LIGHT RUNNER

FIBER OPTIC COMMUNICATION

BENCH TOP LABORATORY

REFERENCE MANUAL

For

Light Runner

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LIGHT RUNNER - Fiber Optic Communication Bench top Laboratory
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Printed and bound in INDIA.

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The realization of loss in optical fibers and room temperature operation of compact semiconductor lasers in 1970, laid the foundation for long distance Fiber Optic Communication (FOC). Technological advances such as Optical Amplifiers, Dispersion Compensators, High speed Transmitters/Receivers, Optical Dense Wavelength Division Multiplexer (DWDM) etc. have contributed to the phenomenal growth of optical fiber communication industry. The increased demand on the bandwidth continues and new innovations such as Photonic Crystal Fibers, Tunable Lasers, High speed modulators, Optical signal processing, compact integrated optical devices, new modulation formats etc. are expected to cater to this need.

In order to exploit the full potential of fiber optic communication, exposure of faculty and students in academic institutions as well as scientists and engineers in R&D institutions and industries, to experimentation in fiber optics has become an absolute necessity. Towards this end, several Fiber Optic Training (FOT) Kits have been developed. However, the FOT Kits available currently in the market primarily deal with single wavelength measurements and demonstrate basic communication principles. Some Kits are more Physics based to expose the user to the basic Physics behind the working principles of optical fibers. Kits dealing with specific components such as Erbium Fiber Amplifiers (EDFA) are also available.

Since EDFAs and wavelength division multiplexing (WDM), have become ubiquitous components in fiber optic communication systems, a need was felt for developing a stand - alone FOT system. In order to expose the user to the basics of WDM and the characterization of various components such as Wavelength multiplexers, Fiber Gratings, Circulators, Couplers etc. used in a DWDM system with signal channels corresponding to the practical (C band) wavelengths. LIGHT RUNNER is such a FOC - Bench Top Laboratory which is expected to meet the above requirements.

LIGHT RUNNER will enable the user to perform the following experiments.

Fiber Characteristics

1. Numerical Aperture
2. Modes in Optical Fiber
3. Attenuation in Optical Fiber
4. Bending Loss in Optical Fiber
5. Dispersion in Optical Fiber

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6. Characterization of LASER Diode
7. Characterization of Photodetector
8. Characterization of WDM Mux and Demux
9. Characterization of FBG and Circulator
10. Characterization of Erbium Doped Fiber Amplifier

Optical Communication System

11. Analog and Digital Fiber Optic Links
12. Time Division Multiplexing of Digital Signals
13. WDM Fiber Optic Link
14. Optical Amplification in a WDM Link
15. Adding and Dropping of Optical Channels in a WDM Link

Testing & Analysis

16. Optical Time Domain Reflectometer
17. Bit Error Rate & Eye Pattern Analysis
18. Power Budgeting
19. Rise Time Budgeting

This manual will help the user to get introduced to the basics of fiber optic components, systems and their characteristics. However, it is not intended to provide extensive discussions on the topic of interest. For more details on the theory, the readers are advised to refer to more advanced texts, some of which are listed at the end of the manual. Similarly, for more details on experiments, visit www.fiberoptika.com and get Help, Forums and FAQ's.

Instructions for Setting up Light Runner Hardware

1. Ensure that the Power Switch on the backside of LIGHT RUNNER is in OFF position. Connect one end of power cord provided into the socket located at the backside. Plug in the other end of power cord, which is a three pin adaptor to a 230 V - 5A socket after ensuring that the plug switch is OFF.

2. There are 2 A - type USB slots given in the kit for connecting external key board, mouse, pen drive etc.

3. Power ON the LIGHT RUNNER with the help of switch located at the backside of the kit.

4. Push button located near to power switch can be used to either restart the LIGHT RUNNER and/or reboot the LCD.

5. Once LCD is lighted up, wait for 2-3 minutes for system to be initialized and ready to use.

6. The integrated LCD in LIGHT RUNNER is having a touch screen facility.

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Light Runner Accessories

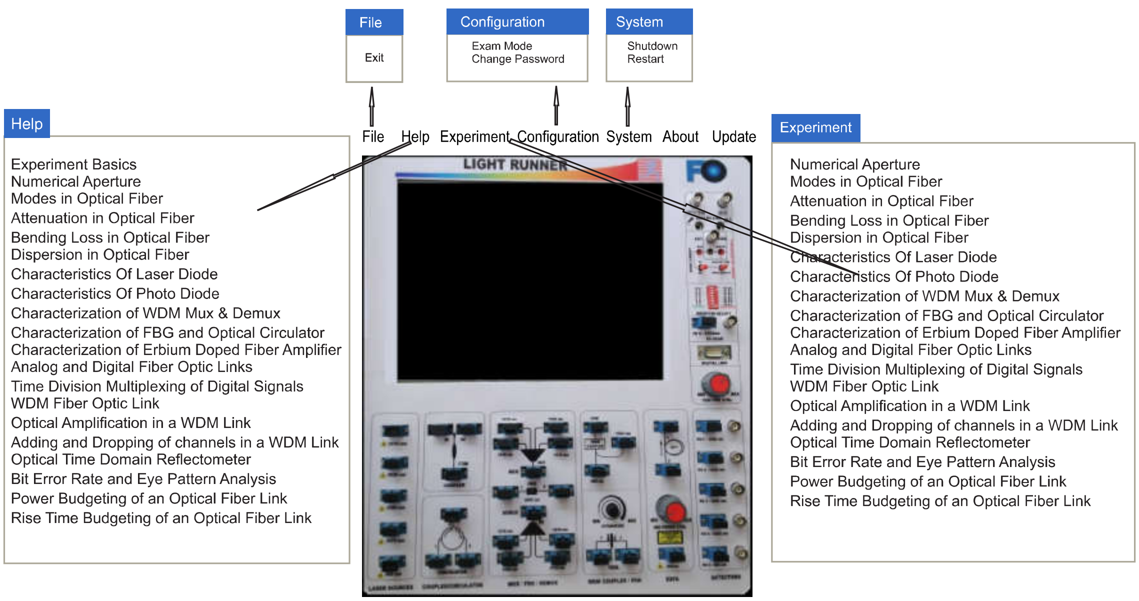
LIGHT RUNNER kit is provided with all the required accessories which are used to perform all the 19 experiments given in the manual. The accessories are given below.

FIBER OPTIC SPOOLS LIGHT RUNNER is provided with connectorised fiber spools of various lengths which are used to set up a WDM link and to study the effect of various optical parameters on the link.	
OPTICAL PATCH CORD SC-PC connectorized SM & MM fiber optic patch cords are provided with LIGHT RUNNER, to make connections between different active and passive components which are given on the front panel of LR.	
BNC CABLES BNC cables are used to see the electrical output on DSO screen.	
OPTICAL POWER METER Optical power meter is used to measure the strength of optical signal at different wavelengths.	
DIGITAL MULTI METER Digital multimeter is mainly used in 'Laser Characterization Experiment' to check the corresponding electrical current at different values of optical power.	
HEADPHONE & MICROPHONE These devices are mainly used in 'Analog Link Experiment' for voice transmission purpose.	
DB 9 SERIAL CABLE DB9 cable is used to interface LIGHT RUNNER with external laptop or system. It is mainly used in 'Digital Link Experiment' for data transmission.	
MANDREL This is mainly used to measure the bending loss at different bend diameters say 40mm, 30mm, 20mm & 10mm.	
VFL - VISUAL FAULT LOCATOR This is a Visible Laser Source used to study the Numerical Aperture & Modes in Optical Fiber.	

Instructions for Using LIGHT RUNNER

LIGHT RUNNER is run through in built software. The detailed description of LIGHT RUNNER software is given below.

1. The main window of software is having seven drop-down menus which are below the "Title Bar" of the LIGHT RUNNER window as shown below in the figure. These drop down menus are as follows.



File - Exit- Software window can be closed by clicking on the 'Exit' button.

Help - It contains the theoretical explanation of all nineteen experiments.

Experiment - This drop down menu gives the option to select the particular experiment that has to be performed. After selecting the particular experiment, experimental window will appear on the screen.

Configuration - In this drop down menu there is a provision for Exam mode and changing password.

System - This drop down menu contains two options. By selecting a particular option, LIGHT RUNNER can be either restarted or shut down.

About - Displays the current version of the software.

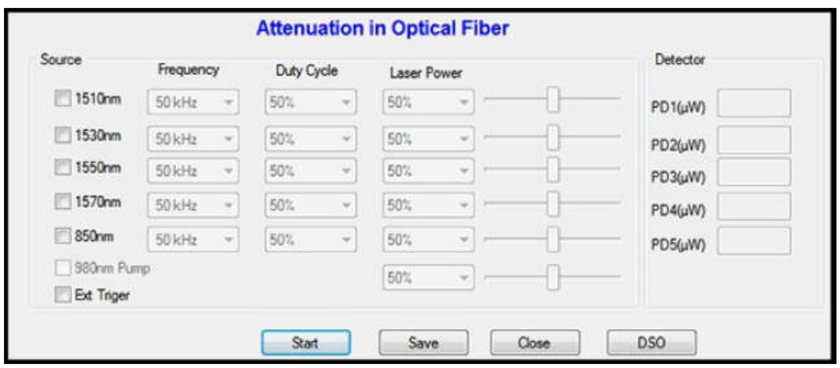
Update - Latest software build can be uploaded to the LR. For details contact Fiber Optika Technologies Pvt Ltd.

- All LR's are supplied with latest software build. If any new upgraded software is released by Fiber Optika for Light Runner, the latest released build will be uploaded on our website (www.fiberoptika.com) under software upgrades page for downloading and upgrading on your already available Light Runner. Please check your current software version from **About** menu. Download the software if your version is older than current available version of software.

Procedure for upgrade:

1. Download & save the upgraded version of the file (lightrunner.bin) on USB drive.
2. On the main window click "Update" then, "Yes" to proceed further.
3. Insert the USB drive to the Light Runner .
4. Upgrade option gets highlighted, click upgrade.
5. It takes few minutes to upgrade the software & will automatically reboot the system.

NOTE: Only software downloaded for Light Runner from our website can be detected and read from the USB drive by the existing Light Runner Software available on your system.



2.Use "Help" Menu to get complete information and procedure for experiments and "Experiment" menu to get into the Experimental Window.

3. On clicking this button, appropriate set of controls and displays will appear on the LIGHT RUNNER screen (Interaction window), as shown below in the figure. This window can be closed by clicking on "Close" push button.

4. In general every "Experiment Screen" is divided in two sections one is source and other is detector.

(a) Laser Source Control- All five laser sources have controlling parameter which have been given at the front of labels 1510,1530,1550,1570 and 850nm. The description of three controlling features is given below.

Frequency - It can be changed in two ways, either by keeping it in continuous mode or in digital mode. In digital mode, frequency can be varied from 1 kHz to max 2.4 MHZ.

Duty Cycle - It can be changed to 10%, 20% or 50%.

Laser Power - Source power can be changed in two ways, either by choosing the value from drop down menu or by using the slider option. It can be varied from 0% to 100% for all five laser sources.

Save – Frequency, Duty Cycle & Laser Power parameters entered on the Input screen can be saved into an external USB drive.

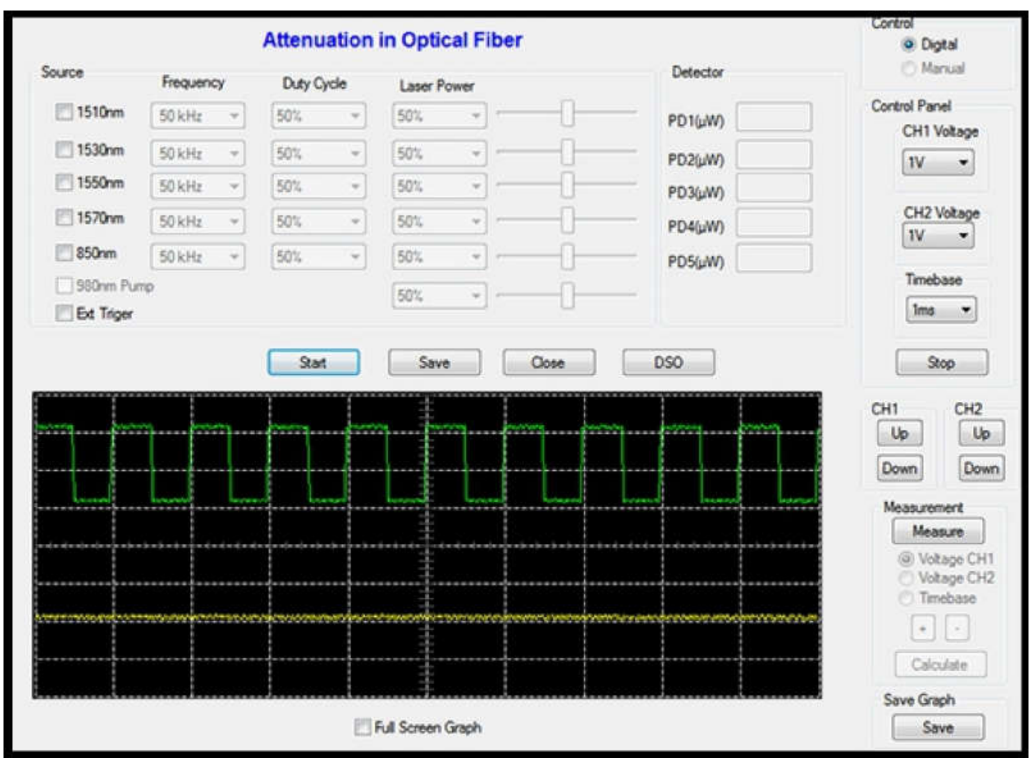
(b) Detector Reading Monitoring- Once the "Start" button in the interaction window of LIGHT RUNNER Software is pressed, the box in front of labels PD1, PD2, PD3, PD4 (all InGaAs IR light detectors) & PD5 (Si detector) will display the value of the arbitrary power seen by that detectors on the LIGHT RUNNER.

5. Before closing the interaction window, the ongoing experiment should be stopped by pressing "Stop" button on the interaction window.

6. Instructions for controlling and monitoring every experiment are specified in the procedure of each experiment.

Help for Using DSO Software

1. The DSO feature is in built with LIGHT RUNNER software. After running any experiment, user can see the electrical equivalent of optical signal on screen by just making the connection through BNC cable to any channel given on top right corner of the LIGHT RUNNER . The DSO control section is shown below in the figure.



2. The position of the electrical signal for each corresponding channel can be changed by clicking on the up (or) down button.

3. DSO can be started or stopped at any time by pressing 'Start' or 'Stop' button respectively, given on the right side of the DSO screen.

4. The voltage and time scale can be changed any time using the controls on the DSO control panel.

5. For making any measurement in terms of the voltage or time delay between pulse click on waveform itself.

6. The measurement of the wave form can be done either for voltage or time based on selecting voltage CH1/Voltage CH2 or Time base respectively.

7. The position of the cursor can be changed during measurement by clicking "+" or "-" buttons.

8. On pressing the 'Calculate' button, result will be displayed on the screen for the two points selected by the user.

9. The graph can be viewed on a full screen by pressing "Full Graph" Button and by pressing the 'Back' button, experimental window will appear on the screen.

10. DSO graph can be saved using the save option onto an external USB drive.

General Instructions For Operating Light Runner

1. Unless otherwise specified, all experiments should have preferentially done with a digitally modulated laser beam with the frequency and duty cycle conveniently chosen by the user (for e.g. 50 kHz frequency and 50% duty cycle).

2. PD1, PD2, PD3, PD4 are InGaAs IR PIN photo diode detectors which are sensitive only to IR wavelengths (In LIGHT RUNNER, for Laser 15XX*).

3. The optical detector labeled PD5 on LIGHT RUNNER is used for measurement of light from 850 nm visible laser in LIGHT RUNNER.

4. BNC connectors near to PD1 - PD6 give electrical equivalent signals of the optical signal detected by the detectors.

15XX- It stands for IR laser source wavelength where XX stands for - 10, 30, 50 & 70.

5. While operating LIGHT RUNNER, if detector is fed with high optical power it will be saturated and will not give correct readings or waveforms (on DSO). For reliable results, users are expected to keep optical power fed to detector below the saturation limit. This can be achieved by adjusting source power in LIGHT RUNNER software or by using variable optical attenuator provided in LR.

6. Saturation of photodetector is characterized by non changing amplitude on DSO (around 4V in DC coupling) with an increasing optical power falling on the photodetector. Finally at higher power levels the DSO shows a DC voltage of 4V even when fed with a digitally modulated signal.

7. All the six lasers provided in LIGHT RUNNER (four C-Band Lasers, one 850nm visible laser and one 980nm Pump Laser) have soft controls (digital controls) for their output optical power regulation. However, for ease of operation and fine adjustments, out of the six lasers, two (1550nm Laser and 980nm Pump Laser) have manual controls in addition to the digital controls. For the 1550nm laser, the user can select the type of control from the LIGHT RUNNER software.

