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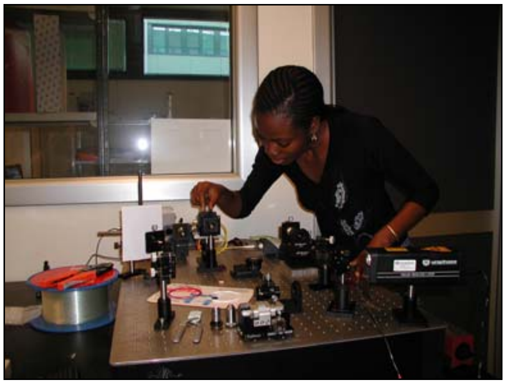

FIBRE OPTICS TRAINING KIT

Introductory Experiments Manual

(upgraded version)

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PREFACE

The purpose of this *Fibre Optics Kit* is to provide the essential basic knowledge and skills needed to work with fibre optics. It is made up of a number of fibre optic components for setting laboratory experiments aimed at understanding the basic concepts of optical fibres and giving practical hands-on experience with the basic components involved in the fibre-optics systems. The kit allows introducing some of the essential laboratory techniques which can be used for characterization of important fibre parameters along with their use in various applications. Obviously, given the limited budget, the kit contains only the core of the hardware needed for fibre optics laboratory work, the idea is that this core will then be further developed according to the interests and specialization of the group which will be using it.

This user guide describes some of the introductory experiments that can be performed with the equipment in the *Fibre Optics Kit*. Basic knowledge of the theory of fibre optics is needed in order to have a complete understanding of the experiments, therefore it should be considered as a supplement to a basic short course on fibre optics. A brief introduction is, however, given for each experiment, so as to provide a background to what is to be performed and the expected outcome.

EXPERIMENT 1.

FIBRE END PREPARATION

BASICS

Fibres have to be prepared for use both in laboratory or field applications. The first thing to do is usually the removal of a sufficient length of the jacket (cable) protective material in order to have at least 20 mm of stripped fibre surface. As a result of the preparation, the end faces of the fibre must be flat, smooth and perpendicular to the axis of the fibre so as to give maximum efficiency of light coupling. In general, this is obtained using the scribe and break technique, where a small crack is made in the fibre. The crack reduces the strength of the fibre and when a pressure higher than the breaking strength of the fibre is applied to the tip of the crack, it leads to sequential fracturing of the atomic bonds at the tip of the crack only. A flat fibre end face can be produced in this way if executed correctly. The procedure can be performed using a very simple tool (fibre scribe) or a variety of more sophisticated devices, and requires some practical skills for producing perfect fibre end face. It should be noted that the length of stripped fibre that should remain after the preparation depend strongly on the application and may vary from 3-4 to 25-20 mm.

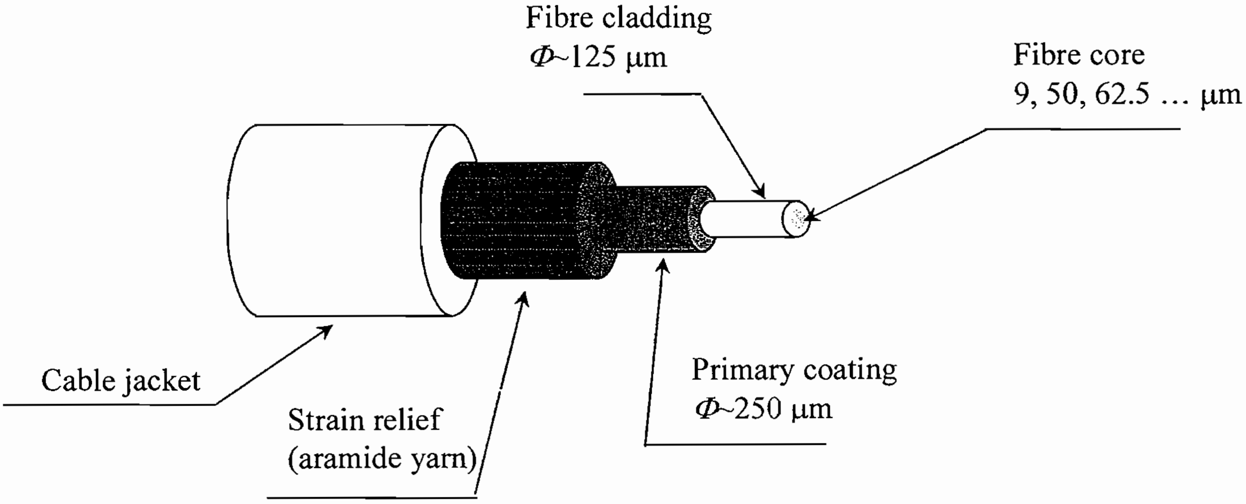


Fig. 1 Structure of a typical simplex fibre cable

This experiment will show how to prepare the ends of bare fibres and fibres with a jacket and is intended to provide the skills needed for preparing fibres for use in all the following experiments.

EQUIPMENT NEEDED

Code	Description
	Single Mode (SM) and Multi Mode (MM) fibre, 1-2 m
	50cm SM simplex cable
	Alcohol
	Kim wipes
	Fibre stripper
	Jacket stripper
	Fibre scribe

DIAGRAM

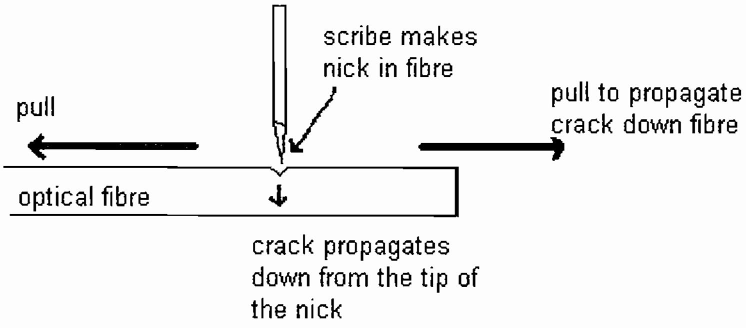


Fig.2.

METHOD

1. Take the fibre stripper with one hand and open it by pulling the handles apart. Take the bare single mode fibre in the other hand between the thumb and the forefinger. Place one end of the fibre across the 'v' groove of the stripper such that about 1cm of the fibre end protrudes from the other side of the tool. Make sure that the arrow on the tool head points in the direction of the fibre end protruding from the tool head, and that it is perpendicular to the fibre. Now gently squeeze the handles of the fibre stripper until it closes on the fibre. Holding the handles in this position, and the fibre firmly in the other hand, pull the stripper along the fibre in the direction of the arrow (on the tool end) until the end of the fibre, applying even pressure to the fibre stripper. Open the stripper and remove the stripped fibre.

