Lab 4 Optical Fiber Information & Communication

EECS 4614 Electro-Optics

Fall 2025

Professor Simone Pisana

1 Safety

Warning: the He-Ne laser in this lab is a **class IIIa laser**. Avoid direct eye exposure to the laser beam!

Follow the laser safety guidelines discussed in the first session and the laser safety manual. If you are unsure about anything, ask your TA.

When cutting optical fibers with the fiber stripper and fiber scribe provided, care must be taken to handle, collect, and dispose any cut fiber pieces, as otherwise the cut fiber pieces would pose a safety hazard. Wear eye goggles. Treat cut fiber tips or pieces as broken tiny glasses and dispose them properly in the sharps waste. Adhesive tape can be used to pick up loose particles.

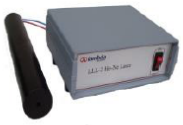
Acknowledgement: This lab handout is based on the equipment instruction manual provided by Lambda Scientific.

2 Introduction

Fiber optics is an integral part of modern communications systems. They are used to transmit light signals over large distances for example enabling high-speed internet. Another application is remote sensing where the variable of interest such as temperature or pressure affects the phase of light transmitted through a fiber. This way, variables can be sensed over big distances without human access after the fiber has been deployed initially. In this lab, you will learn how to handle glass fibers and encounter some of the common challenges when using glass fibers. You will also use glass fibers for sensing.

3 Equipment

Light Sources

Handheld Laser Source (1310 nm/1550 nm) *1 piece*		**LLL-2 He-Ne Laser** *1 piece*	

Detecting Equipment

Optical Power Meter (with detector head) *1 piece*		**Handheld Optical Power Meter** *1 piece*	
Fiber Interference Demonstrator White Screen, *1 piece* Aligning Aperture, *1 piece* Large Fibre Holder, *1 piece* Small Fibre Holder, *1 piece* Fibre Holder Clamp, *1 piece* Mounted Collimating Lens *1 piece*			

Fibres and Fibre Components

Fibre Patch Cable 1 m *4 pieces*		**Fibre Patch Cable** 3 m *1 piece*	
Fibre Spool 1 km *1 piece*		**633 nm Single-mode Fiber** 1 m - FC/PC at one end *1 piece* 2 m *1 piece*	
633 nm Multi-mode Fiber 1 m *1 piece*		**1310 nm or 1550 nm Single-mode Fiber Splitter** *1 piece*	
Variable Optical Attenuator *1 piece*		**Optical Isolator** 1310 nm or 1550 nm *1 piece*	

Mechanical Hardware and Miscellaneous

Mating Sleeve *5 pieces*	
Fibre Scribe *1 piece*	

Fiber Stripper *1 piece*	

4 Optical fiber coupling – for reference only, you completed this in part 1 of the lab

Theory

There are two coupling methods between optical fibers and light sources, direct coupling and coupling through a focusing lens (or condenser). A condenser includes conventional lens and self-focusing lens. The appearance of self-focusing lens seems to be a rod, also called GRIN lens. In fact, it is a small segment of a graded refractive index fiber. Direct coupling is a sort of butt coupling, i.e. the end of an optical fiber is directly aimed at the output light from a light source. The operation procedure of this method is as follows:

Place a fiber end, which has been cut by the fiber scribe, close to the luminous surface of a light source. Adjust it to the best position (the light intensity from a fiber output end achieves its maximum) and fix the position. This method is simple and reliable but special equipment is needed. If the cross section area of the output beam was bigger than the fiber core, it will cause more coupling loss. Coupling via a focusing lens is to make the beam from a light source focused on the fiber end and adjust it to the best position (the light intensity of fiber output end achieves its maximum). This coupling method can increase the coupling efficiency. The formula for calculating the coupling efficiency is:

$$\eta = \frac{P_1}{P_2} \times 100\% \text{ or } \eta = -10 \times \log \frac{P_1}{P_2} (dB)$$

Where P_1 is the optical power coupled into the optical fiber (approximate to the optical output power from the fiber). P_2 is the output optical power from a light source.

Experiments

Note: To get a steady value, please warm-up the laser and the optical power meter for about ten minutes while preparing the fiber.