8. For the 980nm Pump Laser, the type of control, i.e. digital or manual, is determined by their relative strengths. That means if the digital control voltage is higher than the manual control voltage, the former will override the latter and vice versa. Therefore, in order to operate the 980nm Pump Laser in the digital mode, the user is advised to first set the manual control knob to its minimum. Similarly, for operating in the manual mode, the digital control is preferably set to be zero or minimum.

9. To make internal digital power control on, select the 'Digital' from the control block, given in the LIGHT RUNNER software. Manual power control will be active only when checked to 'Manual'.

10. For simplicity in use of Light Runner and to avoid confusions, we recommend to feed

a. PD 1 with 1510 nm Light
b. PD 2 with 1530 nm Light
c. PD 3 with 1550 nm Light
d. PD 4 with 1570 nm Light
e. PD 5 with 850 nm Light

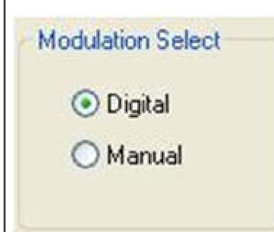
11. Absolute optical power measurements can be carried out using the optical power meter provided along with Light Runner after selecting the proper wavelength range on it. For e.g. for the power measurement of 1550 nm, use 1550 nm range on power meter.

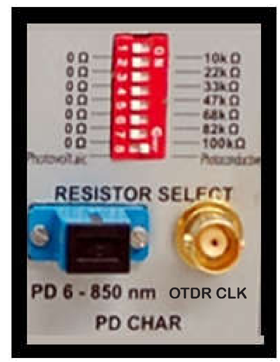
LIGHT RUNNER front panel has a number of optical and electrical connectors with some optical and electrical controls along with indicators.

Controls

These are used to control various parameters on LIGHT RUNNER and are divided into two categories: Electrical controls and Optical Controls. The detail of these controls is specified below:

Electrical Controls

POWER BLOCK This black switch is used for powering on/off LIGHT RUNNER, and a push button which is below the power switch, used to boot the LCD (It is preferred to push the button for at least 10 seconds).	
EDFA BLOCK PUMP CONTROL Rotating the knob clockwise, increases the output power of 980nm Pump Laser. It is combined with a digital control for 980nm laser power which is in software. Optical power coming out of laser will be varied only by one of the controls (digital or manual) at a time depending on their relative strengths.	
CONTROL BLOCK This block is visible in the experiment window of LIGHT RUNNER software. There are 2 different controls which can be selected as per the requirement. The controls are as follows: 1. DIGITAL When user checks the 'DIGITAL' position, 1550nm laser power is controlled only by internal digital circuitry controlled by software. It has no effect of 1550 power control knob on it. 2. MANUAL When user checks the 'MANUAL' position, 1550nm laser power is controlled by 1550 Power control knob given on LIGHT RUNNER.	

LASER SOURCE BLOCK 1550nm Power Control This is a rotating knob, when rotated in clockwise direction, it increases 1550nm laser power if checked to 'Manual' position in the software.	
PD Characterization Block Resistor Selection This is a DIP switch used to select value of the resistor to be put in the circuit. It has 8 small switches and 7 of them represent resistors. The eighth one is for selecting the Photoconductive or Photovoltaic mode of the photo diode. By pushing the small switch up, a particular resistor value can be selected. If more than one small switch is in up position the corresponding resistors will form parallel combination so their effective value will appear in the circuit. **PD6-** This is a BNC connector which gives out the electrical equivalent of the optical power fed to the optical detector PD6.	

Optical Controls

VOA Block (Variable Optical Attenuator block) This is a rotating knob and by rotating this knob in the clockwise direction, the attenuation encountered by the optical signal between connectors will be increased.	

INDICATORS

These are the visual indication given by LED for every laser source according to their ON/OFF status.

Laser Indicators (A yellow triangle below every laser source)-

There are 6 laser sources on LIGHT RUNNER viz. 1510nm, 1530nm, 1550nm, 1570nm, 850nm and 980nm Pump. Every laser source has a caution symbol painted in Yellow LED which will glow when the laser is ON.

Connectors

There are 37 optical ports which can accept SC-PC connector, and there are 16 electrical connectors on LIGHT RUNNER. All necessary cables are provided to make connections.

Electrical Connectors

POWER 110-230V (BACK PANEL)

This accepts one end of POWER cord provided with LIGHT RUNNER. Other end of the power cord should be put into 230-110V, 50/60 Hz power socket.

DETECTOR Block

PD1, PD2, PD3, PD4 and PD5

All these are BNC connectors which gives the electrical signal out, equivalent to the optical power fed at the corresponding optical detectors PD1 to PD5 (Range of signal 0V to 4V). The BNC connectors are connected to the DSO connectors using the BNC cable. Unless otherwise stated all measurements on LR are done with the help of DSO.

ANALOG LINK Block

Microphone-

This is 3.5 mm stereo jack female connector where the user can connect the Microphone provided with LIGHT RUNNER which accepts audio signal input (used in analog link experiment).

Speaker-

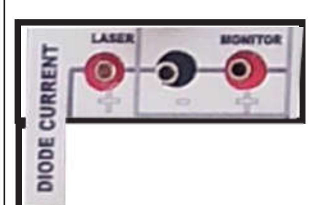
This is 3.5 mm stereo jack female connector. One can connect the stereo headphone provided with LIGHT RUNNER to this socket which gives audio signal out analog link experiment). (used in analog link experiment).

LASER CHARACTRIZATION Block

LASER CURRENT (+/-)

These are the test points which can accept multimeter probes. The voltage measured between “+” and “-” points is directly proportional to the current flowing through the 1550 nm laser diode. It follows the relation:-

1550 Laser diode current = (voltage measured) /27 ohms. User can connect multimeter provided with LIGHT RUNNER. (This is used for laser characterization experiment.



MONITOR DIODE CURRENT (+/-)

These are the test points which accept multimeter probs. The voltage measured between '+' and '-' point is directly proportional to the monitor diode current of the 1550nm Laser on LIGHT RUNNER. It's related by the following relation, 1550 **Monitor photodiode current =**

EXTERNAL MODULATION Block

This block provides facility for External Modulation through an external Signal or Function Generator - For details refer "**Further Exploration**".

DIGITAL LINK Block

This is a DB-9 male connector, which is used in digital link experiment where one end of the DB-9 cable provided with LIGHT RUNNER can be connected to this port and other end to the RS 232 port of another computer. To view data received on the other computer, one can use terminal program, which is pre installed in any windows operating system.

DSO (Digital Storage Oscilloscope)

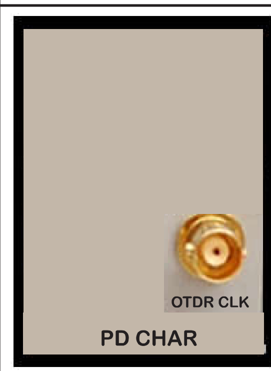
CH1
This is a BNC connector which accepts electrical input signal and acts as the 1st channel of DSO. The photodetector (PD1 - PD6) signal fed to its input can be seen as a waveform using the DSO software pre-installed on the PC.

CH2
This is a BNC connector which accepts electrical input signal and acts as the 2nd channel of DSO. The signal from any of PD1- PD6 fed to its input can be observed as a waveform using the DSO software pre-installed on the PC.

OTDR CLOCK

Input reference clock for Optical Time Domain Reflectometer - OTDR experiment can be taken from this BNC connector to CH1/TRG on the DSO.

NOTE: Keep the toggle switch under EXT MOD to DIGITAL/OTDR CLK.



Optical Connectors

All Optical devices on LIGHT RUNNER are fiber optic components. All connectors accept SC-PC connectors for optical connections and optical patch cords are provided for making optical connections.

MUX Block

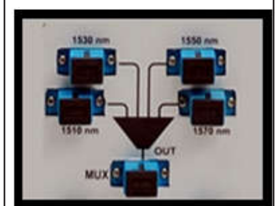
This is an optical wavelength division multiplexer which accepts four different wavelengths (1510, 1530, 1550, 1570 nm) at its inputs and combines them together to appear on its output. It may be noted that it is bidirectional device and hence can act as a Demux too.

IN

These are the four optical input ports of MUX .For proper operation of the device every port should be fed with corresponding wavelength.

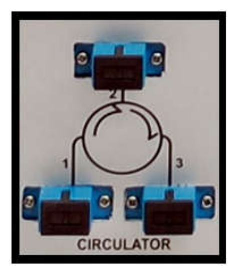
OUT

This is an output port of MUX. Multiplexer combines all signals present on its input port and combined signal is given on output port.



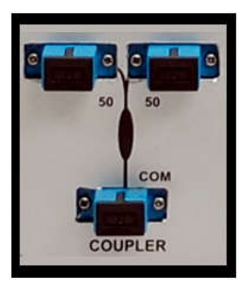
CIRCULATOR Block

This is a three-port optical circulator which acts as a nonreciprocal device. If light is launched at Port 1, it will be passed to Port 2.Conversely if light is launched at Port 2 then instead of appearing at Port 1, it will appear at Port 3 unlike in most of the optical devices.



50-50 COUPLER /SPLITTER Block

It is a three-port device which splits the C-band light fed at com port equally to the two arms (“50” and “50” meaning 50% at each port). The same device can be used as coupler to couple light from two different sources at the two arms and the combined light will appear at the COM port.



DMUX Block

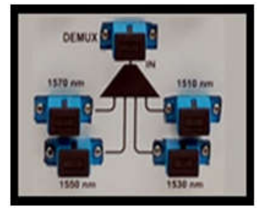
This is an optical wavelength de-multiplexer which accepts optical input, consisting one of different wavelengths combined together, at its port 'IN' and separates outs the signals of four different wavelengths at its output ports. It may be noted that it is bidirectional device, following reciprocity and hence can act as a MUX too.

IN

This is an input port of the optical de-mux which accepts wavelength division multiplexed optical signal i.e. signal which has many wavelengths present together.

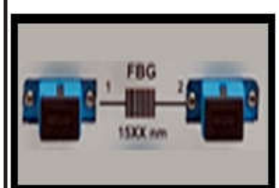
OUT

These are the four optical output ports (1510, 1530, 1550 and 1570 nm) of DEMUX. If the Input signal fed at IN terminal contains wavelengths 1510nm, 1530nm, 1550nm, 1570nm they will appear on corresponding output ports.



FBG Block

This is a Fiber Brag Grating having two ports and acts as a bidirectional device. If optical signal containing multiple wavelengths is launched to any port of this device, it will reflect single wavelength back and rest of the wavelengths present will be passed to other port. (LIGHT RUNNER has FBG which has a reflection peak at 1550nm).



VOA Block

This is a Variable Optical Attenuator having two ports and is bidirectional. If optical signal is fed at one of the port then signal coming through other port will be attenuated by some amount. Attenuation can be controlled by rotating the manual knob. It ranges from 0 to -40 dB.

LASER SOURCE Block

1510nm,1530nm,1550nm,1570nm-

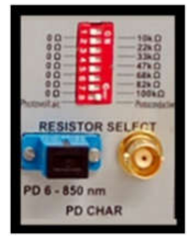
These are the Laser output ports which gives out light at wavelengths 1510 nm, 1530 nm, 1550 nm ,1570 nm respectively. (P_{max} <= 1 mW).

850nm

This is a Laser output port which gives out optical signal at 850nm wavelength. (P_{max}=2 mW).

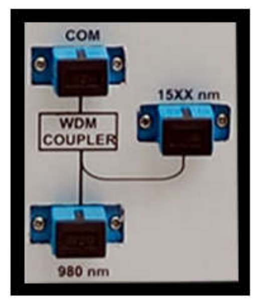
PHOTODETECTOR Block
PD1,PD2,PD3 andPD4-
These are the photodetector input ports, which can be fed with optical signal. It has better sensitivity to wavelengths in the range of 1000nm to 1700nm.
PD5-
This is an input port of a photo diode which can be fed with an optical signal. It has better sensitivity and is useful to detect power of 850nm laser light.

PD Characterization Block
PD6 - This is an InGaAs photodetector input, which can be fed with optical signal. It has a better sensitivity to wavelengths in the range of 1000 to 1700nm.



WDM Coupler

This is a bidirectional three port device whose one output port is common and other input ports are named as 980nm and 15XXnm. This device combines two different wavelength signals present on the input ports and send it to output port (Input and outputs ports are interchangeable). 980nm,15XXnm are the optical input ports. For proper operation of the device it should be fed with optical signal of 980nm and 1550nm wavelength.



EDFA Block
Pump 980nm-
This is a Laser output port which gives out optical signal at 980nm wavelength. (P_{max} <=60mW).

Doped Fiber - Er^{+3} This is Erbium doped optical fiber having two ports and acts as a unidirectional component. This component is used as an amplifying medium for C-band signals. Arrow specifies the direction of 15xx signal to be amplified.

Components

Safety Precautions

Apart from the 'General procedure to setup LIGHT RUNNER', it is necessary to take care of the following safety precautions for the proper functioning of LIGHT RUNNER.

- LIGHT RUNNER is an Opto-electronic instrument and therefore should be handled with extreme care for its smooth operation. Even a moderate shock/vibration can destroy some of the components of LIGHT RUNNER. It is advisable to be careful during packing and unpacking of LIGHT RUNNER.
- LIGHT RUNNER should not be dropped and should always be kept in vertical position. The touch screen LCD should be handled with care and the use of sharp pointed object on the screen must be avoided.
- The manual optical power controls, resistor selection switch in 'PD CHARACTERISATION', Variable Optical Attenuator switch, ON/OFF switch etc on the front panel of LIGHT RUNNER should be operated with care.
- The caps provided with all the optical connectors should be placed back after using LIGHT RUNNER. Cleaning of all the optical connectors of LIGHT RUNNER should only be done with the spray provided.
- Please do not try to open LIGHT RUNNER, because there are no user repairable parts inside LR.
- Lasers are light emitters which are not supposed to receive light. Therefore, it is obligatory to avoid any light falling on the lasers.
- It may be noted that the four C-band Lasers and 850nm Laser are Class III R lasers and are safe with restricted beam viewing, except passed through magnifying optics such as microscopes and telescopes. However, it is advisable to avoid direct looking into any of the laser beams.
- 980nm lasers are of Class III B type and hence are hazardous if the eye is exposed directly, but diffuse reflections such as from paper or other matte surfaces are not harmful.
- Please provide proper earthing for LIGHT RUNNER .

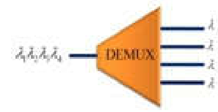
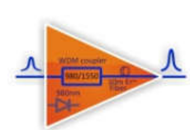
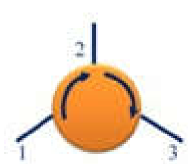
Maintenance Tips

- After using the patch cords, put their caps back to protect the tip from dust and scratches.
- Once the experiment is over, place the dust caps back on the connectors and on the fiber spools.
- Keep LIGHT RUNNER and its accessories in dust free environment.
- The optical adaptors present on the front panel of LIGHT RUNNER and on the fiber spools can be cleaned using the swab and cleaning spray given.
- In order to protect the pigtailed fibers at the adaptor, ensure the cleanliness of the patch cord inserted into the adaptor. The patch cords can be cleaned with the tissue paper and IP solution given.

Do’s and Don'ts

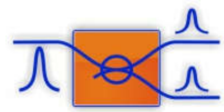
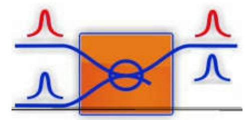
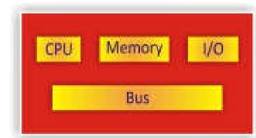
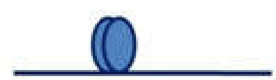
- Switch off lasers when not experimenting on LIGHT RUNNER.
- While experimenting, keep fiber patch cord bending radius more than 3 cm.
- Avoid direct exposure to laser beams.
- Don't leave patch cords and adaptors without dust caps.
- Don't feed laser beam back to the same laser or another laser source.

Symbols Used

S.No.	Components	Symbols
1.	WDM Mux	
2.	WDM Demux	
3.	1510nm Laser,λ_1 1530nm Laser,λ_2 1550nm Laser,λ_3 1570nm Laser,λ_4	
4.	850nm Visible Laser 980nm Pump Laser	
5.	InGaAs Photodetectors (PD_1, PD_2, PD_3, PD_4)	
6.	Si Photodetectors(PD_5)	
7.	Fiber Spool	
8.	Varriable optical attenuator (VOA)	
9.	Erbium Doped Fiber amplifier (EDFA)	
10.	Fiber Optic Circulator	

Symbols

Symbols Used

11.	Fiber Bragg Grating (FBG)	
12.	3 dB Fiber Optic Coupler	
13.	980/15XX nm WDM Coupler	
14.	Microcontroller	
15.	Digital Storage Oscilloscope (DSO)	
16.	Er^{+3} Doped Fiber	
17.	Fiber Optic Patch Cord	
18.	Optical Power Meter	
19.	Multimeter	

Cleaning Tips

GENERAL INSTRUCTIONS FOR FIBER CONNECTOR INSPECTION AND CLEANING

Components

Light Runner uses fiber optic patch cords for connectivity of various components inside it through front panel having female SC adapter ports. The backside of the panel is having SC connectors connecting to the components.