2. To strip more of the fibre, place the fibre back in the stripper with the stripped end and a little of the coated fibre part protruding from the fibre stripper head and repeat the process.

3. To clean the tool, pull back the plastic head and release it so that it snaps back into place. It is possible that the fibre can break during this procedure. Any debris must be removed from the plastic head of the stripper to ensure proper tool usage.

4. Use the kim wipes with some alcohol to clean the stripped part of the fibre by gently pulling it across the length of that section of the fibre.

5. To cleave the end of the fibre, make a small nick along the transverse direction of the stripped part of the fibre and then gently pull the fibre to cleave it. The end face of the fibre should be flat and smooth.

6. Repeat this several times until you are confident and capable of producing a clean cleave easily.

7. Take the simplex cable fibre and with the jacket stripper remove about 6cm of the jacket form the fibre by placing it in hole number 18, cutting and pulling away from the fibre.

8. Separate the Kevlar from the buffered fibre either by using your hand or by bowling it to one side. All the strands of the Kevlar should be gathered together and cut evenly using the Kevlar cutter.

9. Place the tight buffered fibre in hole 26 of the jacket stripper, cut it, pulling it away from the fibre to remove the buffer from the fibre. At this point, repeat steps 1 to 4 to remove the acrylate coating form the fibre.

10. Another way to remove the buffer from the fibre is to use the fibre stripper directly, following steps 1 to 4. Care should be taken as the fibre can be cut in this process.

EXPERIMENT 2.

OPTICAL SOURCE TO FIBRE COUPLING AND FIBRE OUTPUT COLLIMATION

BASICS

In addition to in-fibre components many fibre optic systems may contain also bulk or free space optics, as well as waveguides or integrated optics. The ability to couple light from free space to fibre and to collimate the fibre output in order to interface to other components is therefore crucial in the design and building of such systems.

The optical power that can be coupled into a fibre depends both on the parameters of the fibre (numerical aperture and core diameter) as well as on the brightness of the used optical source. In general, nearly single transverse mode lasers (e.g. He-Ne or single quantum well diode lasers) are required for efficient coupling into a SM fibre, while large emitter diode lasers and LEDs can be used with multimode fibres. Without going into details, we will just recall here the basics for typical air-to-fibre couplers.

In practice, as illustrated in Fig.2, one needs to couple light beam with a diameter D_{in} and divergence θ_{in} into a fibre with numerical aperture NA and mode field diameter a (defined for the wavelength in use). Obviously, to achieve efficient coupling one has to use a lens and focus the beam to a diameter (D_f) approaching the mode field diameter of the fibre a:

$$D_f = 2f\theta_{in} \approx a \qquad (1)$$

On the other hand, the divergence of the focused beam , $\theta_f \approx Din/2f$, should not exceed the numerical aperture (NA) of the fibre, which leads to the condition :

$$f \geq D_{in}/2NA \qquad (2)$$

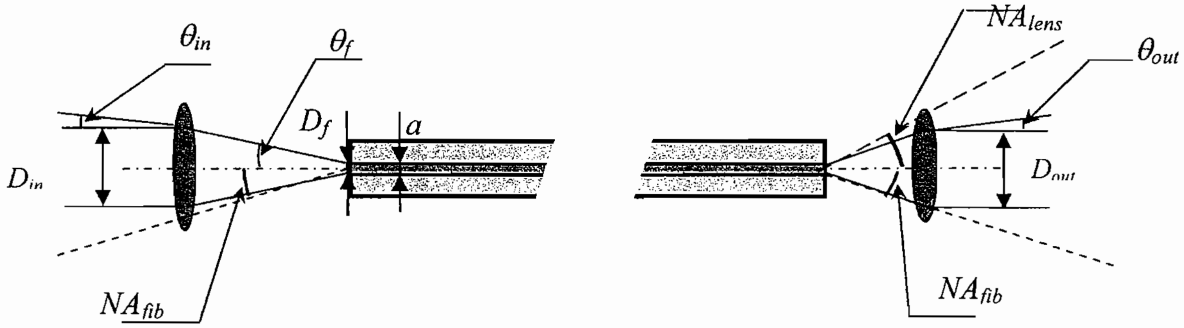


Fig.3. Air-to-fibre light coupling and collimation

In some cases (low beam quality source and small core fibre) it may not be possible to simultaneously fulfil both conditions. In this situation it might be advantageous to use a lens that exactly matches the NA of the fibre, rather then attempting to focus the beam too sharply.

In the case of single mode fibres the mode filed diameter is on the order or even smaller than 10 µm, which imposes the use of aberration corrected lenses. In this experiment two different lens types are used to couple light from a laser source into both a multimode fibre and a single mode fibre.

As it is known, light exits fibres with an opening angle equal to their NA, so the practical use of this light requires collimation. The parameters of the collimating lens are determined by two requirements:

a. to avoid losses the numerical aperture of the collimating lens has to be equal or greater than the numerical aperture of the fibre, i.e.

$$NA_{lens} \geq NA_{fib} \qquad (3)$$

b. the focal length f_c of the collimating lens is decided by the required output diameter D_{out}:

$$f_c \approx D_{out}/2NA_{fib} \qquad (4)$$

EQUIPMENT NEEDED

Code	Description
	Breadboard
	Multimode fibre 2m, core 50 µm and 62.5 or 100 µm, with known NA
	Single mode fibre 2m, known NA
	He-Ne laser (635nm) and/or collimated 670 or 780 nm laser source
F-915T	Fibre coupler (with microscope objective)
F-925	GRIN-rod lens fibre coupler
FPH-S	Fibre holder
	Plano-convex 30 to 50 mm singlet spherical lens
	Microscope objective lens (x10 and x20)
	Short focal distance doublet or aspheric lenses
	0.29 pitch GRIN-rod lens
	2 mirrors
	Lens/mirror holders
	A piece of card/paper
	Posts and post holders
BA1	Mounting base 2
	Screws/ bolts
	Power meter
	Optics catalogue with variety of lenses (e.g. THORLABS, NEWPORT, and EDMUND)

DIAGRAM

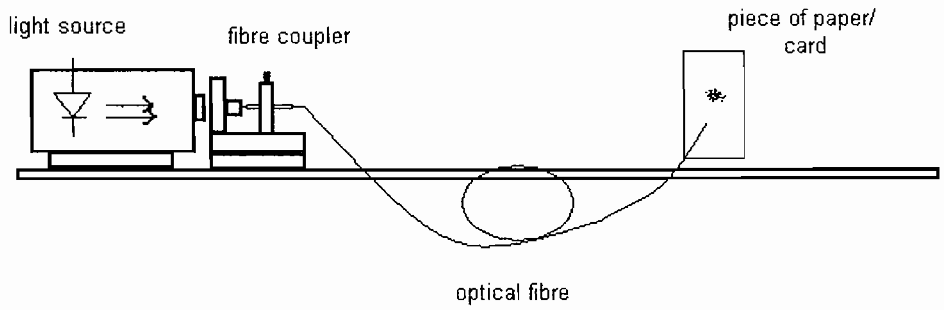


Fig.4.