1) Obtain a 1-m long single-mode bare fiber, strip the coating off on both ends using the fiber stripper and cut two ends by using the fiber scribe. The ends of the fiber must be flat, smooth and perpendicular to the axis of the fiber to achieve maximum efficiency of light coupling.

Fiber scribing tips: after stripping the coating off, use isopropyl alcohol with a piece of lens paper to clean the stripped bare fiber portion first. Hold the fiber while scribing the cleaned stripped fiber portion once. Finally, use the scribe to knock the fiber tip and the scribed fiber should come off easily; if not, scribe the stripped fiber further away from the fiber tip and repeat the same process. The scribed fiber tips should be collected and disposed safely (refer to section 2 Laser and lab safety requirements).

2) After the laser and power meter have warmed up, hold the detector head behind the 5-D mount to measure the output power of the He-Ne laser (P_2).

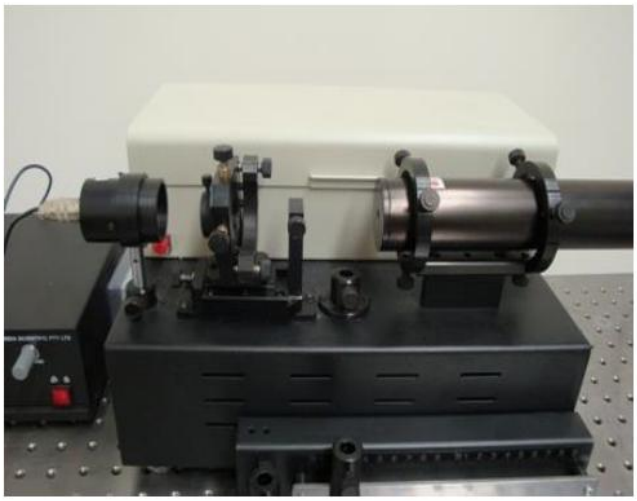


Figure 1 Photo of experimental setup

A. Lens Coupling

1) Prepare the optical fiber end surfaces and then place one end of the fiber in the large fiber holder placed in the 5-D adjustable mount. Attach the other end of the fiber to the small fiber holder then into the fiber holder clamp in front of the side rail according to Figure 2.

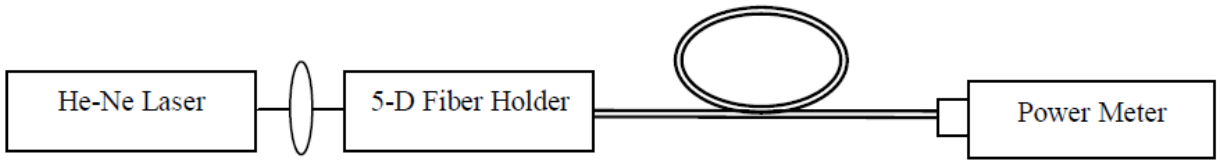


Figure 2 Schematic of fiber coupling through a focusing lens

2) Keep the fiber tip and the GRIN lens apart at approximately 5 to 6 mm, as seen in Figure 3.

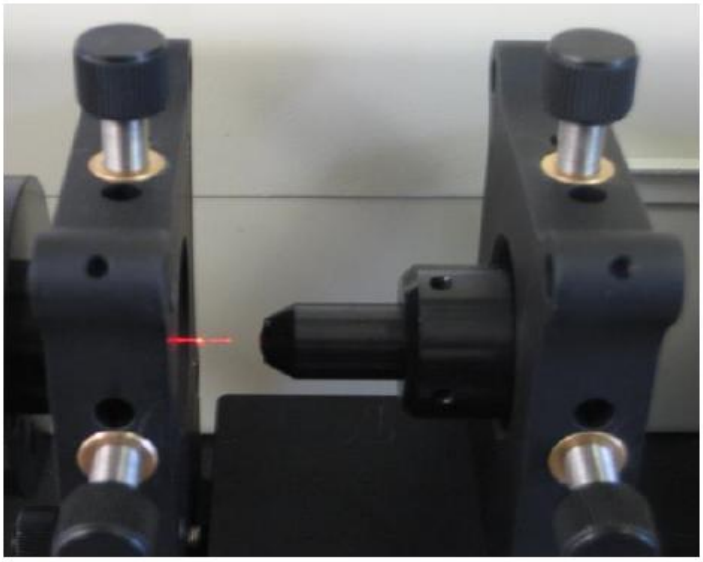


Figure 3 Photo of laser to bare fiber optic coupling

3) Align the 5-axis mount until red light is seen in the bare fiber portion for a few cm in length.