Use of Microscope

This backside connector cannot be accessed for inspection and cleaning in a normal way. This requires bulk head microscope with connector probe to insert into the adapter for accessing the connector inside. The end face of the connector ferrule can be seen on monitor for its cleanliness and any physical scratches etc. A photo of such kind of microscope with connector end-face is shown below –

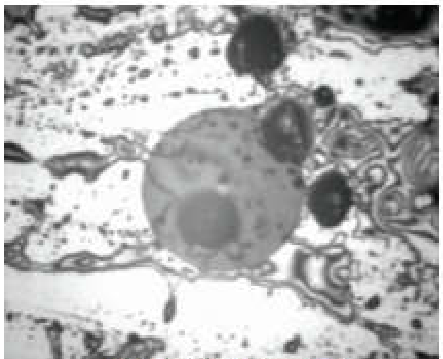
This is an expensive item and has to be purchased separately. This can be used for other fiber optic patch inspection also.

However the ferrule of the connector in patch cord can be inspected through microscope by inserting ferrule into the adapter cap at the end and then viewing through the other end of the microscope.

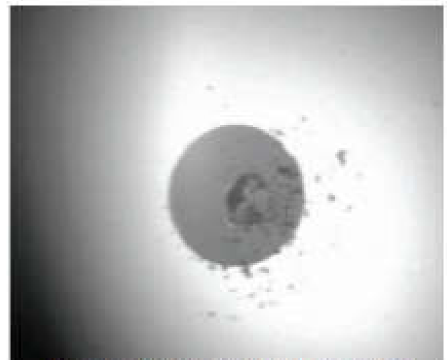
Typical patch panel bulkhead inspection

Connector Contamination

A contaminated connector end face (a sample is shown below) can spoil the connection and even block the light from transferring to the next connector. This may result in either back-reflection of light or in case of high power output from connector (like 980nm pump laser), burning of the connector end face around the fiber periphery in the ferrule



Contaminated connector

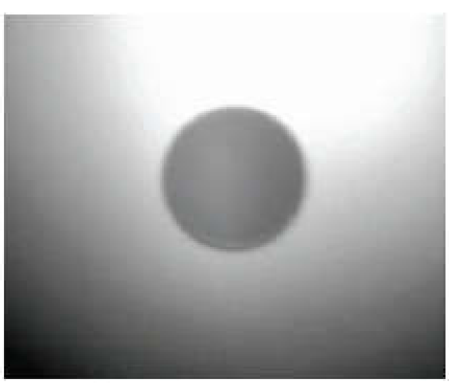


Permanently damaged EDFA connector

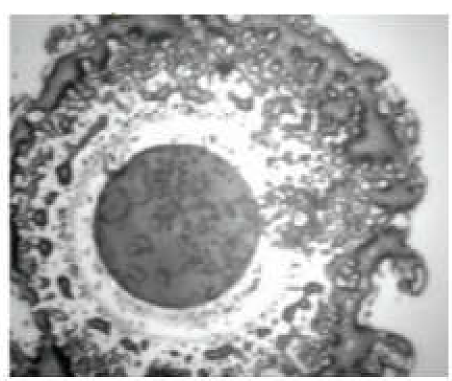
This will result in light getting blocked further and not passing out from the connector to the other connector. Hence the performance of the laser will be affected. In case of 980nm pump laser, it will result into less signal power amplification and that means incorrect EDFA experiment.

Cross Contamination

Cross contamination can occur when a clean connector is inserted in a dirty connector bulkhead. The mating of both connectors tends to move debris and dirt to the center of the connector where it can interfere with the optical transmission and cause extensive damage.



Clean connector



Cross contaminated connector

This cross contamination is relevant in the situation where a clean connector of the component inside the Light Runner can get contaminated when a patch cord having dirty connector mated with it during experimentation.

For instance, let's consider a contaminated connector is plugged into a powered-up 980nm Laser Pump having a clean connector The output power of this laser can be up to 50mW. At this power level, any debris or dirt from externally contaminated connector can get burnt, permanently damaging the connector and blocking the light output from pump laser. This will reduce the performance of amplification by the pump laser.

Hence cleaning of the connectors on the inside pig tails of components and on the external patch cords before mating is important. Equally important is the immediate putting up of the clean dust cap on the ferrule of the patch cord once removed from the Light Runner connection in order to avoid ferrule end-face to catch external environment dust/dirt/oil etc.

Adapter Contamination

Adapters in the front panel can get contamination during every mating & de-mating of connectors inside it. Some ceramic dust from ferrules or the dust/dirt/oil/epoxy on the ferrule end face can fall in the adapter sleeve in the center and can remain there, if not cleaned-up. This may make a cleaned up connector to gather this dust/dirt/oil when inserted into such adapter sleeve. Hence cleaning of adapter is also important. Equally important is the immediate putting up of the clean dust cap on the adapter open port once being kept unused for long time in order to avoid external environment dust/dirt/oil etc going inside the adapter sleeve.

Power Output Level of Lasers in Light Runner

C BAND (1510,1530, 1550 & 1570nm) LASERS - 1mW (maximum)

850nm LASER - 2mW (maximum)

980nm PUMP LASER - 60mW (maximum)

Hence mostly problem would occur when pump laser are being used and on the connectors in the link where such power is going. Any blockage of this power at any interface point can result into back-reflection or burning of connector around the fiber in the ferrule.

Fiber Optic Connector Cleaning - Suggested Practices

Introduction

New connectors must be inspected and cleaned as well. Clean and inspect every connection every time is your best assurance of a reliable optical network. Please note that is important to remove all removable contaminants. References are made in the cleaning process for users to note if a defect/contaminant has moved on the surface of the end face. In some cases something that appears to be a contaminant may be a defect in the surface of the glass or ferrule. In these cases of non removable or defects, we do not have to worry a potential migration of the contamination toward the core area causing system failure in the future.

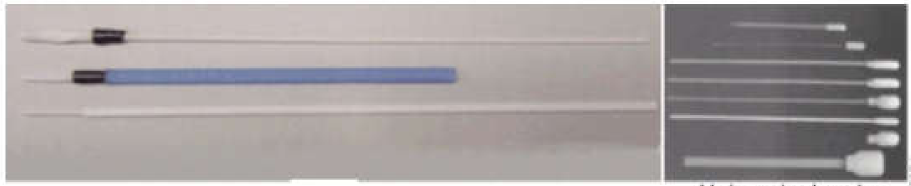
Use of Wipes 'TISSUE PAPERS'

Fabric and/or composite material wipes provide combined mechanical action and absorbency to remove contamination. Wipes should be used with a resilient pad in order avoid potential scratching of the connector end face.This method is appropriate for cleaning connectors with exposed ferrules or termination but cannot be used to clean connector end faces within alignment sleeves. The wipe should be constructed of material that is lint free and non-debris producing during the cleaning process. Please note that dry wipes have been shown to leave a static charge on the end face of the connector which can there after attract particulate contamination. Therefore it is recommended that a static dissipative solvent be used with a dry wipe to eliminate this condition.

Technique for Cleaning with Wipes or Cleaning Cassettes

As mentioned above it is recommended to use a lint-free non-debris generating wipe with a static dissipative solvent. The user should dampen a portion of the wipe with the solvent, place the connector end face into the damp area of the wipe and draw the connector into the dry area of the wipe. A physical wipe of 2-5 cm should be sufficient. This may be repeated in a different area of the wipe if desired, however 1 or 2 strokes should be sufficient for most common contaminants. Upon inspection, if the connector is not clean after the first cleaning, the process can be repeated perhaps with slightly more pressure on the connector to increase the mechanical action and perhaps making several stokes from the damp to dry sections of the cleaning material.

If the connector is still not clean and contamination has not moved it should be considered non-removable contamination and it is recommended not to use such patch cords for connectivity.



Various sized swabs

Use of purpose built swabs or mechanical port cleaning devices provides mechanical action and absorbency to remove contamination. However since the area within a port is very confined and limits mechanical action, it is recommended that a wet/dry cleaning process be utilized for cleaning connector end faces within alignment sleeves. A static dissipative solvent will add chemical action to the cleaning process as well eliminate any residual static charge that may be on connector. The cleaning end of the swab or cleaning material used in the port cleaning device should be lint free, non-debris generating material.

Do not touch or contaminate the cleaning end of the swab or the port cleaning device. It is recommended that the user dampen the swab or port cleaning device with a static dissipative solvent.

Swab Cleaning Detail

Place the dampened cleaning end of the swab into the port and rotate the swab while applying some pressure to the connector end face. Usually pushing so that the compression spring in the connector is slightly activated is ideal for 2.5mm connectors. Rotating the swab 6- 12 times is sufficient.

Solvents

Historically, 99% pure isopropyl alcohol (IPA) has been used as a solvent. However, IPA is easily contaminated. The solvent is hygroscopic and therefore absorbs moisture from the atmosphere including any contaminates present contaminating the solvent and potentially leaving a haze on the connector end face which can be a problem with higher power laser networks. In addition, IPA is flammable and is therefore very subject to contamination.

Also, it is important to select a solvent that is compatible with the cleaning wipe, swab or device. You do not want a solvent will dissolve a binder or glue used in a wipe or swab and generate additional contamination.

Fast drying solvents can be used to clean (flush/rinse) adaptor caps used on inspection or test equipment. These adaptors can also be sources of contamination in the optic network.

Do's

- Always turn off any laser sources before you inspect fiber connectors, optical components, or bulkheads.
- Always inspect and clean the connectors before you make a connection. It is preferable to clean patch chords after inspecting them to understand the level of cleaning required.
- Always use the connector housing to hold during plugging or unplugging a fiber patch cord, otherwise it may damage the connector or the fiber cable.
- Always keep a protective cap on the ferrule of unplugged fiber connectors.
- Always store unused protective caps in a re-sealable container in order to prevent the possibility of the transfer of dust to the fiber. Locate the containers near the connectors for easy access.
- Always discard used tissues and swabs properly.
- Always use the Cleaning materials which we supply with Light Runner as cleaning consumable.

Don'ts

- Never use unfiltered handheld magnifiers or focusing optics to inspect fiber connectors.
- Never connect a fiber connector to a fiberscope while the corresponding system laser is on. It will damage your eyes, due to multiplication of laser power through fiberscope.
- Never touch the end face of the fiber connectors.
- Never twist or pull forcefully on the fiber cable, it may cause more signal loss.
- Never reuse any tissue, swab or cleaning cassette reel.
- Never touch the clean area of a tissue, swab, or cleaning fabric.
- Never touch any portion of a tissue or swab where alcohol was applied.
- Never touch the dispensing tip of an alcohol bottle.
- Never use alcohol around an open flame or spark; alcohol is very flammable.
- Never allow cleaning alcohol to evaporate slowly off the ferrule as it can leave residual material on the cladding and fiber core. This is extremely difficult to clean off without another wet cleaning and usually more difficult to remove than the original contaminant. Liquid alcohol can also remain in small crevices or cavities where it re - emerge

1

Numerical Aperture

Introduction to Numerical Aperture

In optics, the **Numerical Aperture** (**NA**) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. The exact definition of the term varies slightly between different areas of optics. Numerical aperture is commonly used in fiber optics in which it describes the range of angles within which light that is incident on the fiber will be transmitted along it. By incorporating index of refraction in its definition, NA has the property that it is constant for a beam as it goes from one material to another provided there is no optical power at the interface.

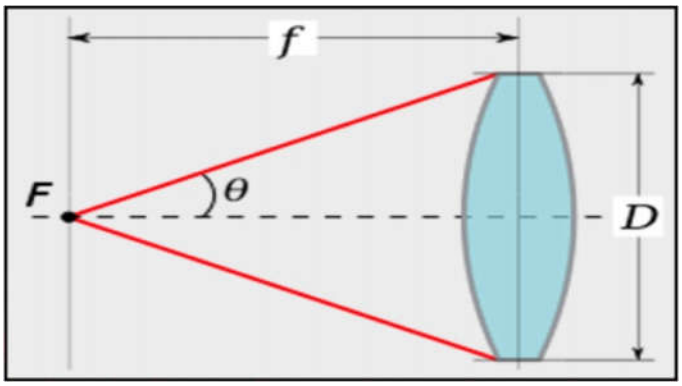


Fig1.1: Showing geometrical representation of acceptance angle.

The maximum incidence angle of a light wave which can be used for injecting light into a fiber core is called Acceptance angle and the sine of the acceptance angle is called Numerical Aperture. Using trigonometric functions, if Θ is the acceptance angle,

$$\text{Tan}\ \Theta = D/2f,$$
$$\Theta = \tan^{-1}(D/2f)$$

Theoretically, Numerical Aperture is equivalent to sine of the acceptance angle, Θ. Hence,

$$\textbf{Numerical Aperture, NA} = \textbf{Sin}\ (\textbf{Tan}^{-1}\ (D/2f)) \qquad (1)$$

Using the theory and the above expression, numerical aperture has been measured with the following statistics.

1) V number calculation for ESTIMATION OF MODES

V number or normalized frequency estimates approximately the number of modes travelling in the core of the fiber. The expression defining the normalized frequency is:

$$V = [2\pi a\ (NA)]/\lambda \qquad (2)$$

Where 'a' is the Core radius, 'λ' is the Wavelength of the light beam travelling and 'NA' is the numerical aperture of the fiber.

According to the above expression, for SMF 28 with 4 microns core radius and 850 nm light source, V number comes to be 4.836. The cut-off normalized frequency for single mode fiber is 2.405. This illustrates that higher modes are also travelling along with the fundamental mode LP_{01} reason being the use of 850 nm light source instead of 1310 nm specified.

2) Calculation of number of modes, M

The number of modes can be roughly estimated by V number by the formula:

$$\textbf{Total number of modes, } M \approx V^2/2 \qquad (3)$$

EXPERIMENT

AIM

To find out the Numerical Aperture and V number estimation of the Single Mode fiber.

COMPONENTS USED

1. Visual Fault Locator (VFL) of 660nm

2. Single Mode Fiber - SMF

3. Black screen

PROCEDURE

1. Set up the light runner as per instructions given in the manual (Refer page no vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Clean the patch chord ends, laser head and screen properly with alcohol (very important in order to observe nice mode pattern).

4. Connect single mode patch chord to the Visual Fault Locator (VFL) and project the laser output towards the screen.

5. Switch on the VFL using the ON/OFF switch.

6. Before starting the experiment, make sure the arrangement is such that Black screen comes directly in front of the laser projection.

7. Set the laser diode power at a value where the mode pattern is clearly visible.

8. Calculate the distance of the screen from the other end of single mode fiber patch chord. Note the distance as 'f'.

9. Measure the diameter of the mode pattern visible in the screen. Note it as 'D'.

10. Change the distance between the screen and fiber patch chord end for various combinations of 'D' and 'f'.

11. Calculate the NA and V number as illustrated in table below.

Fig 1.2: Schematic of the setup to determine Numerical Aperture

OBSERVATION

S.No	D (mm)	f (mm)	D/2f	$\Theta = \tan^{-1}(D/2f)$ (degrees)	NA=sinΘ	NA=Avg.	V number = 2πa (NA)/λ
1.		50					
2.		100					
3.		150					
4.		200					
5.		250					

Number of modes, $M = V^2/2$

RESULTS

The specified value of numerical aperture for SMF 28 corning optical fiber is 0.14 at 1310 nm.

At 850nm it is observed to be around ...... (≈0.12).

Since V number is coming around...... , it is concluded that the fiber is behaving like a single mode fiber validating the theory.

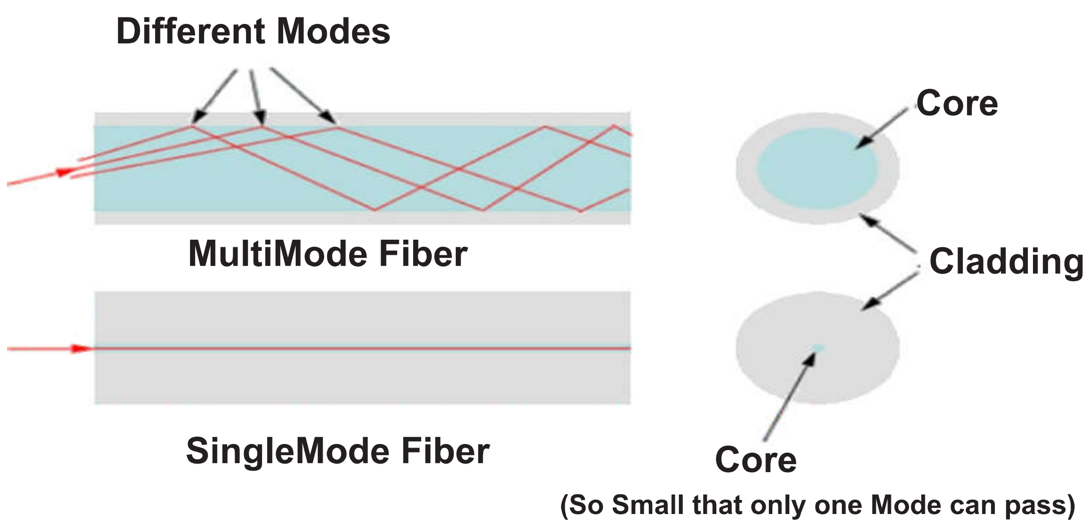
★★★

2 Modes In Optical Fiber

Modes in Optical Fiber

An optical fiber guides light waves in distinct patterns called *Modes*. Mode describes the distribution of light energy or electromagnetic fields across the fiber. We can differentiate between different kinds of fiber, depending upon the output spot projected on the screen.