I. Laser to fibre coupling using microscope objective, spherical singlet and aspheric lenses

1. Mount the laser source on the breadboard. Screw the post holders onto the mounting platforms and screw the lens holder onto the post. Fix the mirrors in the lens holder, using the small nylon tip screw to hold it in place. Mount this onto the breadboard such that the laser source focuses onto one of the mirrors and the reflected light is focused onto the second mirror.

2. Connect the X10 microscope objective lens to the F-915T and mount that also on the breadboard, with the rear focal plane of the microscope objective facing the second mirror. Align the two pieces such that the light from the laser, which is reflected by the mirrors, falls on the centre of the microscope objective, and it is also parallel with its axis. This can be done using a piece of card with a hole, the size of the laser beam, placed in the path of the beam, between the second mirror and the microscope objective. As the light beam passes through the hole in the card, the fresnel reflection from the mirror focused on the card is brought in line or into focus with the laser/the hole in the card. Care must be taken not to look into the laser light or point it into your eyes! Use an infrared sensitive card.

3. Measure the power entering the microscope objective by placing the power meter between the second mirror and the lens.

4. Take about 2 meters of multimode fibre, and prepare the ends as in the fibre preparation experiment.

5. Put one end of the fibre in the fibre holder, with about 0.5cm protruding from the end of the holder. Put the fibre holder into the fibre coupler, with the protruding end of the fibre facing the microscope objective.

6. Use the adjustment knobs of the fibre positioner to bring the end of the fibre into the focal plane of the microscope objective lens to achieve maximum coupling of the laser light into the fibre.

7. By pointing the other end of the fibre onto a piece of paper, you should be able to see the light which is coming out of the fibre patterned onto the paper. The patterns are the different modes of the fibre.

8. Measure the power from the end of the fibre. A coupling loss of 2dB (37%) or less is the target.

9. Change the microscope objective from the X10 to X20 or another of the available lenses listed above. Repeat the procedure of coupling into the fibre (N.B. be sure of the proper orientation of the singlet and aspheric lenses: the flat or higher radius of curvature surface should be towards the focus)

10. Measure again the input/output power for the fibre with this configuration and calculate coupling efficiency. Power meter.

11. Repeat the procedure with the single mode fibre.

12. Using the formulae above and the data for the lenses and the fibre explain the obtained results

II. Laser to fibre coupling using a GRIN-rod lens

13. Take the GRIN-rod fibre coupler and mount that on to the breadboard. Take a 0.29 pitch GRIN-rod lens and insert it into the v-groove (the small hole) in the front of the lens holder and tighten the nylon-tipped screw to hold it in place. The lens should extend out of the coupler, about 1mm towards the source. Be careful not to over tighten the lens into place.

14. Mount the laser source onto the breadboard and align it with the lens using the same procedure as in the microscope objective case. The focusing spot of the source should be on the axis of the lens.

15. Measure the power entering the lens.

16. Take 2m of single mode fibre and prepare the ends.

17. Repeat steps 3 to 8 of the microscope objective coupling using the GRIN-rod lens in place of the microscope objective.

III. Fibre output collimation

18. Using equations 3, 4 estimate the required NA and focal distance for collimating the output of the used single mode fibre into a beam with diameter about 5 mm . Choose from the available lenses the one that matches closely both conditions.
19. Mount the lens in the proper holder (in the absence of one more F-915T this can be a single axes translation along the optical axes) and insert approximately one focal distance away from the fibre exit face. (NB: Also at this step be sure the lens is properly oriented!)
20. Observing both near and far from the lens adjust the proper fibre –lens distance for exact collimation.
21. Measure the collimated light power in order to verify if all light is collected. Check collimated beam spot diameter and compare with the required one.

EXPERIMENT 3.

MEASUREMENT OF FIBRE NUMERICAL APERTURE

BASICS

In optics, the numerical aperture, NA, is a measure of how much light can be collected by an optical system, and is defined as $NA=n\sin\theta_{max}$, where n is the refractive index of the incidence medium (1 for air) and θ_{max} is the maximum entrance angle at which optical ray can enter and propagate in the system. It is easy to show that for step-index fibre the NA is given by

$$NA=(n_{co}^{2}+n_{cla}^{2})^{1/2}\approx n_{co}\,(2\Delta n)^{1/2} \qquad (5)$$

where $n_{co},\ n_{cla}$ and Δn are the fibre core and cladding refractive indices and their difference, respectively. For light rays to be propagated along a fibre they must fall within the acceptance angle defined by *asin(NA)*. The numerical aperture of a fibre is therefore an indication of how much light a fibre can accept or a measure of the fibres acceptance angle. We will measure the numerical aperture of a multimode fibre in this experiment.

EQUIPMENT NEEDED

Code	Description
	2m multimode fibre
	Breadboard
	635nm laser source
	Power meter
RP01/M	Rotational platform
FP-1	2 fibre positioners (can be unscrewed from the fibre coupler mounts)
FPH-S	2 fibre holders
	Posts and post holders
	Mounting platforms

DIAGRAM

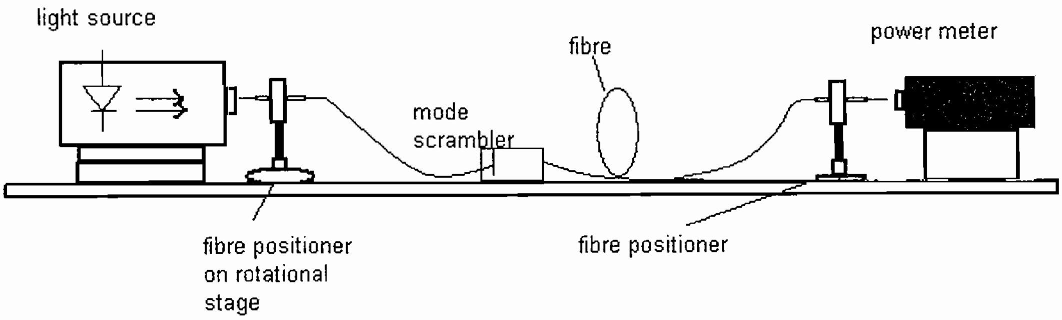


Fig.5.