4) Point the other end of the fiber to white paper (you should see the light spot on the paper).

5) Maximize the optical coupling by finely aligning the 5-axis mount (the optical power meter may be used here and at least 650 μW should be read depending on coupling efficiency).

6) Calculate the coupling efficiency using the optical power meter.

B. Optical fiber transmission loss

When light wave transmits in an optical fiber, the light intensity (or light power) will decrease gradually with an increase in transmission distance. The transmission loss of an optical fiber is related to the transmitted light wavelength and is proportional to the transmission distance (L).

Generally speaking, the loss is expressed by transmission loss coefficient α (λ) that is the loss per unit distance when light wave transmits in the fiber. It is usually expressed by logarithm of the ratio between output power P_1 of a short optical fiber and output power P_2 of a long optical fiber,

$$\alpha(\lambda) = \frac{1}{L} 10 \log \frac{P_1}{P_2} (dB/km)$$

The transmission loss in the optical fiber is caused by many factors including the loss caused by the optical fiber itself and the loss due to the usage conditions as well.

1) Continue from the previous experiment and measure the output power of the 1 m fiber.

2) Compare this with the output power of the 1 Km fiber spool and calculate the transmission loss coefficient.

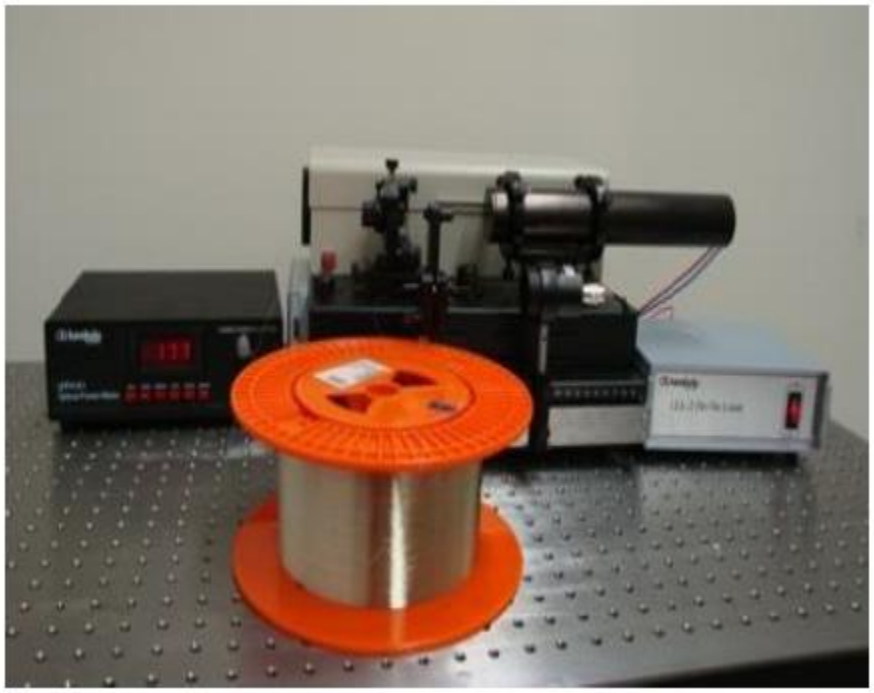


Figure 4 Photo of experimental setup with fiber spool

C. Numerical Aperture (NA) of a multimode fiber

Theory

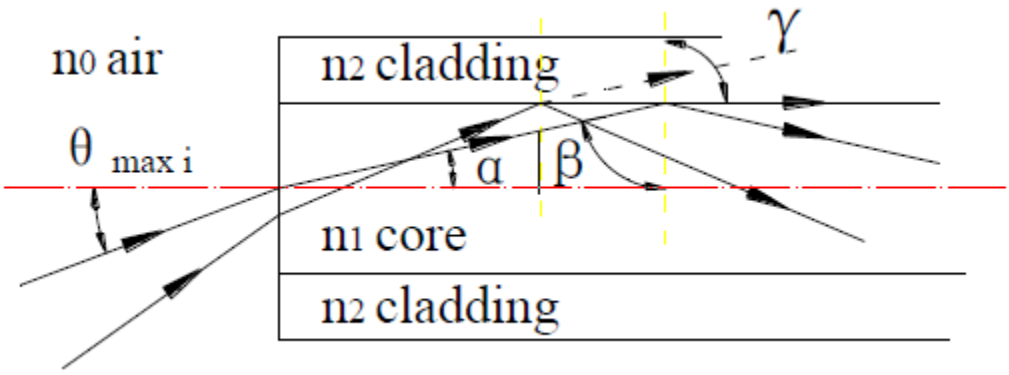
Numerical aperture (NA) is an important parameter of a multi-mode optical fiber. It represents the ability of optical fiber to collect and transmit light, and how difficult the light source can be coupled. The fiber with a larger NA will accept more light energy.

Definition of numerical aperture