Fibers that carry more than one mode at a specific light wavelength are called multimode fibers. Some fibers have very small diameter core that they can carry only one mode which travels as a straight line at the center of the core. These fibers are single mode fibers. Following are the geometric pattern of propagation of light in single to multimode fibers.



The precise output patterns depend on the wavelength of light transmitted and on the variation in refractive index that shapes the core. In essence, the variations in refractive index create boundary conditions that shape how light waves travel through the fiber.

In general Maxwell's equations describe electromagnetic waves or modes as having two components i.e., Transverse Electric (TE) & Transverse Magnetic (TM). Transverse modes are classified into:

Transverse electric (TE) modes:

No electric field in the direction of propagation. These are sometimes called H modes because there is only a magnetic field along the direction of propagation (H is the conventional symbol for magnetic field).

Transverse magnetic (TM) modes:

No magnetic field in the direction of propagation. These are sometimes called E modes because there is only an electric field along the direction of propagation.

Hybrid modes:

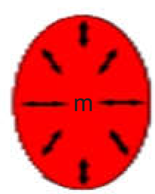
Non-zero electric and magnetic fields in the direction of propagation. These modes result from skew ray propagation & are designated as HE_{lm} & EH_{lm} depending upon whether the components of H or E make the larger contribution.

A mode in an optical fiber is usually represented as LP_{lm} where, LP stands for linearly polarized modes; l represents number of Lobes/Bright spots/Maxima along azimuthal direction & m represents number of Rings along radial direction.

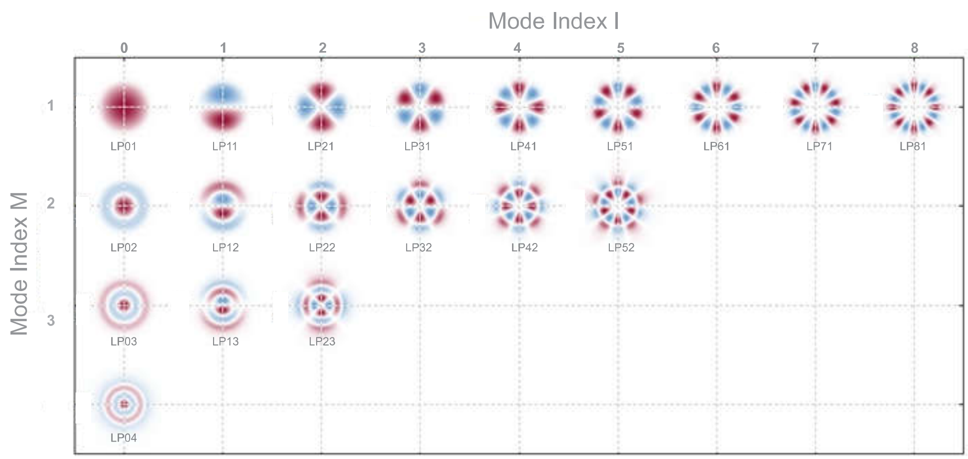
NOTE: [In general there are 2l field Maxima along azimuthal direction & m number of rings along radial direction].

Azimuthal

Radial



Below figure shows the electric field profiles of the guided modes of a step-index fiber, as calculated for one particular wavelength. Any guided field distribution can be considered as a superposition of the guided modes. The intensity profile depends not only on the optical powers in all the modes, but also on the relative phases, and there can be constructive or destructive interference of different modes at particular locations in the fiber.



How to identify the mode by observing the mode patterns?

1. Observe the number of Lobes/Bright spots in the mode pattern around the core (in azimuthal direction).
2. The number of lobes visible is twice the value of integer l in the LP_{lm} mode.
3. Observe the number of rings over the 2l maxima (in radial direction).
4. The number of rings directly corresponds to integer m in LP_{lm} mode.

Experiment 2

EXPERIMENT

AIM

To visualize and identify the modes traversing inside the optical fiber by observing the mode pattern.

COMPONENTS USED

1. Visual Fault Locator (VFL) 660nm
2. Black screen

PROCEDURE

1. Set up the light runner as per instructions given in the manual. (Refer page vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Clean the patch chord ends, laser head and screen properly with alcohol (very important in order to observe nice mode pattern).

4. Connect single mode patch chord to the Visual Fault Locator (VFL) project the laser output towards the screen.

5. Switch on the VFL using the ON/OFF switch.

6. Before starting the experiment, make sure the arrangement is such that the screen comes directly in front of the laser projection.

7. Set the laser diode power at a value where the mode pattern is clearly visible.

8. Observe the mode pattern and identify the mode by studying the theory.

9. Follow the same procedure for multi mode fiber for observing the higher mode patterns.

Fig 2.1: Schematic of the setup to determine modes of optical fiber

OBSERVATION

Mode pattern observed:

For single mode fiber: a bright spot

For multi mode fiber: flower like pattern

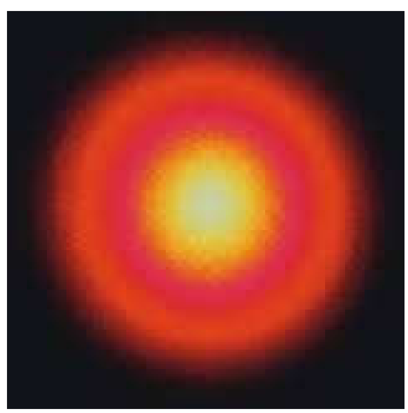


Figure showing mode patterns of a Single Mode Fiber (SMF)

RESULTS

The mode pattern for single mode fiber displayed a bright spot corresponding to LP_{01} mode traversing inside the optical fiber.

For multimode fiber, a flower pattern is observed having 'n' number of rings corresponding to higher order modes.

FURTHER EXPLORATION

Study the relation between LP_{lm} modes & HE_{lm}, EH_{lm} Hybrid/Degenerate modes.

★★★

3

Attenuation in Optical Fiber

Introduction to Optical Fiber

An optical fiber is a cylindrical structure made from a transparent material such as glass and consists of a central core of refractive index n1, surrounded by a cladding of refractive index n2 (see Fig. 3.1). Light gets guided through the fiber by total internal reflection, in which a light ray incident on an interface between a denser medium (a medium of higher refractive index) and a rarer medium (a medium of lower refractive index) at angles greater than the critical angle, gets totally reflected, i.e., undergoes complete reflection. Thus light rays impinging on the core-cladding interface at an angle greater than the critical angle qc (=$\sin^{-1}$(n2/n1)) get total internally reflected, and can propagate through very long distances. Taking typical values, n1 = 1.46 and n2 = 1.45 for silica (doped and un doped SiO2), the critical angle comes out to be approximately 83.3°. Thus any light ray impinging on the core-cladding interface at an angle of incidence greater than 83.3° will get total internally reflected. At the same time, light rays impinging at angles smaller than 83.3° will suffer partial reflection and loose power at every reflection.

In order to satisfy the condition of total internal reflection at the core cladding interface, the rays must be incident at appropriate angle at the entrance of the fiber. Assuming the surrounding medium to be air, the angle of incidence ϕ_0(see Fig. 3.1) should be smaller than $\phi_a = \sin^{-1}\sqrt{n_1^2 - n_2^2}$. For the values of n1 and n2 assumed above this comes out to be approximately 9.8 .

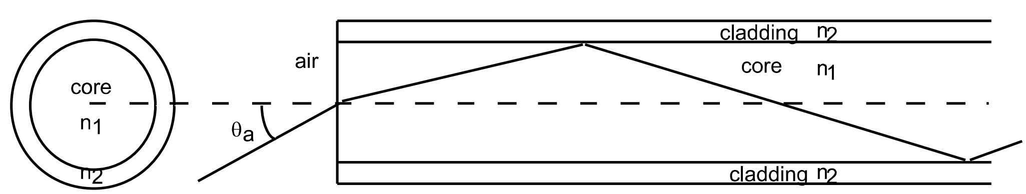


Fig 3.1: Light Rays entering at angles smaller than ϕ_a will get guided through the fiber

Experiment 3

Signal Attenuation

Although total internal reflection at the core-cladding interface is lossless but as the light rays propagate through the fiber, they get attenuated because of various mechanisms like absorption due to impurities, scattering due to inhomogeneities in the core medium, imperfections at the core-cladding interface etc. Absorption is caused primarily by metallic impurity ions like copper, chromium, iron and nickel. The presence of such impurities can be reduced to parts per billion (ppb) levels using vapor phase oxidation methods. One of the major contributors to the loss in fiber is the presence of water dissolved in the glass matrix. An impurity level of just 1 part per million (ppm) of water can cause a loss of about 75 % in one kilometer length of the fiber.

Another fundamental mechanism responsible for loss is the Rayleigh scattering This is the same mechanism responsible for the blue color of the sky and the red color of the rising and setting sun. Rayleigh scattering is caused by non-uniformities of dimensions smaller than the wavelength that are frozen into the fiber during its manufacture. The amount of Rayleigh scattering depends on the wavelength and decreases with increasing wavelength, with a dependence on the wavelength l given by l. Thus, for example, the Rayleigh scattering at 1500nm will be 16 times smaller than the Rayleigh scattering at 750nm.

Loss can also occur when the fiber is bent. For small bending radius, the loss can be quite significant. Hence when laying standard fibers, the bends in the fibers should be kept a minimum and radius of the bend should be kept larger than typically 25 mm. Losses also occur at splices/joints and connectors between fibers and for non identical fibers a finite loss can occur even when the fibers are perfectly aligned (due to NA mismatch and core diameter mismatch).

The loss in an optical fiber is measured in logarithmic units of decibels per kilometer (dB/km) and is defined by the following equation,

$$\alpha\,(dB/km) = -\frac{10}{L}\log\left(\frac{P(L)}{P(0)}\right) \qquad (1)$$

Where $P(0)$ is the optical power at the input ($z = 0$) and $P(L)$ is the optical power at the output, i.e. L km away from the input end. Here we assume z to be the direction along the length of the optical fiber.

Thus if we assume that the optical power at the entrance face of the fiber is 1 mW and after a distance of 10 km the measured power is 0.1 mW, then the loss coefficient of the fiber will be 1 dB/km. If light propagates in the same fiber over a distance of 30 km, then the loss suffered would be 30 dB, and using Eq. (1) we can calculate the output power at the end of 30 km as 1mW.

Attenuation is a very important property of any optical fiber and it decides the maximum distance that the light wave can propagate and still be detectable at the output by a receiver. Attenuation is a function of wavelength and the minimum attenuation of silica optical fibers occurs at a wavelength of 1550 nm. Typically optical fiber loss is found to be in range of 0.20 to 0.30 dB/km at1550nm and therefore even after propagating through 80 km of such a fiber, the output would be 1 % of the input power.

Measurement of Attenuation

One of the standard ways of determining the attenuation through an optical fiber is to measure the values of optical power within the fiber at two locations separated by a distance L km and using the expression given by Eq. (1). We can measure the power emanating from the light source but to know the optical power within the fiber we need to know the coupling efficiency into the fiber too. Since this is usually not known, one uses the method referred to as the 'cut back method'. In this technique, light is launched into an optical fiber of length L and then power exiting from the fiber is measured. Then without disturbing the input, the fiber is cut near the input end (about 1 m from the input end) and the power exiting is again measured. Knowing the length of the fiber cut in this process, attenuation coefficient of the fiber can be estimated.

EXPERIMENT

AIM

To Study the length dependence of attenuation in the given optical fiber at different wavelengths.

COMPONENTS USED

1. C Band Lasers - 1

2. Laser - 850nm

3. InGaAs Photodetector - 1

4. Si Photodetector (PD5) - 1

5. Fiber Spools - 3

FORMULA USED

If P_1 represent the input power and P_2 is the output power after passing through an optical fiber of length L km,

$$\text{Attenuation,} \quad A(dB) = -10\log\left(\frac{P_2}{P_1}\right) = 10\log\left(\frac{P_1}{P_2}\right)$$

$$\text{Attenuation coefficient,} \quad \alpha\,(dB/km) = \frac{A}{L} = -\frac{10}{L}\log\left(\frac{P_2}{P_1}\right)$$

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 850nm laser source to the photo detector PD5 with the help of patch cords.

4. Connect the BNC connector adjacent to PD5 to anyone channel (say CH1) of the DSO with the help of BNC cable.

5. Enable the 850nm laser by using stylus and set the following parameters :
For example - (a) Frequency = 50 KHz
(b) Duty cycle = 20%
(c) Laser power = 60%

6. Click on the 'Start' button, waveform will appear at CH1 on the DSO screen.

7. In case of detector saturation, reduce the laser power level below the saturation level by using software control (Refer the note given on pg no. xii).

8. After adjusting the power level below the saturation level, note down the optical power displaying in front of the label PD5 as P_1.

9. Stop the experiment by clicking on the 'STOP' button.

10. Disconnect the patch cord from the detector (PD5) and connect this end to the fiber spools of known length (L).

11. Connect the other end of the fiber spool to the photo detector PD5 by using a patch cord (Refer the connections shown in Fig 3.2).

12. Run the experiment by clicking on the 'Start' button.

13. Note down the output power, displaying in front of PD5 as P_2.

14. From the above measured values, calculate the value of attenuation coefficient and total attenuation at 850nm wavelength.

15. Repeat the experiment for any of the C-band lasers with respective detector for different length of the fiber spools.

16. In the procedure given here instead of cutback method, the power exiting at a short length and a long length is measured.

17. Since an additional fiber of length *L* has been introduced in the fiber path, the loss at the extra connector (assumed to be 0.5 dB) should be taken care of in the estimation of attenuation coefficient.

18. Similarly each extra connector in the experiment adds 0.5 dB loss to the measurement.

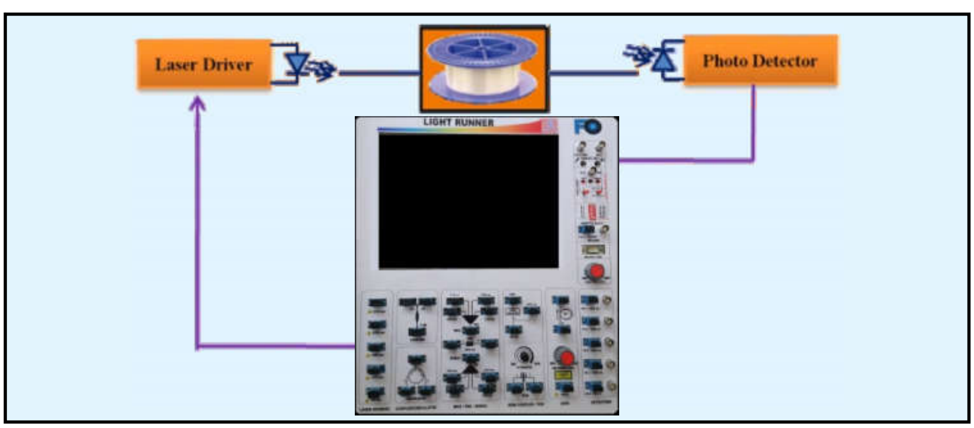


Fig 3.2: Schematic of the setup to determine attenuation of fiber as a function of length and wavelength

OBSERVATION

Wave-length (nm)	Fiber Length, L (km)	Fiber Input Power, P_1 (mW)	Fiber Output Power, P_2 (mW)	Total Attenuation A, in dB = 10 log (P_1/P_2)	Number of Connectors	Attenuation after accounting for connector loss, A	Fiber attenuation coefficient, α in dB per km
850	1.0				2		
	2.0				2		
	3.0				2		
	4.0				4		
	5.0				4		
	6.0				4		
					4		
1550							

RESULTS

As expected the measured attenuation coefficient at 850nm wavelength is much higher than C band wavelengths.

FURTHER EXPLORATION

1. Connect an additional patch chord to the fiber and try to estimate the losses at the two new connectors introduced in the fiber path. Since the patch chord length is very small, the additional loss is primarily due to the connectors.

2. You can check that bending the fiber introduces additional losses. Try to design an experiment based on the kit to measure the loss due to bending. Ensure that you do not bend the fiber too much so as to break the fiber. Try bend diameters of 30 mm and 50 mm. May be you can attach an additional patch chord in the fiber length and try bending the fiber in the patch chord.