METHOD

1. Mount the laser source and the rotational stage onto the breadboard such that the beam form the laser source passes over the centre of the rotational stage.

2. Mount the post holder onto the rotational stage and secure the post in the post holder. Mount the fibre positioner onto the postholder.

3. Prepare the ends of the multimode fibre and insert one end into the fibre positioner using the fibre holder. The tip of the fibre should be extended out of the fibre holder and orientated such that the fibre tip is at the centre (zero position) of the rotational stage. The tip of the fibre should on rotation of the stage, remain at the centre of the laser beam.

4. Mount a fibre positioner onto the breadboard and insert the other end of the laser into the fibre holder of the positioner.

5. Mount the power meter such that the output from the fibre is incident on the detector head of the power meter. Make a protective hood of aluminium for the detector in order to keep stray light form the room of the detector.

6. Block the laser path and take the power meter reading (reference reading).

7. Measure the power of the laser (at the end of the fibre) accepted by the input end of the fibre. Rotate the stage (in the positive and negative directions) and take the power readings for the corresponding rotations.

8. Plot a graph of power received by the detector against the sine of the angle. Measure the distance between the two points where the power is 5% of the maximum power level. The numerical aperture is half this value.

9. Compare the obtained result with NA specified by the producer.

10. Estimate the core refractive index using for the cladding refractive index a value of 1.46.

EXPERIMENT 4.

FAR FIELD DISTRIBUTION OF SINGLE FIBRE MODE

In predicting the performance characteristics of single-mode fibres, the geometrical distribution of light in the propagating modes is more important than the core diameter and the numerical aperture. The field of the fundamental mode in single mode fibre bears little resemblance to the refractive index profile and therefore the area of the doped core region itself does not truly represent the area of the mode field.

In conventional step-index fibres, the mode (for wavelength above the cut-off wavelength) is nearly HE_{11} and its intensity distribution is therefore very well-approximated by a Gaussian function:

$$I(r)=I(0)exp(-r/r_0)^2 \qquad (6)$$

where r_0 is the radius measured at $1/e^2$ point; $mfd=2\,r_0$ is usually called mode field diameter.

When the radiation propagating in a single mode fibre reaches a cleaved end face, it radiates into the surrounding medium. The core of single mode fibres is typically 5-10 μm, so for telecom wavelengths the near filed region is quite short ($r_0^2/\lambda \approx 100$ μm). This makes the near-filed distribution measurement more difficult (usually it has to be done by a properly designed optical image transfer system) and makes more interesting the far-field measurement.

Assuming a spherically symmetric fibre and neglecting for simplicity the so called obliquity factor ($\sim\cos\theta \approx 1$ for small angles), the far-field amplitude distribution is given by the Hankel transform of the near filed distribution. So, if one measures the far-field distribution, the fibre mode distribution can be recovered by performing inverse Hankel transform. The aim of the far-field scan technique is to accurately measure the angular distribution of the intensity of the single mode fibre.

EQUIPMENT NEEDED

Code	Description
	2m, SM fibre (possibly with cut-off wavelength below 600 nm)
	Breadboard
	635 nm He-Ne laser or collimated 670 nm diode laser
	Power meter
F-91TS	Singlemode coupler stage
F-915T	Fibre coupler for microscope objective
FPH-S	2, Fibre holders
	Microscope objective lens
FP-1A	Fibre positioner
RP01/M	Rotational stage
FM-1	Mode scrambler
	Post and post holders
	Razor blades

DIAGRAM

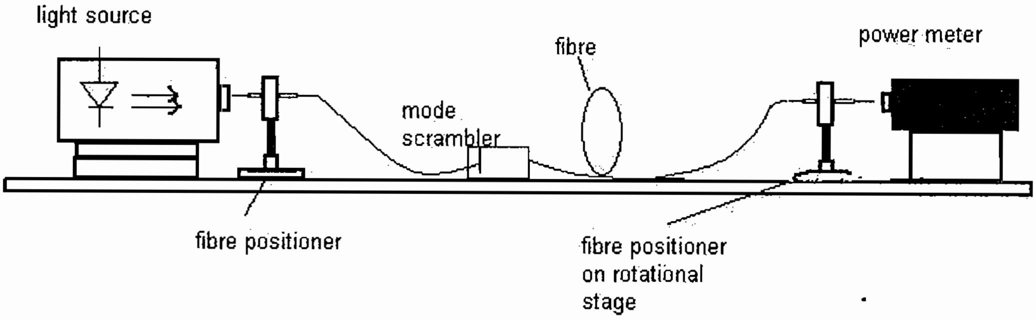


Fig.6.

METHOD

1. Mount the laser, the fibre coupler combination, and the microscope objective on the breadboard. The laser light should strike the lens at its centre. The beam should be parallel to the axis of the lens.

2. Prepare the single-mode fibre ends and place one end in the fibre holder and insert it into the fibre coupler.

3. Bring the fibre into the focus of the focus of the lens. Using the adjustment knobs on the FP-1 positioner of the coupler, and the X, Y stage of the coupler maximise the power coupled into the fibre.

4. Mount the mode stripper on the breadboard, placing it at a convenient place near the launch end of the fibre. Open the mode scrambler by turning the adjustment knob anticlockwise. Put the fibre (from the coupler end) between the two corrugated surfaces of the mode scrambler and turn the knob clockwise till the corrugated surfaces touch the fibre, and hold it in place firmly.

5. Insert the other end of the fibre into a fibre positioner with the aid of a fibre holder, and mount the fibre positioner onto the rotational stage.

6. Use the razor blade and adhesive tape to form a slit no greater than 1mm on the detector head of the power meter. The tape should not be transparent to the laser light. Alternatively, one can use a 1 mm pin-diode without masking.

7. Mount the masked power meter detector head at least 10mm from the end of fibre.

8. By rotating the rotational stage measure the far-field power distribution of the fibre, using the detector, as a function of the angular rotation of the fibre end. The rotational steps should not be more than 0.5°. Take the power measurements using both positive and negative angular deviations. This is to compensate for any angular misalignments.

9. Plot a graph of the power distribution vs angle. Fit by a Gaussian curve and find width of the radius of this curve at $1/e^{-2}$ height. Estimate the mode field diameter of the fibre (you would need also to measure the exact distance fibre-measurement plane).

EXPERIMENT 5.

FIBRE ATTENUATION MEASUREMENTS

BASICS

The attenuation in optical fibres is one of the most important measurands for optical transmission systems, because, combined with dispersion effects, it determines the maximum distance between repeaters. Distributed loss mechanisms are mainly absorption and scattering, both leading to exponential attenuation (for given mode). Fibre attenuation is one of the primary specifications of any optical fibre and it is also one of the easiest to measure. The cutback method has developed to the standardised measurement for high precision attenuation measurements on fibres (ITU-T G.650).