1) Maximum theoretical numerical aperture NA_{max} is expressed by

$$NA_{max} = n_0 \sin\theta_{\max i} = \sqrt{n_1^2 - n_2^2} \sim n_1\sqrt{2\Delta}$$

where $\theta_{\max i}$ is the maximum incidence angle, n_0 is the refractive index of ambient medium. $\Delta = (n_1 - n_2)/n_1$ is the relative refractive index difference.

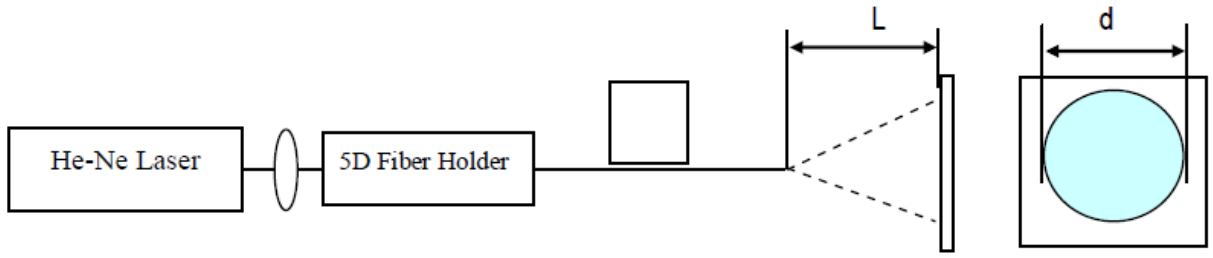


Schematic definition of NA

2) Far-field effective numerical aperture

Far-field effective numerical aperture is determined by the far-field intensity distribution of an optical fiber. It is defined as the sine value of half angle where the light intensity of the optical fiber far-field decreases to 5% of the maximum.

Experiment



Schematic diagram for NA measurement

1) Align the He-Ne laser into the collimating lens then place one end of the **multimode fiber** in the large fiber holder placed in the 5-D adjustable mount. Attach the other end of the fiber to the small fiber holder then into the fiber holder clamp in front of the side rail with the end of the fiber facing the white screen. Make necessary adjustments to align the optical axis of the laser with the fiber and then adjust the 5-D mount to couple the laser light into the end of the optical fiber to achieve the maximum coupling. Use power meter to help obtain maximum coupling.

2) Project the optical fiber far-field output on the white screen (for better accuracy, attach grid paper to it) and measure the beam spot diameter (or read the number of grids).

3) Calculate the numerical aperture by using following formula

$$NA = \frac{d}{2L}$$

where L is the observation distance between the fiber output end and the viewing screen, d is the beam spot diameter of optical fiber output. For example, assume the distance between the optical fiber output end and white screen is 50 cm, d = 20 cm, the numerical aperture of 0.2 can be obtained immediately.