NOTE

The 50/50 coupler given along with the LIGHT RUNNER can be used in the attenuation experiment for simultaneously observing and measuring the input power and output power from the fiber spool. This can be done by connecting the 'COM' port of the 50/50 coupler to the laser and connecting one of the output arms to a photo detector and the other to a fiber spool. Before doing this connection find out the splitting ratio of the 50/50 coupler.

★★★

Experiment 3

4

Bending Loss In Optical Fiber

Bending in Optical fiber:

Optical fibers are recognized as the superior medium for delivering high bandwidth communications signals over long distances. The key attribute that enables this performance is very low attenuation, i.e., signals experience very little power loss as they propagate along the length of the optical fiber.

Several extrinsic effects can increase the fiber attenuation. A critical effect is bending the fiber from a straight axis. Bending can increase the attenuation of an optical fiber.

Macrobending:

Macrobending of an optical fiber is the attenuation associated with bending or wrapping the fiber. Light can "leak out" of a fiber when the fiber is bent; as the bend becomes more acute, more light leaks out. This effect is shown schematically in Figure below. In the figure on the left, a small percentage of the light is refracted out of the waveguide when it is bent. The figure on the right schematically illustrates that more light is shown refracted out of the fiber when it is bent to a smaller diameter.

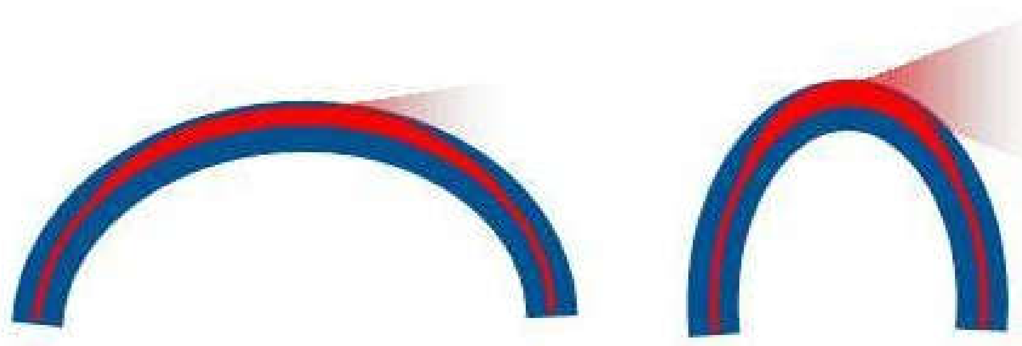


Fig 4.1: Light Rays showing Macro & Micro bending

Macrobending is commonly modeled as a “tilt” in the refractive index profile based on the radius of curvature of the fiber bend. The attenuation increases exponentially as bend radius decreases.

Radiative losses occur whenever an optical fiber undergoes a bend of finite radius of curvature. Fibers can be subject to two types of bend:

a. Macroscopic bends having radii that are large compared to the fiber diameter.

b. Random microscopic bend of the fiber axis that can arise when the fibers are incorporated into cables.

The tighter the bend, worsens the losses. If bending radius is smaller than critical radius it causes damage to optical fiber.

EXPERIMENT

AIM:

To observe the loss occurring in optical fiber link due to Macro bending.

COMPONENTS USED:

1. Laser Source - 1550nm

2. Optical Power Meter

3. SMF - Single Mode Fiber Patch cord (1 m)

4. Mandrel

.

PROCEDURE:

1. Connect the one end of SMF patch cord to the 1550 nm laser and the other end to the optical power meter. Make sure the optical fiber is straight & no loops or bend observed.

2. Turn on 1550 nm laser and optical power meter, and note down the measured value of optical power.

3. By using mandrel (40 mm diameter part); bend the patch cord properly.

4. Record the optical power against as shown in table below.

5. Repeat steps (3, 4) with bending diameters (40mm, 30mm, 20mm & 10mm).

6. Using the data from the table, carefully plot on a single graph the bending loss in dB as a function of bend radius. Comment on the results.

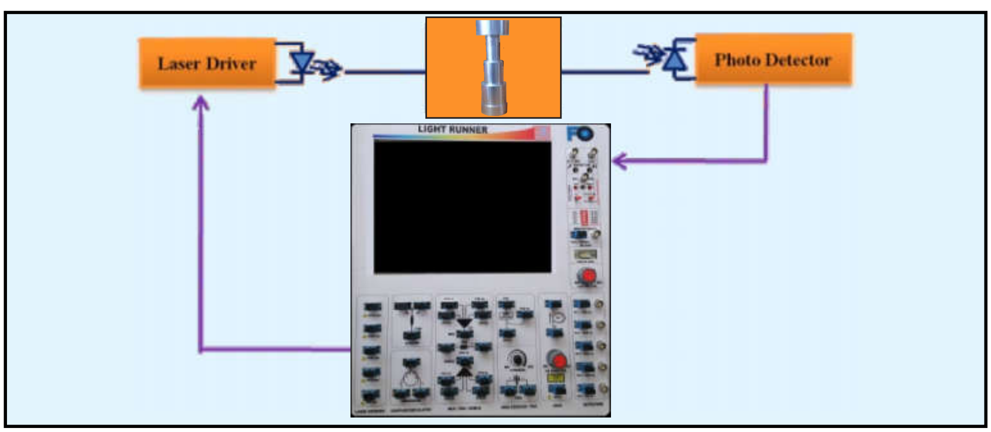


Fig 4.2: Schematic of the setup to determine bending loss

OBSERVATION:

Sl No	Bend Radius	No of turns	Output Power	Bending Loss

1. The bending loss is observed when fiber is wrapped over the mandrel.

2. On increasing number of turns, bending loss increases linearly.

3. Loss is inversely proportional to the diameter of the bend i.e. the loss is more when fiber is wrapped around lesser diameter region in the mandrel.

FURTHER EXPLORATION:

The same link could be seen in the OTDR, so as to quantify the loss occurring due to different bend radius.

★★★

Experiment 4

5

Dispersion in Optical Fiber

Introduction to Pulse Dispersion

Most optical fiber communication systems employ digital communication techniques. In this technique information to be sent is coded in a digital form with a string of 1s and 0s. For example to send a single speech signal which has an analog bandwidth of about 4 kHz, the analog speech signal is sampled at a rate of 8000 times per second and each sample is coded with eight bits, thus giving a bit rate of 64000 bits per second or 64kb/s. Each 1 is represented by a light pulse and each 0 is represented by the absence of a light pulse. Thus for each speech channel, there would be a sequence of 1s and 0s arriving at the rate of 64000 times per second. The time interval between two adjacent pulses in this sequence would be 15.625 ms. If we need to send simultaneously 1000 such speech channels then the bit rate would be 64×10^{6} bits per second or 64 Mb/s. In this case the time interval between two adjacent light pulses would be 15.625 ns. For a 2.5 Gb/s system, the inter pulse separation would be 0.4 ns only. Thus as the bit rate increases, the time interval between adjacent pulses decreases.

Now in an optical fiber system as the optical pulses propagate through the fiber, they broaden in the time domain. Thus a 1 ns pulse launched into an optical fiber can broaden to 10 ns after propagating through a certain length of the optical fiber. This effect is termed pulse broadening or pulse dispersion. This is caused due to many different mechanisms. Since each pulse carries information, in order to receive the information at the output with minimal errors, adjacent pulses should not overlap in time. Thus in a 2.5 Gb/s system the inter pulse separation is 400ps and a commonly used criterion for permissible pulse dispersion is to allow for a maximum dispersion of a quarter of the pulse duration. In the non return to zero (NRZ) scheme the pulse duration is equal to the inter pulse separation and thus for a 2.5 Gb/s system the maximum tolerable dispersion is about 100ps. Single mode optical fibers are specified by the dispersion coefficient D in units of ps/km-nm. This implies that if the source spectral width is $\Delta\lambda$ and the distance of propagation through the fiber is L km,then the accumulated dispersion would be $D\,L\,\Delta\lambda$ ps. Thus if the dispersion in the fiber is 1 ps/km-nm and the spectral width of the source is 1 nm, then for a 2.5 Gb/s system using this fiber, the maximum distance of propagation would be 100 km since in 100 km, the pulse would accumulate a dispersion of 100 ps. Pulse dispersion in single mode fibers takes place primarily due to two mechanisms:

(a) Material dispersion

(b) Waveguide dispersion.

Material dispersion arises due to the dependence of the refractive index of the fiber material on wavelength while waveguide dispersion arises due to the waveguide geometry. Material dispersion in silica based fibers goes through a zero at about 1270 nm. Thus at this wavelength, the dispersion in a pulse would be due to waveguide effects only. It happens that the sign of the material dispersion and waveguide dispersion are opposite beyond the zero material dispersion wavelength. Thus by appropriate design of the transverse refractive index profile of the fiber, it is possible to cancel the effects of waveguide and material dispersion. This leads to zero total dispersion in the fiber. Conventional fibers have a zero dispersion wavelength of 1310 nm and these are referred to as G652 fibers. It is possible to shift the zero dispersion wavelengths to higher wavelengths. A single mode fiber with zero dispersion at 1550 nm is referred to as Dispersion Shifted Fiber (DSF) and corresponds to G653 fiber. Fibers with non zero values of dispersion in the band 1525 nm to 1565 nm are referred to as Non Zero Dispersion Shifted Fibers (NZDSF) and correspond to G655 fiber.

A G652 fiber has a dispersion of about 17 ps /km-nm at the wavelength of 1550 nm. Thus if we take a laser source with a spectral width of 2nm and take a fiber of length 5 km, the accumulate dispersion would be about 170 ps. This is a very small dispersion value and measurement of this would require sophisticated instrumentation. Since dispersion is the manifestation of the wavelength dependence of time to propagate through a certain length of fiber, we measure the time taken by two different wavelengths to traverse a certain length of fiber. In order to have a measurable effect we choose two wavelengths which are wide apart namely 850 nm and 1550 nm. The difference in propagation time between these two wavelengths will be primarily due to material dispersion.

A pulse of light (which contains many frequencies) travels at a velocity referred to as the group velocity. If $n(\lambda)$ is the refractive index of the fiber at a wavelength λ, then the group refractive index $n_g(\lambda)$ is given by,

$$n_g(\lambda) = n(\lambda) - \lambda \frac{dn}{d\lambda} \qquad (1)$$

And the speed of a light pulse at a wavelength λ would be given by,

$$v_g(\lambda) = \frac{c}{n_g(\lambda)} \qquad (2)$$

Thus the group index and hence the pulse speed depends on how the refractive index varies with wavelength. This dependence is usually described by a relation referred to as the Sellemeier relation. For pure silica an approximate relation is given by,

$$n(\lambda) = 1.451 - 0.003\left(\lambda^2 - \frac{1}{\lambda^2}\right) \tag{3}$$

where λ is in µm. Using eqs. (2) and (4) we obtain for the group refractive index,

$$n_g(\lambda) = 1.451 + 0.003\left(\lambda^2 + \frac{3}{\lambda^2}\right) \tag{4}$$

Using the above equation we can estimate the speed of a pulse at two different wavelengths due to material dispersion. Thus the approximate speed of a light pulse at a wavelength of 850nm is $2.036*10^5$ km/s while the approximate speed of a light pulse at a wavelength of 1550nm is $2.052*10^5$ km/s. Thus if two pulses one at a wavelength of 850nm and the other at a wavelength of 1550nm are simultaneously launched into an optical fiber, then after a distance of *L* km, the difference in arrival times between the two pulses would be,

$$\Delta\tau = \frac{L}{v_g(0.85)} - \frac{L}{v_g(1.55)} \tag{5}$$

For a fiber of length 1 km this comes out to be about 37 ns.

The experiment utilizes the above fact that different wavelengths travel at different speeds (which is nothing but dispersion) and uses two very different wavelengths so that the time difference is measurable using simple instrumentation.

Using the experiment it is possible to check if lower wavelengths travel slower or faster than longer wavelengths, whether the time difference increases linearly with increasing length of the fiber or decreases etc.

EXPERIMENT

AIM

(a) Determine the time delay between pulses in single mode fiber due to group velocity dispersion.

(b) Compare the experimental result with theoretical prediction calculated from refractive index spectrum of pure silica.

COMPONENTS USED

1.1550nm and 850nm Laser

2. InGaAs and Silicon Photodetector

3. 50/50 Coupler

4. 980/15XX Coupler

5. Fiber Spools

FORMULA USED

The difference in the delay of propagation between two pulses, one at 850nm and another at 1550nm, due to a length L of the fiber,

$$\Delta\tau = \frac{L}{V_g(0.85)} - \frac{L}{V_g(1.55)}$$

$$V_g(\lambda) = \frac{c}{n_g(\lambda)}$$

v_g is the group velocity and n_g the group refractive index given by

$$n_g(\lambda) = 1.451 + 0.003\left(\lambda^2 + \frac{3}{\lambda^2}\right)$$

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 850nm laser to the appropriate port of the 3dB coupler which delivers more power as compare to other port. (To check the power please connect the 'COM' port of the coupler to the power meter by using a patch cord).

4. If the right port of the coupler gives less power as compare to left port of the coupler for 850nm laser then connect it to the left port of the coupler otherwise keep the same connections.

5. Connect 1550nm laser to the other port of the 3 dB coupler by using a patch cord.

6. Connect the 'COM' port of the 3 dB coupler to the 'COM' port of the WDM coupler by using a patch cord.

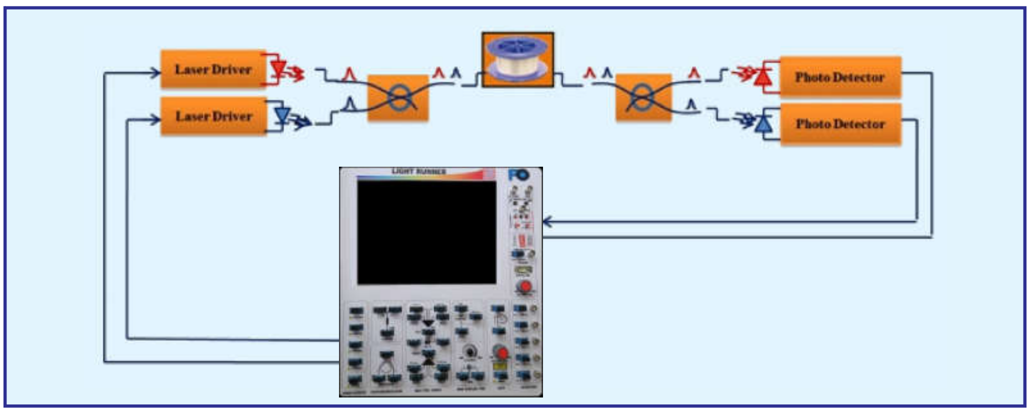


Fig 5.1: Schematic of the experimental arrangement to estimate the pulse delay difference as a function of length of the fiber.

7. Connect 15xx and 980 port of the WDM coupler to the respective photo detectors PD3 and PD5 by using patch cords.

8. Connect BNC connectors adjacent to PD3 and PD5 to CH1 and CH2 of the DSO by using BNC cables.

9. Enable the 850nm laser by using stylus and set the following parameters :
For example - (a) Frequency = 50 KHz
(b) Duty cycle = 20%
(c) Laser power = 60%

10. Click on the 'Start' button, waveform will appear at CH2 on the DSO screen.

11. In case of detector saturation, reduce the laser power level below the saturation level by using software control. (Refer the note given on pg no. xii).

12. Now enable the 1550nm laser and set the following parameters:
For example - (a) Frequency = 50 KHz
(b) Duty cycle = 50%
(c) Laser power = 100%

13. Click on the 'Start' button, waveform will appear at CH1 on the DSO screen.

14. In case of detector saturation, reduce the laser power level below the saturation level by using the software control (Refer the note given on pg no. xii).

15. Without disturbing the power level of both the lasers, enable both the lasers and click on the 'Start' button to run the experiment.

16. For clear view of the waveforms at both the channels, set the channel time by using DSO control option, given on right side in the experimental window.

17. Measure the time delay between the rising edges of the both the pulses at Ch1 and CH2. (For DSO measurement, please refer the instructions given on the pg. x of the manual).

18. Now connect a fiber spool of known length L between the 'COM' ports of the 3 dB and WDM couplers by using patch cords.

19. Determine the time delay between the arrival of 850nm and 1550nm at the detector as a function of wavelength. (Please note that due to material dispersion, 850nm pulse travels slower than the 1550nm pulse).

20. Repeat the above procedure to measure the time delay for different length of the fiber spools.

21. From the above measurements, determine the delay per Km between 850nm and 1550nm pulses.

22. Calculate the time delay between both of the pulses by using the given formula also and compare the theoretical result with the experimental result obtained.

OBSERVATION

Fiber Length (km)	Delay between positions of 850nm and 1550nm laser pulses (ns)	Dispersion per km
1.0		
2.0		
3.0		
4.0		
5.0		
6.0		

Average Dispersion per km =

Dispersion from Sellemeier Equation =

RESULT

Due to dispersion, pulses of light launched at 850 nm and 1550 nm take different times and the time difference determined per km is consistent with the estimation obtained from the Sellemeier equation for silica.