Briefly the method includes the following steps. The optical output P_0 at the end of the fibre is measured first. To compare the output with the input, the line is cut to a short length. There the input P_i is measured with constant light source power, unchanged coupling and detector. Obviously, the attenuation A in dB is found to be:

$$A = 10 \log(P_i/P_o) \qquad (7)$$

If attenuation is needed at different wavelengths, different diode lasers are normally used. Alternatively, the range of interest can be covered by a tuneable source (e.g. ASE from an Er-doped amplifier at telecom wavelengths).

It is worth noting that when a multimode fibre is concerned, the total attenuation depends on the mode spectrum and on the power distribution of the different mode, so there may not be an exponential fall without mode-scrambling.

EQUIPMENT NEEDED

Code	Description
	Breadboard
	Laser sources: 635, 850nm and 1300nm
	Power meter
FPR1-C1A	Fibre positioner for connector (unscrewed from the F-92-C1)
FP-925	GRIN-lens fibre coupler
F-915T	Microscope objective Fibre coupler
F-91TS	Fibre coupler platform
FM-1	Mode scrambler
	Singlemode fibre spool
	Multimode patch cord
	Objective lens
	0.25 pitch GRIN-rod lens
	Mirrors (2)
	Lens holders
FP-1	Fibre positioner
	Post and mounting platform
FPH-S	Fibre holder (2)
FPH-CA6	FC-chuck
	IR card

DIAGRAM

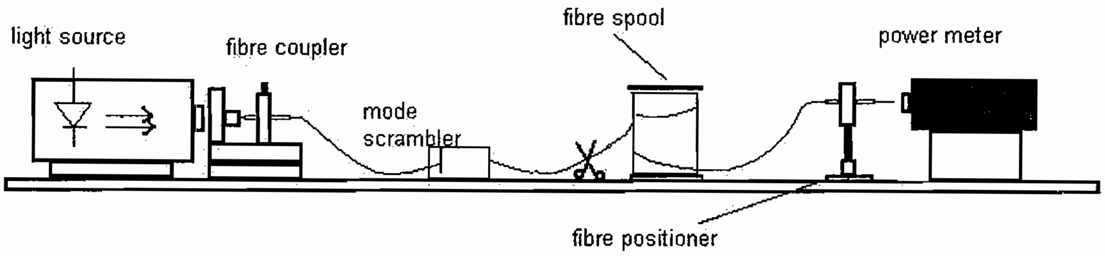


Fig.7.

METHOD

(with visible light source- 635nm)

1. Mount the F-915T fibre coupler onto the F-91TS. Fix on the microscope objective and mount the assembly onto the breadboard.

2. Taking the fibre spool, carefully find and free about 50cm of the two ends of the fibre. Prepare both ends of the fibre. Take one end and place it in a fibre holder, and insert it into the fibre coupler. Note the length of the fibre being used should be indicated on the fibre spool).
3. Mount the fibre positioner using the posts, onto the breadboard at a convenient position, and place the other end of the fibre, in a fibre holder, into the fibre positioner.

4. Mount the 635nm laser diode onto the breadboard and measure its power. Align the laser with the microscope objective end of the fibre coupler as in Experiment 2.

5. Place the mode scrambler at a convenient place near the launch end of the fibre. Open the mode scrambler by turning the adjustment knob anticlockwise. Put the fibre (from the coupler) between the two corrugated surfaces of the mode scrambler and turn the knob clockwise till the corrugated surfaces touch the fibre, and hold it in place.

6. Measure the power from the far end of the fibre (mounted on the fibre positioner) using the power meter.

7. At a length of about 2m after the mode scrambler, break the fibre. Remove the fibre spool (remove the fibre from the fibre positioner) and indicate on the fibre spool the new length of fibre, for furthur use. Taking the part of the broken fibre which is from the mode scrambler, prepare the end and insert it into the fibre positioner and measure the output power.

8. Calculate the fibre attenuation with the readings obtained.

METHOD

(with connectorized infrared wavelength source - 850nm and 1300nm)

9. Remove the visible laser source. Mount the FPR1-C1A fibre positioner adapted for chuck onto the breadboard using a post and the mounting platform so that it is the same height as that of the F-91TS platform.

10. Using Kim wipes and alcohol, clean the connector end of the laser source and patch cord. Connect one end of the multimode patch cord to the 850 nm laser, and insert the other end into the FC-type chuck (FPH-CA6). Insert the chuck into the FPR1-C1A fibre positioner, using the adjustable screws to hold it securely in place.

11. Replace the F-915T from the F-91TS with the F-925 GRIN-lens fibre coupler. (Do not remove the fibre from the mode scrambler or touch the mode scrambler). Insert a 0.25 pitch GRIN-rod lens into the v-groove of the coupler.

12. Align the fibre positioner holding the patch cord with the GRIN lens so as to obtain maximum power from the lens. Use an IR card to detect the position of the light and use the power meter to measure the power output from the lens.

13. Insert the fibre holder containing the input fibre (step 2), into the F-925 coupler. Align the fibre to the lens to obtain maximum coupling of power into the fibre.

14. Repeat steps 6 to 8. Repeat the measurement at 1300 nm.

EXPERIMENT 6.

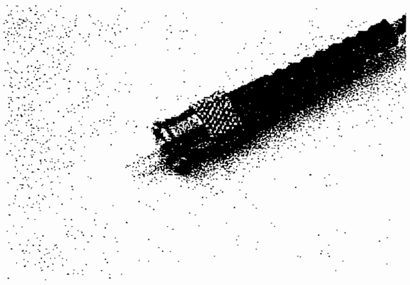
FIBRE-TO- FIBRE COUPLING

BASICS

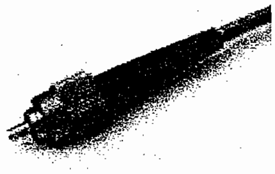
In addition to coupling external light sources to fibres and out-coupling light from fibres to external detectors, in many laboratory measurements and practically in all field fibre optic works it is necessary to be able to couple light from fibre to fibre. This need has motivated the continuous effort for developing methods allowing to efficiently and reliably connecting fibres which may be of different types and have different, numerical aperture, core and cladding diameters, etc.

The loss due to fibre coupling depends on the types of fibres being joined together, the size and eccentricity of the core, the refractive index profile and the numerical aperture. Mechanical misalignment, that is longitudinal, lateral, and angular misalignment of the fibres is also of primary importance.