5 Mach-Zehnder optical fiber interference

Theory

An optical fiber Mach-Zehnder (M-Z) interferometer is constructed by using a piece of optical fiber to replace the air gap of a traditional M-Z interferometer. This interferometer can be used to make various passive optical components such as fiber-based optical filter, optical switch, and sensors. It has been widely used in optical fiber communication and optical sensing.

Optical fiber M-Z interferometer is composed of a beam splitter. After coherent light enters the input end of an optical fiber beam splitter, an interference pattern is formed at the joint of the two single mode optical fibers with same length from the output end of the beam splitter.

The light intensity distribution of interference field (interference fringes) is related to the optical path difference and the angle between the two optical fibers on the output ends. If a fixed angle is assumed, the optical path difference caused by external factors corresponds directly to the light intensity distribution (interference fringes) in the interference field.

In general, there are two kinds of optical fiber sensors: one is to detect and convert information by a sensing element while optical fiber is only used as a transmission line; the other is that optical fiber itself acts as both sensing element and transmission medium. The working principle of an optical fiber sensor is that the measured condition changes the transmission parameters of an optical fiber or the light wave parameters of a carrier vary with these parameters. The change of optical signals reflects the change of the measured physical condition.

Note: it is recommended to perform the following experiment in a low light environment.

Pressure sensing

The fiber pressure sensor used in this experiment is based on dual-beam interference. According to dual-beam interference theory, the interference intensity is expressed as

$$I \propto 1 + \cos\delta$$

where δ is the phase difference corresponding to the optical path difference between the two arms of an interferometer. The interference intensity reaches its maximum when δ is equal to integral multiples of 2π. Pressure on a fiber segment changes the optical path of one arm of interferometer and as a result, it changes the optical path, or phase, between the two arms of the interferometer. The phase change is reflected by the change of light intensity according to formula above.

Experiment

1) Referring to Figure 5, prepare the 1 m optical fiber, then couple the laser into the end of the 1 m single-mode fiber through the collimating lens. The FC/PC end can be placed in the fiber clamp facing the white screen until optimum coupling is achieved.

Note: The power indicator can be used to monitor the output power of the fiber.

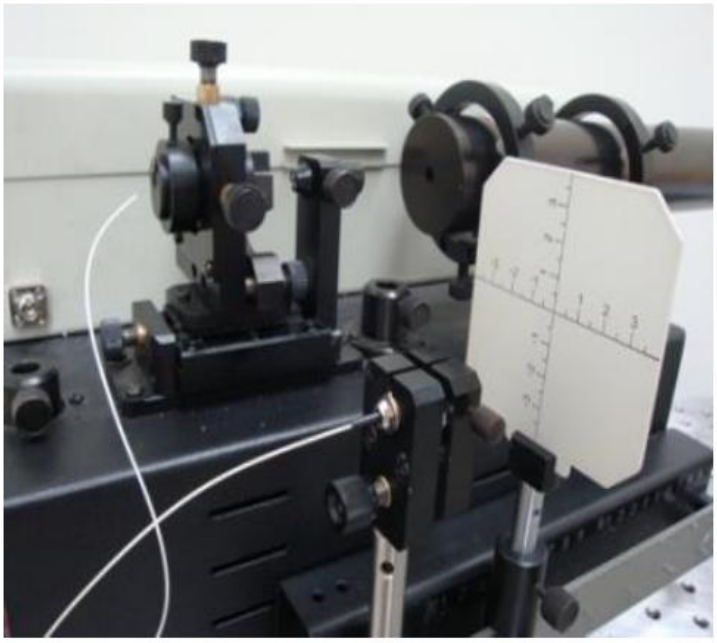


Figure 5 Photo of experimental setup for fiber coupling

2) Connect the FC/PC end of the single-mode fiber to the interferometer through the FC/PC connector labelled as “Fiber Optic Input”. The interference pattern should be observed on the ground glass screen as shown in Figure 6.

Note: ambient light may need to be turned off before observing the interference pattern if it is too weak to observe the interference fringes under ambient light.

Figure 6 Photo of interference pattern observed on ground glass screen

3) Fix the relative positions and analyze the interference phenomena.