FURTHER EXPLORATION

1. The single mode fiber acts as a multimode fiber at 850nm and single mode fiber at 1550nm. Observe whether the distortion in the output is the same at 850nm and 1550nm or not.

2. Find out the time delay between 850nm pulse and other C-band pulses, i.e.1510nm, 1530nm and 1570nm compare it with the results you obtained for 850nm and 1550nm.

NOTE

It may be noted that the 3dB coupler is meant for C-band operation and therefore when used with 850nm light it won't split the beam into equal halves. Care should be taken to identify the port which passes more 850nm light and use it for taking the 850nm light out of the coupler.

6

Characteristics of Laser Diode

Characterization of LASER Diode

The optical transmitter in an optical fiber communication system consist of a laser diode which is electrically driven by the input information and which gives rise to optical pulses that are launched into the optical fiber. The laser diodes are made from compound semiconductor materials such as InGaAsP and by choosing appropriate fractions of ratios of individual elements in the semiconductor, it is possible to achieve any lasing wavelength in the range of 1525 to 1565 nm.

A laser diode is a forward biased p-n junction and when a current is passed through the junction, the electrons and holes recombine resulting in the emission of photons of appropriate frequency (wavelength) depending on the band gap energy of the semiconductor material (see Fig. 6.1)

Laser diodes are characterized by various important characteristics. These include the threshold current for lasing, the output power for different diode currents, the wavelength of emission and the spectral width. When a laser diode is forward biased, then for low currents (few mA), the laser oscillation cannot take place as the gain is below the loss in the laser cavity and the output power is very low which is primarily generated by spontaneous emission. As the current is increased, at a certain value of current called the threshold current, the output power begins to rise rapidly as the current is increased. Beyond the threshold current, the output power increases almost linearly with the input current. Every laser diode has a maximum current rating and it is important to never exceed this value, as otherwise the laser diode will get damaged.

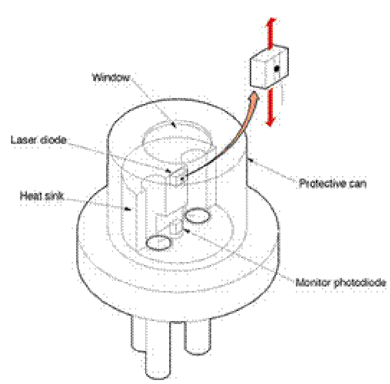


Fig 6.1: Internal structure of Laser diode

Most of the diode lasers used in communication technology comes along with an integrated monitor photo diode which is used to maintain a constant laser optical power (see Fig 6.1). A part of the laser beam falling on a monitor photo diode which is placed behind the laser diode, produces light generated carriers in the monitor photo diode. This optically generated monitor photo diode current can be used as a feedback for an external electronic circuitry to maintain a constant current flowing through the laser diode. Monitor photo diode is highly beneficial for the long term power stability of the diode laser.

The light output versus current characteristic can be measured using the components provided with the kit. In order to measure other characteristics such as wavelength of emission, spectral bandwidth of the laser diode, one would require other equipment such as an optical spectrum analyzer.

EXPERIMENT

AIM

(a) To determine the relationship between the laser current and output optical power and hence find out the threshold laser current.

(b) To check the linearity between Laser Diode and Monitor Diode Current.

COMPONENTS USED

1. Laser – 1550nm

2. Photodetector – PD3 (or power meter)

3. Multimeter -1

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 1550nm laser source to the optical power meter by using a patch cord.

4. Switch on the optical power meter and set it in 1550nm wavelength range.

5. Enable the 1550nm laser by using stylus and set the following parameters :
(a) Frequency = Continuous mode
(b) Duty cycle = 50%
(c) Laser power = 0%

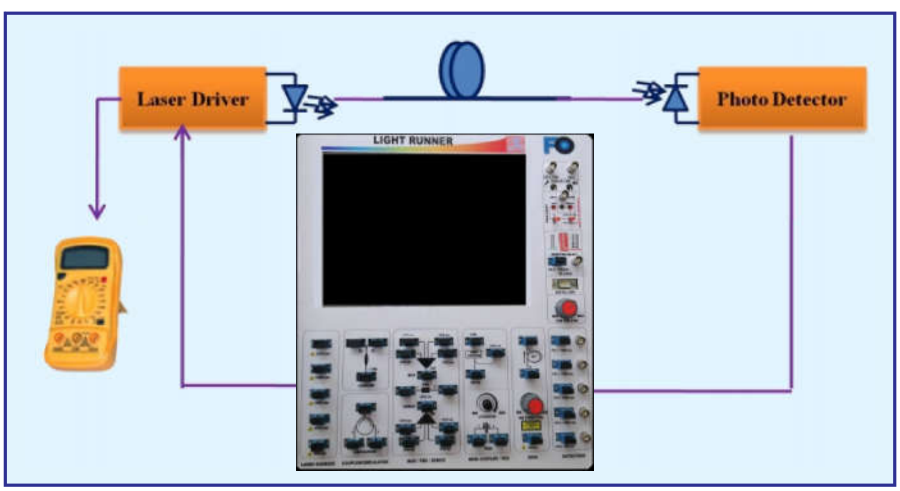


Fig 6.2: Schematic arrangement to determine Laser Diode characterization

6. Before starting the experiment, choose the 'MANUAL' option given at the top right corner of the experimental window and set the 1550nm laser manual power knob to its minimum position by rotating it in anticlockwise direction.

7. Insert the +ve and –ve terminal of the multi meter to the Laser diode ports in 'LASER Characterization' block.

8. Set the multimeter at 2V or 20V position for voltage measurement .

9. Click on the 'Start' button to run the experiment.

10. Now start increasing the 1550nm laser power in steps with the help of the power knob and note down the corresponding voltage for each value of the power.

11. Calculate the value of the laser diode current by dividing the voltage with 27Ω internal resistance.

12. Now insert the +ve and –ve terminal of the multimeter to the monitor diode ports in 'LASER Characterization' block and follow the above steps from 6 to 10 to measure the value of the voltage.

13. Calculate the value of the monitor diode current by dividing the voltage with 22KΩ internal resistance.

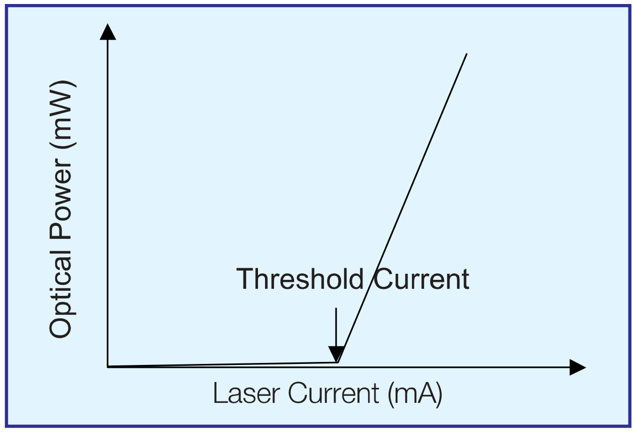
14. From the above measurements, plot the graph for laser diode current versus optical power and same for monitor diode also.

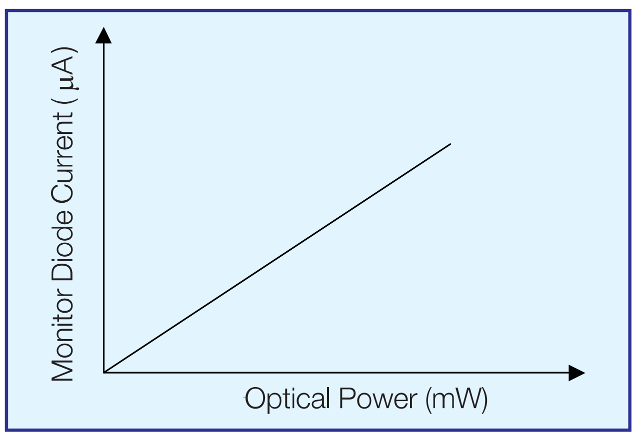
OBSERVATION

Laser Current (mA)	Laser Optical Power (mW)	Photodiode Current (μA)

RESULT

From the measurements it is found that beyond the threshold current, the optical power of the laser is linear with respect to it's the forward current and the monitor diode current is directly proportional to the laser power.





7

Characteristics of Photodiode

Introduction to Photo Diode

A photodetector is a device which converts optical power into electrical current.Usually it is a reverse biased p-n diode with an intrinsic region between the p and n regions and hence the name PIN photo diode (see Fig 7.1). An incident photon is absorbed by the semiconductor and results in the creation of electron hole pair in it. The generated electrons and holes are swept away from the junction region by the applied voltage resulting in a current in the external circuit. The amount of current depends on the light power incident on the photodetector. This is quantified by a quantity called responsivity *R* which is the ratio of the current produced by the photodetector to the optical power incident on it. The responsivity is measured in units of amperes per watt (A/W). Thus if the responsivity of a photodetector is 0.4 A/W, then an optical power of 2 mW incident on the photodetector would generate a current of 0.8 mA.

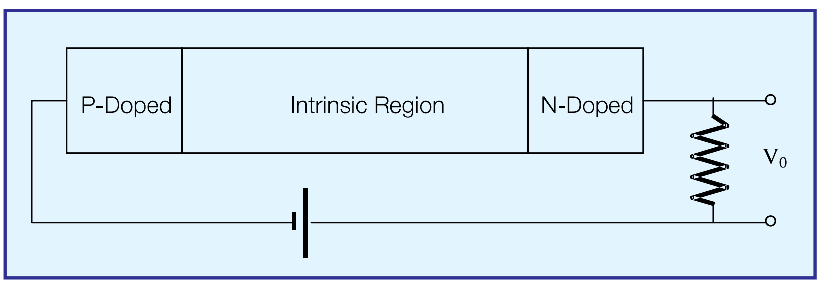


Fig 7.1: Block Diagram of reverse biased PIN Photo Diode (Photoconductive mode)

Photodiodes can be operated either in photoconductive or in photovoltaic mode depending on whether they are externally biased (photoconductive) or not (photovoltaic). In the photovoltaic mode, (like in a solar cell) the voltage developed across the photodiode is a nonlinear function of the light intensity incident on it. However, when the photodiode is operated under reverse bias (photoconductive mode) the photocurrent generated is linearly dependent on the light intensity up to about six orders of magnitude of power variation. Since the junction capacitance decreases due to reverse biasing, photodiode operated in the photoconductive mode is faster than photovoltaic mode even though the former is noisier. Usually, photodiodes in photoconductive mode are operated in conjunction with a transimpedance amplifier to convert the photocurrent developed into a voltage that is easier to measure and for further amplification.

Bandwidth is another very important characteristic of a receiver. If modulated light wave is incident on a photodetector then it should produce a similar modulated current output since the current generated by the photodetector depends on the corresponding incident light power. Now if the frequency of modulation of the input light wave is increased, it would be found that the depth of modulation in the output current reduces and for very high frequency of input light modulation, the current produced by the photodetector remains almost constant. One of the primary reasons for the drop in the depth of modulation of the current output is the *RC* time constant of the photodetector circuit. The photodetector is characterized by a capacitance *C* and if the photodetector circuit has a resistance *R* then the photodetector circuit behaves like an *RC* circuit. It is well known that the speed of operation of an *RC* circuit is limited by the time constant *RC*. The corresponding bandwidth is given by,

$$BW = \frac{1}{2\pi RC}$$

By measuring the rise time of the photodetector the quantity RC can be estimated. Knowing the value of R, the corresponding capacitance of the photodetector can be found.

From the communication point of view, the important fact to notice is the dependence of rise-time on the load resistance R in the circuit. Although, larger resistance will give a higher voltage at the output of the detector circuit, it would bring down the bandwidth of the detector and hence high speed operation is not possible. Hence it can be understood that larger the bandwidth, the smaller will be the output and hence signal-to-noise ratio (SNR). In communication systems, the user has to make a trade-off between bandwidth and SNR.

EXPERIMENT

AIM

(a) To operate a PIN photo diode in photovoltaic and photoconductive modes
(b) Study its frequency response in both the configurations.

COMPONENTS USED

1. Laser – 850nm

2. Silicon Photodetector -1 (PD6)

FORMULA USED

Bandwidth of the photo detector = $f_{3dB} = \frac{1}{2\pi RC} = \frac{0.70}{t_r}$

where t the response time of the photo detector, C the capacitance of the photo diode, R is the resistance used.

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect 850nm laser source to the photo detector PD6 with the help of patch cord (Refer the connections shown in the Fig 7.2).
4. Connect the BNC connector adjacent to PD6 to anyone channel (say CH1) of the DSO with the help of BNC cable.
5. Now see the 'PD CHARACTERIZATION' block, there is a DIP switch, used to select the value of the resistor to be put in the circuit and to select the mode of the operation.

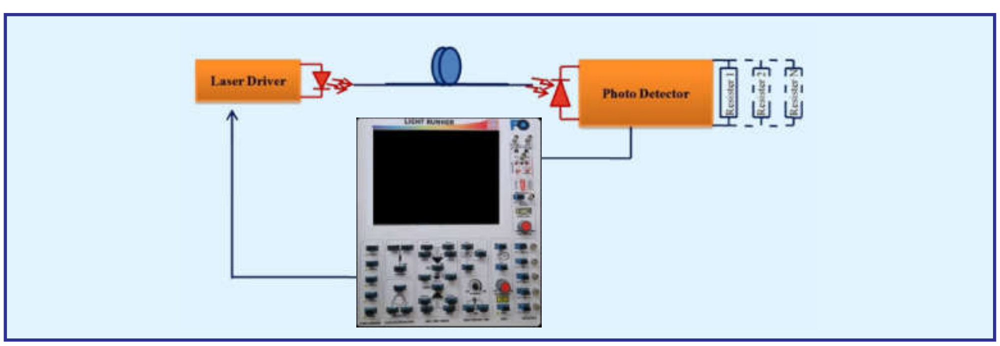


Fig 7.2: Schematic arrangement for Photodiode characterisation

6. Select the photoconductive mode of the operation and choose the largest resistance by pushing up the small switches.
7. Enable the 850nm laser by using stylus and set the following parameters :
(a) Frequency = 5 KHz
(b) Duty cycle = 20%
(c) Laser power = 60%
8. Click on the 'Start' button, waveform will appear on the screen.
9. In case of detector saturation, set the laser power level below the saturation level by using the software control (Refer the note given on pg no. xii).
10. For clear view of the waveform, channel voltage can be increased using DSO control option given on the right side in the software window.
11. Measure the rise time and output voltage of the waveform from DSO.
12. Change the value of the resistor and measure the rise time and output voltage of the waveform.
13. Similarly measure the rise time and output voltage of the photo detector for each of the given lower resistance.
14. From the rise-time measurements, calculate the bandwidth and the junction capacitance of the photo detector by using the given formula.
15. Now select the photovoltaic mode of the operation by flipping the switch in other direction and follow the above steps from 6 to 14 to calculate the bandwidth and the junction capacitance of the photodetector.

OBSERVATION

Photoconductive Mode

Resistance (Ω)	Output Voltage	Rise Time, t_r (μs)	Bandwidth $=0.70/t_r$(MHz)	observed Capacitance, C (pF)

Photovoltaic Mode

Resistance (Ω)	Output Voltage	Rise Time, t_r (μs)	Bandwidth $=0.70/t_r$(MHz)	observed Capacitance, C (pF)

RESULT

It is found that the rise time of photodetector is directly proportional to the resistance and inversely proportional to the output voltage. The capacitance of the photo diode is derived in photovoltaic and photoconductive modes.

FURTHER EXPLORATION

Study the linearity of the photodetector in both photoconductive and photovoltaic modes by varying the optical power incident on it over several orders of magnitude, for example from 1μW to 1 mW.

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8

Characterization of WDM Mux and Demux

Introduction to Wavelength Division Multiplexing

A WDM mux is a device that combines a set of different wavelengths propagating in different fibers connected at the input ports of the device into one output fiber. Similarly a WDM Demux is a device that separates different wavelengths propagating through a single fiber into separate fibers. These devices are very important components in a wavelength division multiplexed fiber optic communication system. In such a system, different wavelengths carry independent information and all the wavelengths use the same fiber to propagate from one terminal to the other. Thus they all use the same transmission fiber which results in an increased capacity of the link. Thus if there are 4 wavelength channels each carrying bit rates of 2.5 Gb/s, then when multiplexed into the fiber link the fiber link would be carrying a total capacity of 4 x 2.5 = 10 Gb/s. Larger the number of multiplexed channels larger would be the total capacity of the communication link.

WDM began in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm (or 850 nm and 1310 nm) regions, sometimes called wideband WDM. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were now spaced at an interval of about 400 GHz in the 1550-nm window. By the mid 1990s, dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz. By the late 1990s, DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even 25 GHz intervals.