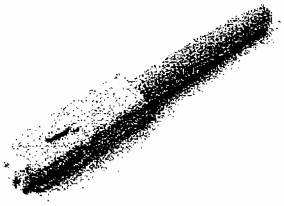
This experiment focuses on methods for temporary coupling, including butt fibre to fibre coupling, coupling using GRIN-rod lens, and joining with the use of mechanical and elastic-tube splices and connectors.
Concerning the connectors, here we want to emphasize that they are under continuous development, rapidly generating new designs and styles. Each new design was meant to offer better performance (less light loss and back reflection), easier and/or termination and lower cost. Of course, the marketplace determines which connectors are ultimately successful. Below we present three of the most popular connector types.



ST (an AT&T Trademark) is the most popular connector for multimode networks, like most buildings and campuses. It has a bayonet mount and a long cylindrical ferrule to hold the fiber. Most ferrules are ceramic, but some are metal or plastic. And because they are spring-loaded, you have to make sure they are seated properly. If you have high loss, reconnect them to see if it makes a difference.



FC/PC has been one of the most popular singlemode connectors for many years. It screws on firmly, but make sure you have the key aligned in the slot properly before tightening. It's being replaced by SCs and LCs.



SC is a snap-in connector that is widely used in singlemode systems for its excellent performance. It's a snap-in connector that latches with a simple push-pull motion. It is also available in duplex configuration.

Fig.8. Three of the most-popular connector types

EQUIPMENT NEEDED

Code	Description
	Breadboard
	1m single mode fibre (2)
	1m SM simplex cable (2)
	Posts and post holders
	635nm laser
	Microscope objective lens
	0.25 pitch GRIN-rod lens (2)
	Splice
	FC connector assembly (2)
	Mating sleeve
	Epoxy (1)
	Syringe
	Lapping sheets
	Polishing fixture for FC connectors
	Power meter
FP-1	Fibre positioner
F-915T	Fibre coupler for microscope objective
F-91TS	Fibre coupler platform

DIAGRAM

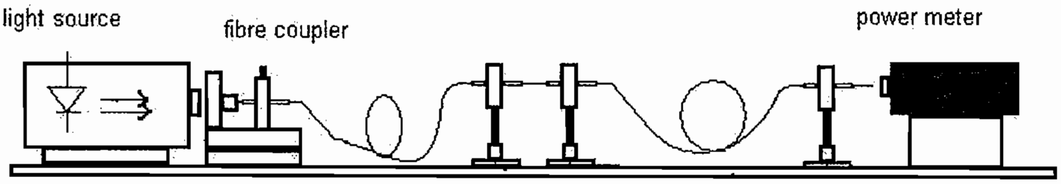


Fig.9.

METHOD

(dry butt fibre coupling)

1. Prepare the ends of 2 pieces of single mode fibre. Using the microscope objective, the laser source and the F-91TS/F-915T fibre coupler (mounted on the breadboard), couple the light source into the fibre.
2. Mount the output end of the fibre inserted in the fibre positioner (FP-1), onto the breadboard and measure the output power.
3. Mount the second fibre positioner onto the rotational stage and mount this assembly onto the breadboard such that the two fibre positioners are inline and facing each other. Insert the second piece of fibre into the fibre holder and into the fibre positioner. Insert the other end of this fibre into another fibre positioner on the breadboard for the output power to be measured.
4. Extend the fibre ends such that they are touching each other (dry butt coupling). Adjust the x-y-z of the fibre positioners to achieve maximum coupling.
5. Measure the maximum power out of the second fibre segment of the setup. Calculate the loss for butt coupling.

METHOD

(mechanical and elastic-tube splicing)

6. Take the two ends of fibre which have been butted together and remove them form the fibre holders. Clean the ends of the fibre with alcohol, using Kim wipes. Insert the fibre ends into the elastomeric splice. Measure the output power form the end of the fibre connection using the power meter.
7. Remove the fibre ends from the elastomeric splice and insert them into the FIS ultra splice. Again measure the power outputted.
8. Compare the fibre coupling loss due to dry butt coupling, elastomeric splicing, and with the use of the FIS ultra splice.

METHOD

(connectors)

9. Take the one of the simplex cables and thread the strain relief boot and the metal crimp sleeve onto it. Prepare both ends of the cable, with one end having a bare fibre length of about 20cm. The other end should have extending from the end of the fibre jacket, 0.8cm of the Kevlar, 1.8cm of the tight buffer, and 3.5cm of the bare fibre.

10. Fan out the Kevlar away form the tight buffer and in the preparation, all of it must be on the out side of the connector.

11. Mix the epoxy and empty the packet into a syringe. Place the needle into the connector until it stops at the base of the ferrule. Inject the epoxy until a small bead forms on the end of the ferrule. Withdraw the syringe quickly from the connector, taking care not to any of the epoxy on to the connector.

12. Insert the fibre into the back of the connector, rotating the fibre slightly will help the fibre get into the precision hole inside the connector. Slide the fibre into the connector until it stops. The fibre should exit the top end of the ferrule. Make sure that the Kevlar is still fanned out, away from the connector.

13. Carefully holding the connector and simplex cable in one hand, slid the crimp sleeve up the cable with the other hand. Push the crimp sleeve over the Kevlar such that the Kevlar is between the back of the connector and the crimp sleeve. Care must be taken at this stage as the fibre can easily break, or slide of the connector.

14. Hold the connector, crimp sleeve assembly in one hand, and the crimp tool in the other, put the .190 hole of the crimp tool around the larger portion of the crimp sleeve and close the crimp tool slightly. Now carefully move your index finger to the bottom of the crimp sleeve, with the thumb at the top of the connector. As the connector and the crimp sleeve are pushed together and held in place by the thumb and finger, crimp the sleeve.

15. After crimping the large part of the crimp sleeve, move the connector assembly and holding the connector housing, crimp the smaller part of the crimp sleeve with the .151 round hole of the crimp tool.

16. Point the connector ferrule upside down to allow the epoxy to cure uniformly around the fibre. This will take about 10 minutes.
17. After the epoxy has cured, scribe the protruding fibre as close to the ferrule as possible (Experiment 1). A small stub of fibre will be left at the tip of the ferrule.

18. Using the grey lapping sheet (15um), hold the connector upwards and gently file the small stub of fibre on the tip of the ferrule, using a circular motion. The dull side of the lapping sheet is used to polish! This is done until there is no sharp scratch on the polish sheet from the ferrule tip.

19. Place the connector into the FC polishing disc, securing it in place. With the same 15um polishing sheet on top of a foam pad, (dull side facing upwards), move the polishing dics in a figure 8 motion across the sheet. After about 20 or so strokes, only a light mark should be evident on the lapping sheet.