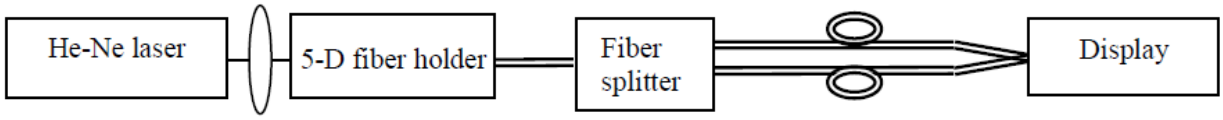


Figure 7 Schematic of optical fiber beam splitter

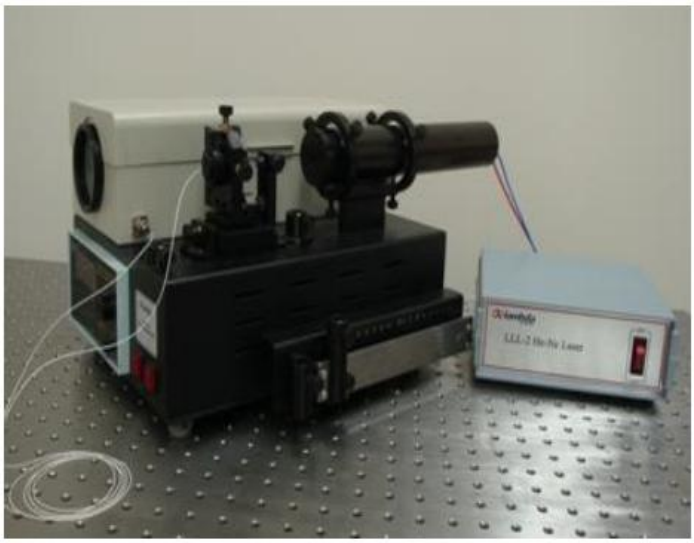


Figure 8 Photo of experimental setup for fiber M-Z interferometer

4) Adjust the pressure controller to analyse the interference pattern.

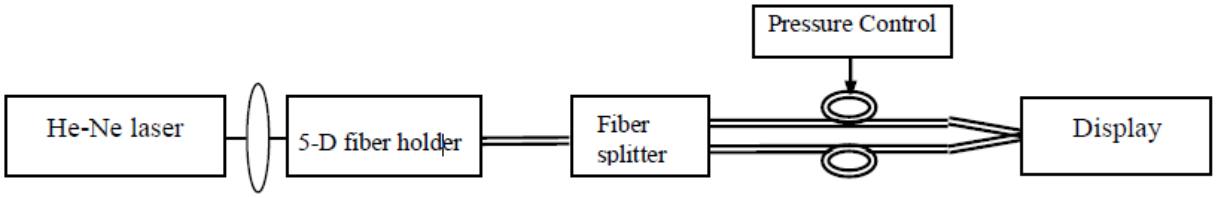


Figure 9 Schematic of optical fiber pressure sensing

Note: The length of optical fiber for pressure sensing is 60 mm. **Warning**: Avoid applying excessive pressure to the fiber, as otherwise the bare fiber could break.

5) Determine the sensitivity by relating the number of fringes that change at the center of the display to the travel of the micrometer (note the micrometer is found on the back of the unit).

6 Fiber curvature

1) Obtain a 3-m fiber patch cable and couple the light from the handheld laser source into the optical fiber.

2) Use a handheld optical power meter to measure the output power through the fiber.

3) Wind the fiber around your hand and record the measured output.

4) Change the winding number and radius. Observe and analyze the relationship between fiber output power and winding number and winding radius.

Figure 10 Handheld laser source and power meter connected by fiber

7 Variable optical attenuator

Theory

Optical attenuator is a passive optical component used to attenuate light power. The attenuation can be either variable or fixed. In optical fiber communication, variable optical attenuator is mainly used to adjust the optical line voltage level. In measuring the sensitivity of a light receiver, a variable optical attenuator is continuously changed in order to observe the error rate of a light receiver. Variable optical attenuator is also used for calibrating power meters and assessing other light transmission devices. Fixed optical attenuator has a comparatively simple structure. If the voltage level is too high on an optical fiber communication line, fixed optical attenuators need to be added into the line in series.