A WDM mux or demux is characterized by some important operating characteristics. These include:

(a) Insertion loss: If P_{in} is the power entering the mux at a specific wavelength and P_{out} is the power exiting the mux then the insertion loss of the mux at this wavelength is defined by

$$IL(dB) = -10\log(P_{out}/P_{in}) \qquad (1)$$

Thus if for an input power of 1 mW the output power is 0.8 mW then the insertion loss would be 0.97 dB.

Insertion loss is a very important characteristic of a multiplexer or a demultiplexer and specifies the loss encountered by signals passing through the multiplexer or the demultiplexer. The lower the insertion loss, the better is the device. The loss encountered by the signals at the multiplexer and demultiplexer should be factored in the design of the fiber optic link.

(b) Cross talk: It refers to how well two different wavelength channels are isolated in a given output. Thus if the output port 1 is designated for the wavelength λ_1 is to exit, in principle there should be no light at any other wavelength exiting from port 1. Due to the design or fabrication errors, a small amount of power at other wavelengths (usually corresponding to adjacent channels) may also be exiting from the same output port. This is referred to as cross talk.

Let λ_i be the wavelength which is supposed to exit from the ith port of a DEMUX. If P_i is the power exiting at λ_i from the i port of the demux and if P_j is the power exiting from the ithport at any other wavelength λ_j then we define the cross talk of the i output as,

$$CT(dB) = 10\log (P_j / P_i) \qquad (2)$$

If the j channel is an adjacent channel to the i channel then the cross talk is referred to as adjacent channel cross talk, otherwise it is referred to as non adjacent channel cross talk.

For example:-

Let us consider a four wavelength demultiplexer. Assume that at the input of the demux equal powers of 1.2 mW at each wavelength λ_1 to λ_4. If the output from Port 1 (the intended port for wavelength λ_1) at a wavelength λ_1 is 1 mW and if at the same output port the powers at λ_2, λ_3 and λ_4 are 0.02 mW, 0.01mW and 0.005 mW respectively, then the cross talk at the Port 1 comes out to be -17 dB adjacent channel cross talk and -20 dB and -23 dB non adjacent channel cross talks respectively.

It may be mentioned that apart from errors in the design or fabrication of the device, any deviation of the wavelength of the laser source can also result in deterioration of the performance of the multiplexer or the demultiplexer in terms of insertion loss and cross talk.

EXPERIMENT

AIM

(a) To determine the insertion loss and loss uniformity of each channel of WDM Mux.
(b) To determine the optical cross talk in adjacent channels of WDM Demux for various wavelengths.

COMPONENTS USED

1. C-Band Lasers - 4
2. 4 channel WDM Mux
3. 4 channel WDM Demux
4. InGaAs Photodetectors - 4

FORMULA

Insertion Loss (dB) = $-10\log(P_2 / P_1)$
P_1 is the input power to the Mux and P_2 is the output power from the Mux.
Cross Talk (dB) = $10\log(P_3 / P_1)$

P_1 is the optical output power at the specific wavelength designated for the port (say i) and P_3 is the output power at the same port for other adjacent/other channel wavelengths.

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect any C-band laser source (say 1510nm) to InGaAs (say PD1) photodetector with the help of the patchcord.
4. Connect the BNC connector adjacent to PD1 to anyone channel (say CH1) of the DSO with the help of BNC cable.
5. Click on the 'Start' button, waveform will appear on the screen.
6. In case of detector saturation, set the laser power level below the saturation level (Refer the note given on pg no. xii).

7. Disconnect the patch cord from PD1 and connect it to the power meter for optical power measurement.

8. Switch on the power meter and set it for 1550nm range and note down the power value as P1.

9. Click on the 'Stop' button to stop the running experiment.

10. Disconnect the patch cord from the optical power meter and connect it to the 1510nm channel of the MUX.

11. Now connect the 'OUT' port of the MUX to the optical power meter with the help of patch cord.

12. Click on the 'Start' button and note down the output power as P2.

13. From the above measurements, calculate Channel Insertion loss by using the given formula.

14. Add 0.5dB extra connector loss in calculated value due to the additional patch cord used to include the MUX in the light path.

15. Repeat the above mentioned steps from 3 to 14 to calculate the insertion loss for other channels of the MUX.

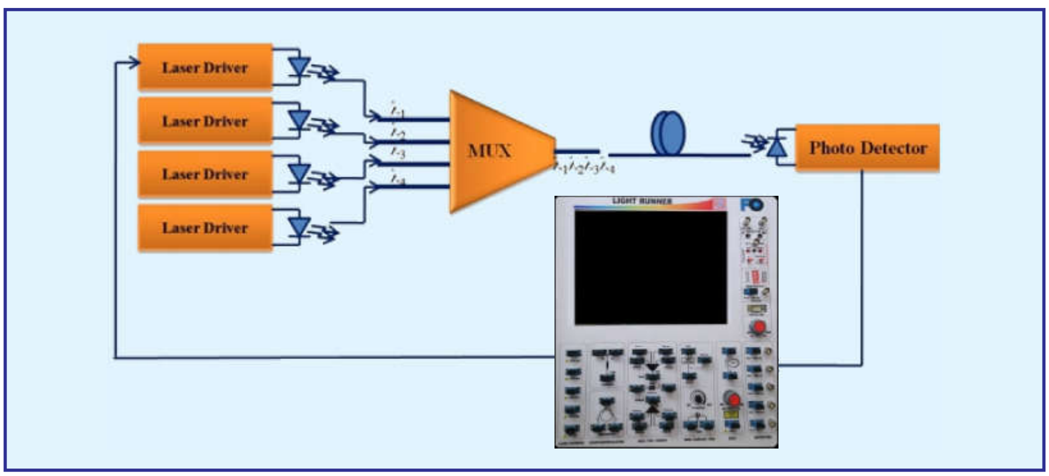

Fig 8.1: Insertion loss of each channel of WDM mux.

Cross Talk Measurement:

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect any C-band laser source (say 1510nm) to InGaAs (say PD1) photodetector with the help of the patch cord.

4. Connect the BNC connector adjacent to PD1 to anyone channel (say CH1) of the DSO with the help of BNC cable.

5. Click on the 'Start' button, waveform will appear on the screen.

6. In case of detector saturation, set the laser power level below the saturation level (Refer the note given on pg no. xii).

7. Disconnect the patch cord from PD1 and connect it to the power meter for optical power measurement.

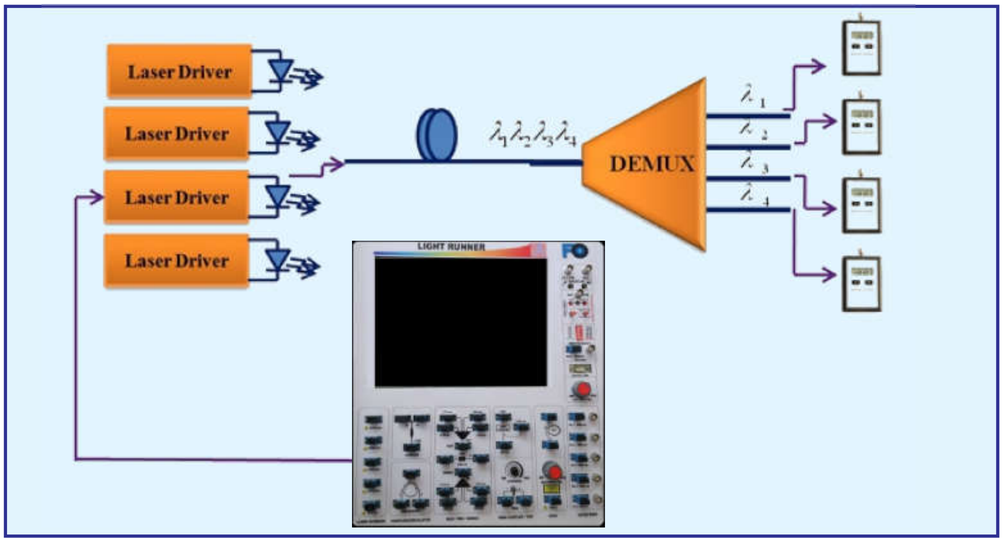

Fig 8.2 Schematic of the setup to measure cross talk in each channel of WDM Demux for various wavelengths.

8. Switch on the power meter and set it for 1550nm range and note down the power value as P1.

9. Click on the 'Stop' button to stop the running experiment.

10. Disconnect the patch cord from the optical power meter and connect it to the 'IN' port of the DEMUX.

11. Now connect the 1510nm port of the DEMUX to the optical power meter with the help of patch cord.

12. Click on the 'Start' button and note down the output power as P2.

13. From the above measurements, calculate Channel Insertion loss by using the given formula.

14. Now disconnect the patch cord from 1510 port of the DEMUX and connect it to other ports (1530nm, 1550nm, 1570nm) of the DEMUX (one at a time).

15. Note down output power coming at these ports with the help of power meter and consider it as P3.

16. From the above measurement, calculate the optical cross talk by using the given formula.

17. Repeat the above mentioned procedure to find out the optical cross talk for other channels also.

OBSERVATION

Insertion loss of MUX channels

Channel Wavelength (nm)	Input Power, P_{in} (mW)	Output power, P_{out} (mW)	Insertion Loss, *IL* in dB = -10 log (P_{out}/P_{in})	Insertion Loss after correcting for connector loss
1510				
1530				
1550				
1570				

Measurements for optical cross talk

Laser Wavelength (nm)	1510nm channel, P_1 (mW)	1530nm channel, P_2 (mW)	1550nm channel, P_3 (mW)	1570nm channel, P_4 (mW)
1510				
1530				
1550				
1570				

Cross Talk for 1510nm

Cross Talk at 1530 channel = 10log (P_2/P_1) =

Cross Talk at 1550 channel = 10log (P_3/P_1) =

Cross Talk at 1570 channel = 10log (P_4/P_1) =

Cross Talk for 1530nm

Cross Talk at 1510 channel = 10log (P_1/P_2) =

Cross Talk at 1550 channel = 10log (P_3/P_2) =

Cross Talk at 1570 channel = 10log (P_4/P_2) =

Cross Talk for 1550nm

Cross Talk at 1510 channel = 10log (P_1/P_3) =

Cross Talk at 1530 channel = 10log (P_2/P_3) =

Cross Talk at 1570 channel = 10log (P_4/P_3) =

Cross Talk for 1570nm

Cross Talk at 1510 channel = 10log (P_1/P_4) =

Cross Talk at 1530 channel = 10log (P_2/P_4) =

Cross Talk at 1550 channel = 10log (P_3/P_4) =

RESULT

The insertion loss of each WDM MUX channel and the loss uniformity is determined. The optical cross talk involved in WDM DEMUX is measured.

FURTHER EXPLORATION

You may perform the experiment to determine the insertion loss and cross talk at each port for the combination of MUX and DEMUX (i.e mux followed by demux) and analyze the result.

NOTE

The 50/50 coupler given along the LIGHT RUNNER can be used in the insertion loss of the MUX experiment for simultaneously observing and measuring the input power to and output power from the MUX. This can be done by connecting the 'COM' port of the coupler to the laser and connecting one of the output arm to the photo detector and other arm to MUX. Before doing this connection please find out the splitting ratio of the 50/50 coupler.

9

Characterization of FBG and Circulator

Introduction to Fiber Bragg Grating

Fiber Bragg Grating (FBG) is an optical fiber with a periodic variation of core refractive index along the fiber length (see Fig. 9.1). A FBG acts as a highly wavelength selective reflector, with a high reflectivity at a given central wavelength and the reflectivity dropping to very small values close to the central wavelength (see Fig. 9.2). The central wavelength, the peak value of reflectivity and the bandwidth of the reflection spectrum depends on the effective refractive index of the grating in the fiber core, period of grating, on the index modulation of grating and the length of the grating.

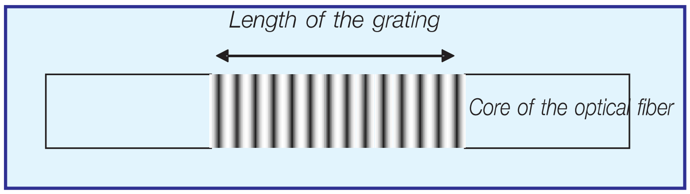

Fig 9.1: Fiber Bragg Grating

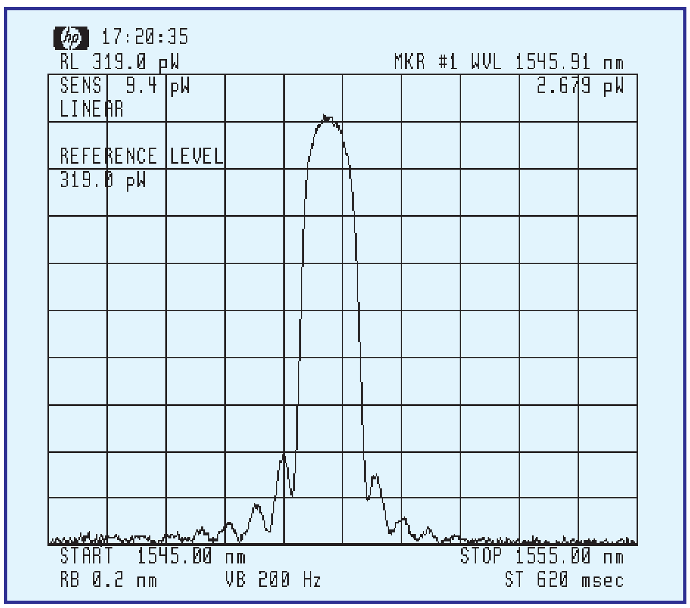

Fig 9.2: A typical FBG Reflection Spectrum

If Λ is the period of the index modulation (also known as the pitch of the grating), L the length of the grating and Δn the index modulation, the central wavelength λ_c, peak reflectivity R and the bandwidth $\Delta\lambda$ (spectral width over which reflectivity is high) are approximately given by,

$$\lambda_c = 2n_e\Lambda \tag{1}$$

$$R = \tanh^2\left(\frac{\pi \Delta n\, L}{\lambda_c}\right) \tag{2}$$

$$\Delta\lambda = \frac{\lambda_c^2}{n_e\, L}\left(1 + \left(\frac{\Delta n\, L}{\lambda_c}\right)^2\right) \tag{3}$$

Here n is the effective refractive index of the grating in the fiber core.

As an example, let us consider an FGB with a period of 0.53 mm, an index modulation of 10 and a length of 5 mm made in a single mode fiber having a mode effective index of 1.45. Using the above set of equations we obtain the following characteristics of the grating: λ_c = 1537 nm, R= 59% and $\Delta\lambda$ = 0.36 nm. By measuring λ_c, R and $\Delta\lambda$ of a grating, the values of Λ , L and Δn can be estimated from Eqs.(1-3). FBGs find wide applications in the optical fiber communication systems. They are used in laser transmitters for single frequency oscillation, in optical add drop multiplexers, fiber lasers, and fiber optic sensors.

FBGs find wide applications in the optical fiber communication systems. They are used in laser transmitters for single frequency oscillation, in optical add drop multiplexers, fiber lasers, and fiber optic sensors.

In the experiment described here, the primary measurement is the peak reflectivity of the grating. In order to measure other quantities, additional equipments are required. For example for measuring the central wavelength and the spectral bandwidth an optical spectrum analyzer or a tunable optical filter would be required. Using these additional instruments it is also possible to show effects of strain and temperature on the grating performance and thus demonstrate its application to sensing.

Introduction to Optical Circulator

An optical circulator is a multiport device with non reciprocal transmission characteristics. Fig 9.3 shows a three port optical circulator. When light enters from port 1 of the circulator, it exits from port 2. If light enters from port 2 of the circulator, instead of its emerging from port 1 it now emerges from port 3 (showing non reciprocity). Such a device finds wide applications in many areas such as dispersion compensation using FBGs, add/drop multiplexers etc. For example if a FBG with a central wavelength of λ_1 is placed at port 2 and if light at wavelengths λ_1 , λ_2 and λ_3 are incident on port 1of the circulator then out of the three wavelengths exiting from port 2, FBG reflects back wavelength λ_1 .

This wavelength propagates back towards port 2 of the circulator and exits from port 3 while the wavelengths λ_2 and λ_3 continue to propagate along port 2. Thus this acts as a drop filter for wavelength λ_1.The most important characteristics of a circulator are insertion loss and cross talk. These are defined as follows: If the power entering port 1 is P_1 and if the output at port 2 is P_2 and that at port 3 is P_3 then the insertion loss is defined as,

$$IL(dB) = -10\log\left(\frac{P_2}{P_1}\right) \tag{4}$$

Cross Talk is defined as,

$$CT(dB) = 10\log\left(\frac{P_3}{P_1}\right) \tag{5}$$

Apart from these characteristics other important characteristics of a circulator include its polarization dependence in terms of polarization dependent loss (PDL) and polarization mode dispersion (PMD), the wavelength of operation and the power handling capacity. With additional equipment these characteristics can also be measured using the kit.