20. Remove the connector from the disc and clean both the ferrule end and the disc with alcohol and the Kim wipes. Place the pink lapping sheet on the rubber pad and use alcohol to wet the sheet. With the connector fixed in the polishing disc, again use the figure 8 motions to polish the fibre. After about 20 strokes, inspect the end of the ferrule. Remove the connector from the polishing disc and clean it with alcohol and Kim wipes as before.

21. Repeat the polishing process again using the white, 0.3um lapping sheet, and a little alcohol.

22. Clean the polishing disc at the end of the process.

23. Repeat the whole process, that is, steps 9 to 16 for the other simplex cable.

24. Couple the laser light into the bare fibre end, using the microscope objective and the fibre coupler setup. Measure the output power (from the connector end).

25. Clean the mating sleeve and the connector ends with alcohol and then, mate the two connectors so that the two fibres are jointed together. Measure the power from the bare fibre end of the second simplex cable and determine the loss in power.

EXPERIMENT 7.

INSERTION LOSS MEASUREMENTS

Fibre optic systems for both telecom and other applications are growing in complexity and usually contain a number of in-fibre components like splices, connectors, modulators, polarisers, wave-plates, etc. Each of them brings up an additional loss to the systems, and the measurement of this value is essential for properly designing sources and detection.

A way of measuring the loss characteristics of a fibre or device is to use the insertion loss technique. Most devices are pigtailed with connectors attached, and this method of measuring their insertion loss is most appropriate. This is also appropriate for bare fibre pigtailed components. This is the second alternative test method for fibre attenuation measurements. The measurements consist of the evaluation of the power loss due to the insertion of the device to be tested between the launch and receiver system, after the system has been calibrated to find the reference power.

EQUIPMENT NEED:

Code	Description
	Breadboard
	Fibre positioner
	Patch cord
	Simplex cable with connector on one end and bare fibre on the other
	50cm or less of fibre, with one end connectorized (from Experiment 5)
	1x2 coupler
	Elastometric splice (3)
	Power meter
	Laser source (1300nm)
	Mating sleeve
	Kim wipes
	Alcohol

DIAGRAM

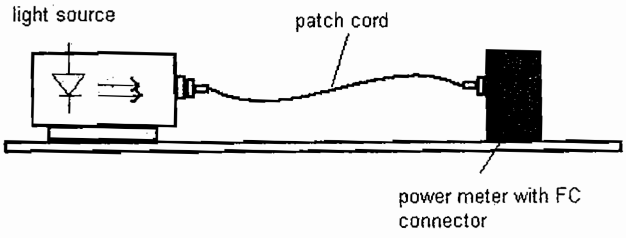


Fig.a, calibration measurement

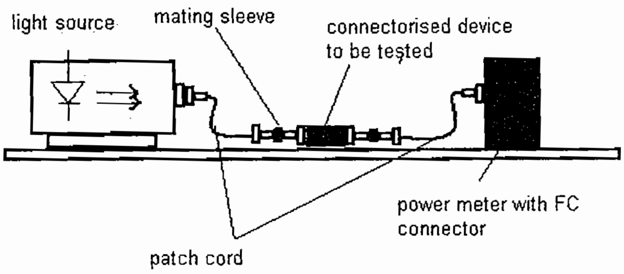


Fig.b, Insertion loss measurement

Fig.10.

METHOD

1. One of the connectorized simplex cabled fibres from Experiment 5 can be used, otherwise, one piece of a patch cord cut in two (50cm maximum) will do. The bare fibre end should be cleaved and cleaned.
2. Connect a patch cord from the laser source to the power meter. Measure the power taking that to be the reference.
3. Remove the connected patch cord from the power meter end and mate it to the connector end of the simplex cable.
4. Mount the bare fibre end of the cable onto a fibre positioner and mount it on the breadboard, aligning it with the detector of the power meter so that the power meter is able to capture the entire radiation from the fibre end.
5. Measure the output power and find the loss of the connector.

METHOD

(for bare fibre pigtailed components, e.g. a 1x2 coupler)

1. Clean the ends of the connectors and the mating sleeves with alcohol for each use.
2. Connect one of the cables with only one connector at the end to the laser source, and the other cable to the power meter.
3. Join the bare fibre ends with one of the elastometric splices. The ends should have been cleaned.
4. Measure the power (calibration).
5. Carefully taking the coupler, inspect the ends of the buffered pigtail and if ok, clean them. Otherwise, prepare the ends as in Experiment 1.
6. Removing one of the fibre ends from the splice, and splice together anyone of the ports of the coupler, noting that particular port as port A, to the pigtailed end from the source.
7. Splice the bussole to one of the two remaining ends or ports of the coupler. Taking that to be port B.
8. Splice the power meter to the remaining coupler port C, and measure the power form that port.
9. Remove the bussole from port B and splice it to the power meter, and splice port C to the bussole. Measure the power of that port.
10. Take port B now as the input port and measure in turn the power out of ports A and C as done before.

11. Take port C as the input port and measure the power form ports A and B alternately.

12. Calculate the insertion loss, the minimum isolation and the coupling percentage of the devices. (It should be noted that the insertion loss is inclusive of one splice).

EXPERIMENT 8.

ADVANCED WORK

OPTICAL TIME DOMAIN REFLECTOMETRY (OTDR)

BASICS

OTDR is the basic technique for measurement of location dependant attenuation. It is by far the most important tool for diagnostics of fibre optics links and allows locating problems caused by different reasons, like non perfect connectors and splices, use of out-of-specs fibres, environmental influences, etc. The method is non destructive and only one end of the fibre link is needed.
The fundamental principle of the OTDR is the same used for the pulsed radar.

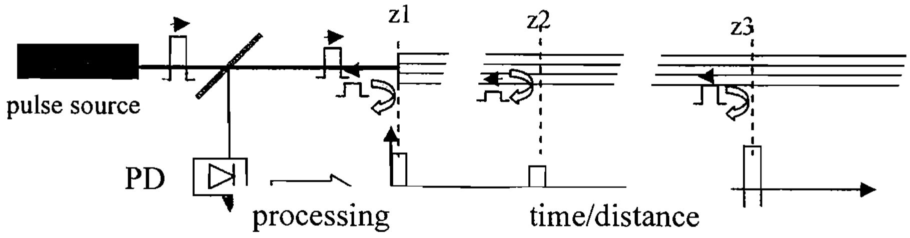


Fig.11. Sketch of OTDR principle of operation

A pulse from a pulsed laser source is coupled (after a beam-splitter) into the investigated fibre link. Defects and impurities in the fibre and at connector and splicing points will reflect back light, so attenuated pulse replicas will return and be directed by the beam-splitter onto the photo-detector (PD) with a delay time $t=2z_i/v_g$, where $v_g = c/n_g$ is the group velocity of the pulses in the fibre. Obviously, for pulses of duration τ the location resolution is limited by $\Delta z, \approx v_g \tau /2$. This picture is actually oversimplified; the OTDR is not just a 'fault' locator. A deeper analysis of the light propagation forward and backward in fibre is needed for understanding the more important OTDR application and can be found in many textbooks, one of the first comprehensive treatment has been done by Nakazawa ("Rayleigh backscattering theory for single-mode optical fibers", Opt. Soc. Am., vol. 73, no. 9, pp. 1175 - 1179, 1983). Here we will try to present only very briefly the physical picture.