Experiment

Refer to the figure below and measure the performance of the variable optical attenuator.

1) Connect the hand-held light source with the VOA via patch cables.

2) Monitor the light power from the output while adjusting the VOA.

3) Determine the VOA range.

Figure 11 Handheld laser source and power meter connected through the attenuator

8 Optical fiber beam splitter

Theory

Optical fiber beam splitter is a passive component used for light splitting, combining, inserting, and distributing. In an optical communication system, fiber beam splitter is used for splitting the input of an optical signal from data trunk and data circuits, and it is also used for the acquisition of a reference optical signal from the light path to find out the characteristics and status of light emitting out of components and transmission line. At present, optical fiber beam splitters have become an indispensable device in optical fiber network, local area network and CATV network.

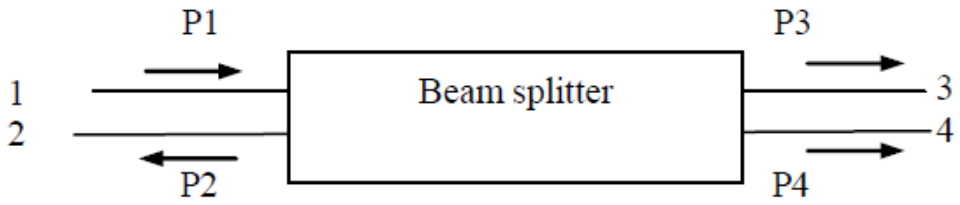


Figure 12 Schematic of fiber beam splitter – Note the beam splitter in the lab doesn't have port 2.

There are a variety of optical fiber beam splitters that can be made by partly heating up 2 or more (up to 100) optical fibers and then fusing them together.

The main parameters are splitting ratio, insertion loss, and isolation.

A. Splitting ratio

It is the ratio of optical powers between output ports. For example, if the ratio of light powers between output port 3 and output port 4 in Figure 12 is: $P_3/P_4=3/7$, which means the beam splitting ratio is 3:7. For a general 3-dB splitter, the ratio of light powers between two output ports is 1:1. For a direction coupler with two output ports, the beam splitting ratio varies from 1:1 to 1:99.

B. Insertion loss

Insertion loss is the loss magnitude of a beam splitter. It is expressed by the logarithm of the ratio between the sum of light power from all output ports and input light power. The unit is dB. For example, the loss is expressed by α, if P_1 is input light power to port 1, P_3 and P_4 are output light powers from port 3 and port 4, respectively, then, we get

$$\alpha = -10 \times \log\left(\frac{P_3 + P_4}{P_1}\right)(dB)$$

Generally, $\alpha \leq 0.5$ dB is preferred.

C. Isolation

In Figure 12, the power is meant to go from port 1 to ports 3 and 4. Any light incoming from port 3 would be undesirable in port 4, and vice versa. However, in fact, there is a non-finite isolation between ports 3 and 4. If $A_{3\text{-}4}$ represents the isolation between port 3 and port 4, where light is inserted in port 3 and detected in port 4, then

$$A_{3-4} = -10 \times \log \frac{P_4}{P_3} (\text{dB})$$

Experiment

Refer to Figure 13 and measure the performances of a beam splitter.

1) Connect the hand-held light source with the fiber splitter.

2) Measure the light powers of the output ports

3) Determine the splitting ratio and calculate the ‘insertion loss’ and ‘isolation’.

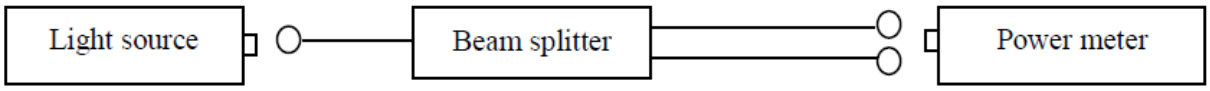


Figure 13 Schematic of beam splitter measurement

Figure 14 Photo of experimental setup for splitter measurement