to an oscilloscope to measure the amplitude. The measurement starts with the 1 metre long POF patch cable only. The next measurement uses the 10 metre POF cable, then the 20 metre and the 30 metre. Now we start to combine the 10 and 20 metre cable. The comparison to the single 30 metre cable

reveals the attenuation of the coupling of two fibres.
A suitable measurement table could be look like:

POF Length	Scope Amplitude	Gain Factor	Attenuation
1			
10			
20			
30			
30 (20 + 10)			
40 (30 + 10)			
50 (30 + 20)			
60 (30 + 20 +10)			

The measurements are carried out for the red as well as the green LED. To be precise, we have to take the spectral sensitivity of the photodetector into consideration and correct the measured values accordingly.

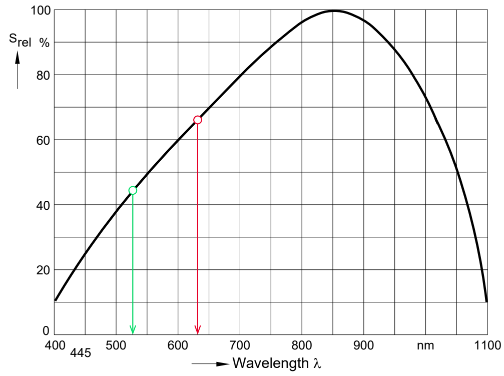


Fig. 33: Spectral sensitivity curve of the used photodetector

4.3 Dual wavelength channel plastic fibre

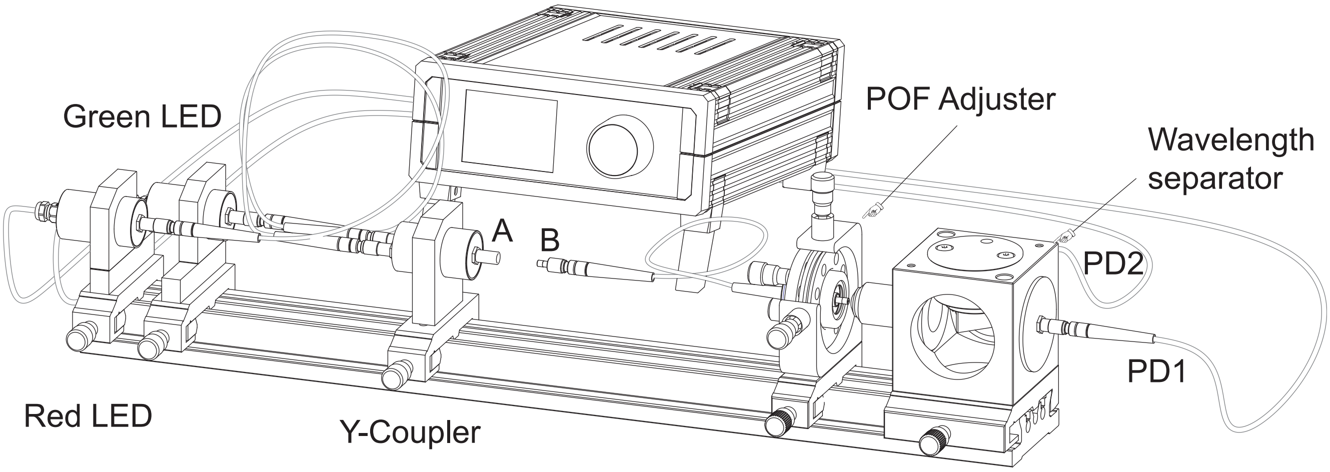


Fig. 34: Complete setup for dual wavelength transmission

This arrangement is the premium setup for simultaneously transmission of two wavelength via one plastic optical fibre. For this purpose both LEDs are set with their mounting plates onto the rail. By means of two short POF patch cable they are connected to the inputs of the Y-coupler. At the output of the coupler (A) the mixture of both light rays are visible. The colour can be changed from red via yellow to green, depending on the individual LED current settings.
On the other end of the rail the wavelength separator and the POF adjuster are placed. The POF adjuster has a fixed patch cable which end (B) can be directly connected to the Y-coupler (A). The POF patch cable PD1 and PD2 are not yet connected to the wavelength separator, so that the light can freely move through the F-SMA jacks. With a piece of white paper the spot can be visualized while gently moving the POF adjuster. In the correct position a sharp round red or green spot on the other side of the separator becomes visible. After this, the PD1 and PD2 POF patch cable are connected, so that the measurements can take place. By means of the adjustment screws of the POF adjuster the amplitude shown on the oscilloscope is maximized. The position may also be optimized for best amplitude.
Between A and B POFs with different lengths can be attached and the results recorded.

	GREEN			RED		
POF Length	Scope Amplitude	Gain Factor	Attenuation	Scope Amplitude	Gain Factor	Attenuation
1						
10						
20						
30						
30 (20 + 10)						
40 (30 + 10)						
50 (30 + 20)						
60 (30 + 20 +10)						

Measurements