The total losses in the fiber are caused by different mechanisms and the total attenuation coefficient can be different at any point of the fiber, and in general can be split into two components: absorption losses and Rayleigh scattering losses. A part of the isotropically scattered optical power is refracted at the boundary core/cladding and is totally lost and the other part is recaptured by the numerical aperture of the fiber and propagates in the forward and backward direction. The part directed backwards is called *backscattered optical power*. Its magnitude is directly proportional to the backscattering coefficient normally denoted by *S*. For the backscattering coefficient *S* one can derive analytical relations describing its magnitude for the single-mode and multi-mode fibers with a given refraction index profile. For example, under some simplifying assumptions, the backscattering coefficient for a single-mode optical fiber can be obtained in the form:

$$S = \frac{\frac{3}{2} NA^2}{\left(\frac{mfd}{a}\right)^2 V^2 n_1^2} \quad , \quad (8)$$

where NA is the numerical aperture as defined in eq.5 , *mfd* is the mode field diameter , *a* the core diameter, V the so called normalized frequency $V = (2\pi a/\lambda)NA$. For the case of a multi-mode fiber with a step-index profile the backscattering coefficient is given by a simpler relation:

$$S_{step} = 0.38 \frac{NA^2}{n_1^2} \qquad (9)$$

The backscattered power is, similarly to the forward propagating total optical power, attenuated on the route to the input face of the fiber. At the end, one can obtain that the optical power reaching the detector at a moment *t* and originating from a particular length element *dz* is given by:

$$dP_{scat}(t) = R_{st} S \alpha_s P(z) dz e^{-\alpha_r(z)} f(t,z) \qquad (10)$$

where P(z) is the power arriving at location z, α_s is the scattering coefficient, α_r is the loss coefficient upon return, R_{st} takes into account also the attenuation of the beamsplitter (usually 3 dB), f(t,z) is a function of the temporal shape of the input signal. For a rectangular input pulse the equation above can be integrated and expressed as a function of distance:

$$P_{scat}(t) = R_{st} S(z) \alpha_s(z) P(z) e^{-\alpha_r(z)} \Delta z \qquad (11)$$

Usually the OTDR signal is given in dB scale, as an exercise please re-write it recalling the dB definition.

GUIDELINES TO THE EXPERIMENTAL SETUP

The setup presented here is based on a special short pulse laser source available for the Ghana kit only. It incorporates a Nd:LSB microchip laser delivering sub-5 ns long pulses. When applied to OTDR, this source allows to have a very high location resolution and easy signal detection. The relatively high peak power, however, requires care in the work with the source and may require particular attention to avoid nonlinear effects in long fibres.

The setup is shown on Fig.12. Be sure to wear protective glasses before turning the laser driver on! The laser can be coupled efficiently to a single mode fibre (cut-off wavelength 780 nm) using an IR coated microscope objective (Newport LA10B) and single-mode fibre coupler mount F-915T. The compact size of the laser source allows using a standard 1'' holder; it may be useful to mount it on additional translation stage to avoid the use of steering mirrors. Depending on the fibre used, a coupling efficiency of 20-30% is expected, be sure to obtain optimum coupling before proceeding with measurements.

As a beam-splitter, a 2x1 SM coupler is used. The output of the coupler (port 2) should be connected to the studied fibre sample using connector or mechanical splice (S). Several pieces of different length fibre with known parameters may be connected in series at a later stage. In the beginning, disconnect the fibre sample and couple port 3 to the detector. Providing a proper triggering signal, observe on the oscilloscope the laser pulses reflected from the end face of port 2 and traveling to 3 through BS.

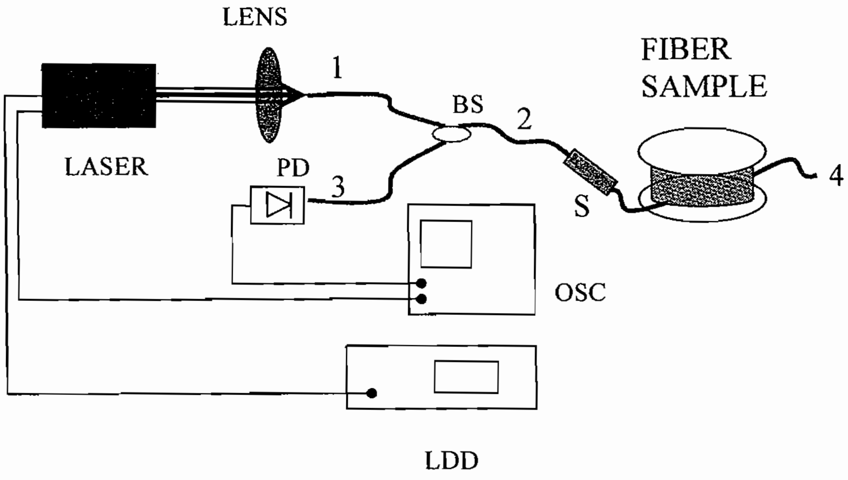


Fig.12 . Experimental setup

Having done this, connect the sample fibre by the splice S. Estimate the delay of the signal coming from the Fresnel reflection of face 4 of the sample fibre (it is recommende to start with relatively short fibre samples, e.g. 10 -15 m). Adjust accordingly the time scale (and sensitivity) of the oscilloscope, and find the delayed retro-reflected pulse. Estimate the expected signal attenuation and compare with the measurement.

After successful completion of this task (some patience and practice with the scope settings may be needed), repeat the procedure with longer fibre and also with adding different pieces of fibre and connecting them in different way.

This is just the beginning of exploring OTDR and the potential of the setup. Read the short introduction above (and of course also at the detailed treatment in the Nakazawa paper) and figure out how the back scattered signal curve (eq.11) should look like; you may found out that more sensitive detection and more sophisticated signal processing is needed. Use an avalanche photodiode and attempt more complicated measurements.