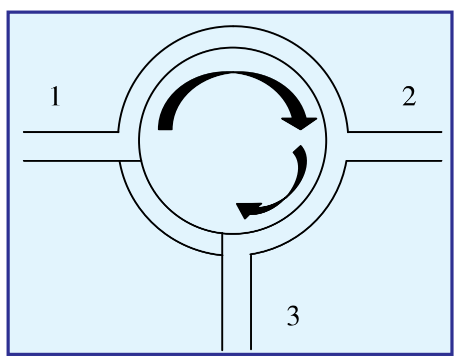

Fig 9.3: Schematic of Optical Circulator

EXPERIMENT

AIM

a) To determine the reflectivity of given Fiber Bragg Grating at four different wavelengths and verify its wavelength selectivity.
(b) To measure the insertion loss and optical cross talk of a 3 port optical circulator at various wavelengths.

COMPONENTS USED

1. FBG
2. Fiber optical circulator
3. C band Lasers-4
4. InGaAs Photodetector-1

FORMULA USED

Reflectivity of FBG = $\frac{P_1 - P_2}{P_1}$ x 100%
Where P is the input power to the FBG and P_2 is the output power from the FBG.
Insertion loss of the circulator = $-10\log(P_2 / P_1)$
P_1 is the input power to the port1 and P_2 is the output power from the port 2 of the circulator.
Cross talk in circulator = $10\log(P_3 / P_1)$
P_3 is the output power at port3 due to input power P_1 at port1 of the circulator.

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect any C-band laser source (say 1550nm) to InGaAs (say PD3) photodetector with the help of the patchcord.
4. Connect the BNC connector adjacent to PD3 to anyone channel (say CH1) of the DSO with the help of BNC cable.
5. Click on the 'Start' button, waveform will appear on the screen.
6. In case of detector saturation, set the laser power level below the saturation level (Refer the note given on pg no. xii).

7. Disconnect the patch cord from PD3 and connect it to the power meter for optical power measurement.

8. Switch on the power meter and set it for 1550nm range and note down the power value as P1.

9. Click on the 'Stop' button to stop the running experiment.

10. Disconnect the patch cord from the optical power meter and connect it to the port1 of the circulator.

11. Connect the port2 of the circulator to one end of the FBG with the help of patch cord.

12. Connect the other end of the FBG to the InGaAs photo detector PD3 with the help of the patch cord.

13. Now connect the remaining port3 of the circulator to the other photodetector (say PD2) with the help of the patch cord.

14. Take 2 BNC cables and connect the BNC connectors adjacent to PD3 and PD2 to both of the channels (CH1 and CH2) of the DSO.

15. Click on the 'Start' button, both transmitted and reflected waveforms will appear on the DSO screen corresponding to CH1 and CH2.

16. Disconnect the patch cord from PD3 and connect it to the power meter for optical power measurement.

17. Switch on the power meter and set it for 1550nm range and note down the transmitted power value as P2.

18. From the above measurements, calculate the reflectivity of the FBG for 1550nm wavelength.

19. Repeat the above mentioned procedure for other wavelengths (1510, 1530, 1570nm) also and calculate the FBG reflectivity for each one of them.

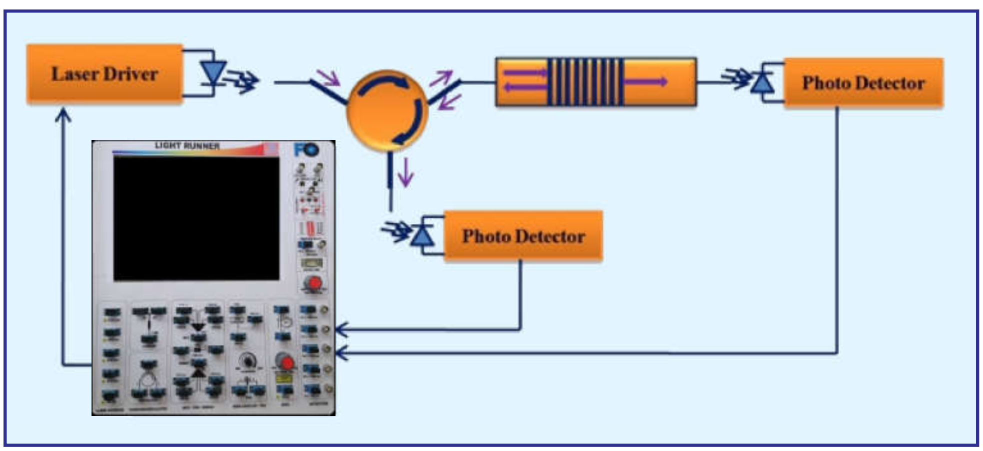

Fig 9.4: Schematic arrangement for the reflectivity of FBG

Optical Circulator

Insertion Loss & Cross Talk Measurement:

1. Repeat the above mentioned steps from 1 to 6 to fix the laser power level below the detector saturation.

2. Disconnect the patch cord from PD3 and connect it to the power meter for optical power measurement.

3. Switch on the power meter and set it for 1550nm range and note down the power value as P1.

4. Click on the 'Stop' button to stop the running experiment.

5. Disconnect the patch cord from the optical power meter and connect it to the port1 of the circulator.

6. Connect the port2 of the circulator to optical power meter with the help of patch cord.

7. Click on the 'Start' button and note down the output power as P2.

8. Now disconnect the patch cord from the port2 of the circulator and connect it to the port3 for determination of the optical power coming there and consider it as P3.

9. With the help of above measurements, calculate the insertion loss and cross talk for the optical circulator.

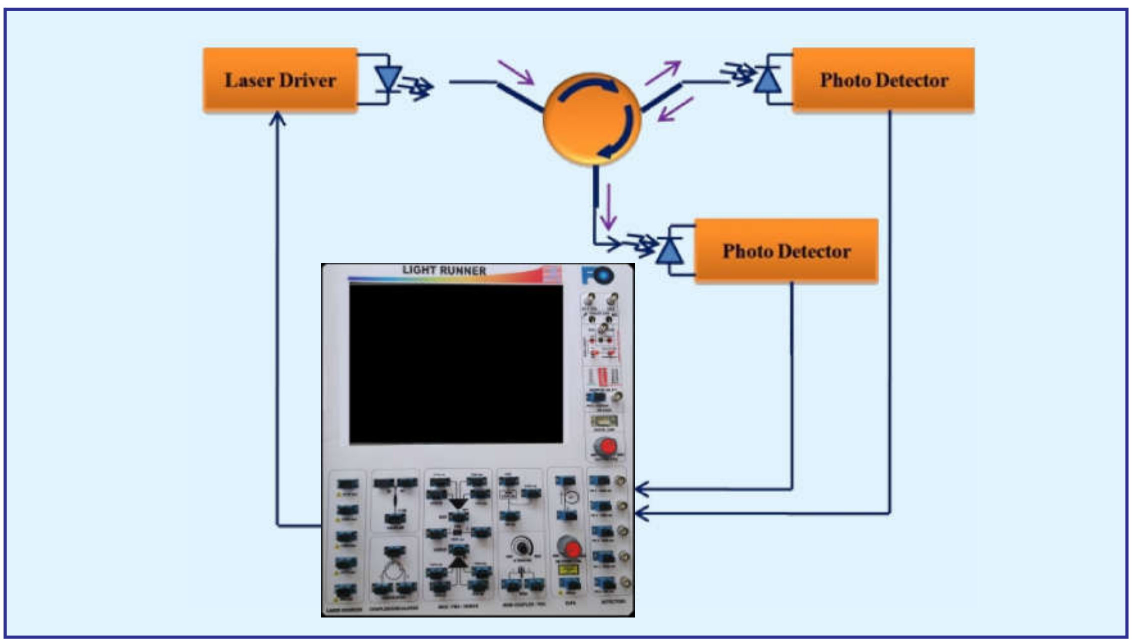

Fig 9.5: Schematic arrangement for measuring the insertion loss and cross talk of optical circulator in its optical channels

OBSERVATION

Reflection efficiency of FBG

Laser Wavelength (nm)	Expected Optical Power P_1 (mw)	Optical power with FBG, P_2(mW)	Reflectivity $\frac{P_1 - P_2}{P_1}$ X 100 (%)
1510			
1530			
1550			
1570			

Insertion loss (port1 to port2) and cross talk (Port2 to Port3) of Optical Circulator

Wavelength (nm)	Input power at Port 1 of Circulator, P_1 (mW)	Output power at Port 2 of circulator P_2 (mW)	Optical Power at Port 3, P_3 (mW)	Insertion Loss, *IL* in dB = -10 log (P_2/P_1)	Cross Talk, *CT* in dB = 10 log (P_3/P_1)
1510					
1530					
1550					
1570					

RESULTS

It is shown that the reflectivity of an FBG is a strong function of wavelength. The insertion loss of each port of optical circulator and cross talk between ports for various wavelengths are determined.

FURTHER EXPLORATION

1. Find out if the reflectivity of the FBG depends on the direction of light launching to the FBG.

2. A combination of FBG and Circulator could be used to realize Add/Drop filter. This is described in Experiment 15.

NOTE

The 50/50 coupler given along with LIGHT RUNNER can be used in the insertion loss of FBG/Circulator experiment for simultaneously observing and measuring the input power and output power from the FBG/Circulator. This can be done by connecting the COM port of the 50/50 coupler to the laser and connecting one of the output arms to a photodetector and the other to the FBG/Circulator Port 1/Port 2. Before doing this connection please find out the splitting ratio of the 50/50 coupler.

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10

Characterisation of Erbium Doped Fiber Amplifier

Introduction to Erbium doped fiber amplifier

Erbium doped fiber amplifier (EDFA) is an optical amplifier device, which amplifies an input optical signal in its own domain without converting it to an electronic signal. EDFAs have revolutionized fiber optic communication systems and have ushered in the technique of wavelength division multiplexing (WDM) to achieve very high bandwidth communication systems.

Fig 10.1 shows a schematic arrangement of an EDFA. The heart of the EDFA is a short piece (~ 10 to 20 m length) of erbium doped fiber which is pumped by a 980 nm pump laser diode through a wavelength division multiplexing coupler which multiplexes the pump wavelength of 980 nm and signal wavelengths in the range 1525 nm to 1565 nm (also referred to as the C-band of communication). The erbium ions in the erbium doped fiber absorb the pump power and get excited to a higher energy level. With sufficient pump power, a state of population inversion is created between the excited level and the ground level of the erbium ions. If light in the wavelength range of 1525 nm to 1565 nm propagates through such a population inverted fiber section, then it gets amplified by the process of stimulated emission as in a 3-level laser. Thus the signal power exiting the doped fiber is greater than the signal power entering the doped fiber leading to optical amplification.

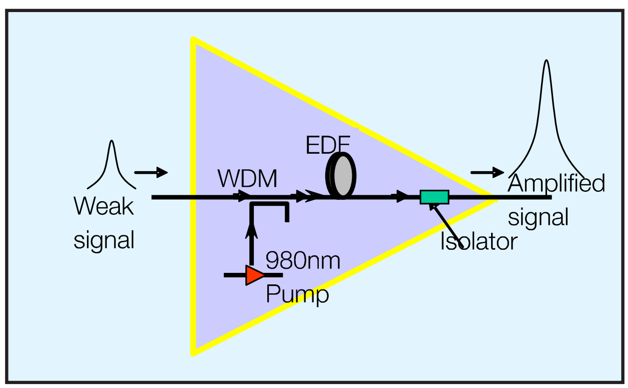


Fig 10.1: Schematic of Erbium Doped Fiber Amplifier

The gain G of an EDFA is defined as,

$$G(dB) = 10\log\left(\frac{P_{out}}{P_{in}}\right) \qquad (1)$$

Where P_{in} and P_{out} represent the optical powers entering and exiting through EDFA. Thus if the input power is 1 mW and at the exit, power is 100mW then the gain will be 20 dB. The gain of an EDFA depends on the wavelength of the input signal. For small input powers the gain of an EDFA peaks about at a wavelength of 1532 nm and falls off for wavelengths smaller than 1525 nm and greater than 1565 nm.

For a given signal wavelength, the gain also depends on the input pump power and the input signal power. For a given input signal power as we increase the input pump power, the gain would increase and get saturated for high pump powers. This is referred to as ‘pump saturation’ and happens when the pump power is sufficient to excite all the erbium ions to the excited level.

Similarly for small input signal powers, the gain remains almost the same with increase in signal power. But as the input signal power increases, the gain starts to drop. This is referred to as signal saturation. If the small signal gain of an EDFA is G_0 dB then the output signal power when the gain of the EDFA becomes G_0 – 3dB is referred to as the saturation output power of the EDFA.

Variation of gain with wavelength is a very important characteristic of an EDFA. Due to the properties of the erbium ions, different signal wavelengths experience different values of gain in an EDFA. This leads to a non flat gain spectrum and can cause problems in a WDM system employing EDFAs since then different wavelengths would experience different gains and the corresponding powers at the end of the link would not be identical. Usually gain flattening filters are used to flatten the gain of an EDFA. This aspect can be measured by measuring gain at different signal wavelengths.

Noise is a very important characteristic of any amplifier. In an EDFA, erbium ions occupying the excited energy state can spontaneously emit radiation. The spontaneous emission occurs over all directions and out of the total emission a fraction of it couples into the forward and backward propagation direction in the doped fiber. The spontaneous emission propagating through the doped fiber gets amplified just like the signal and results in what is termed amplified spontaneous emission (ASE) in the forward as well as backward direction. The ASE appearing at any wavelength other than the signal wavelength can be filtered using optical filters while the ASE appearing at the same wavelength as the signal appears along with the amplified signal. The ASE power has no correlation to the signal and thus constitutes noise in the amplified signal.

The optical signal to noise ratio (OSNR) is defined as the ratio of the optical signal power to the noise power at the output of the EDFA. The OSNR of an EDFA is given by,

$$OSNR = \frac{GP_{in}}{2n_{sp}(G-1)h\nu B_0} \qquad (2)$$

Where P_{in} is the input optical power, G_0 is the amplifier gain, B is the optical bandwidth over which the optical power is being measured (which must at least be equal to the signal bandwidth) and n_{sp} is the spontaneous emission factor given by,

$$n_{sp} = \frac{N_2}{N_2 - N_1} \qquad (3)$$

Where N_1 and N_2 representing the erbium ion population in the ground state and the excited state respectively. Since the minimum value of N_1 is 0, the minimum value of n_{sp} is 1. For incomplete inversion the value of n_{sp} would be greater than 1 resulting in a smaller value of OSNR.

EDFAs are also characterized by the quantity referred to as noise figure. The noise figure of an EDFA is defined as the ratio of the electrical SNR at the input to the electrical SNR at the output. The following expression gives the noise figure F of an EDFA.

$$F = \frac{1 + 2n_{sp}(G - 1)}{G} \qquad (4)$$

For large gains F is approximately given by $2n_{sp}$. Since the smallest value of n_{sp} is 1 the minimum noise figure is 2 or in decibel units 3 dB.The spontaneous emission power exiting from the amplifier is given by,

$$P_{ASE} = 2n_{sp}\ (G - 1)\ h\nu\,\Delta\nu \qquad (5)$$

If we measure the spontaneously emitted power adjacent to the signal wavelength on either side of the signal wavelength, we can estimate the value of $2n_{sp}(G-1)$. Knowing the value of this quantity and the gain of the amplifier G (in linear units), it is possible to estimate the noise figure of the amplifier from Eq. (4). Equivalently in the time domain extinction method, the signal source is switched on and off at a duty cycle of 50% and modulated at about 125 kHz. In this measurement, the amplified signal is measured when the source is on and the ASE is measured when the source is off. This will give the values of signal gain and the ASE power from which the noise figure can be estimated.

EXPERIMENT

AIM

To study the behaviour of EDFA in terms of gain, signal saturation and pump saturation at different signal wavelengths.

COMPONENTS USED

1. C band Lasers-4
2. InGaAs Photo detector-4
3. 980 nm laser
4. EDFA
5. 3 dB coupler
6. VOA

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 1550nm laser source to one end of VOA with the help of the patchcord.

4. Connect the other end of the VOA to the 'COM' port of 3dB coupler (to split the signal equally in two parts) with the help of patch cord.

5. Now connect the one port of the 3dB coupler to anyone of the InGaAs photo detector (say PD3) by using a patch cord.

6. Connect the BNC connector adjacent to PD3 to anyone channel (say CH1) of the DSO with the help of BNC cable (CH1 will show the 1550nm input signal without amplification).

7. For the amplification of the input signal, connect the other port of the 3 dB coupler to the port 2 of the erbium doped fiber (amplifying medium) with a patch cord.

8. Connect the port 1 of the erbium doped fiber to the 'COM' port of the WDM coupler with a patch cord.

9. To maintain the state of population inversion in amplification process, connect 980nm laser source to the 980 port of the WDM coupler by using a patch cord.

10. Connect 15xx port of the WDM coupler to the other InGaAs photo detector (say PD2) with a patch cord.

11. Connect the BNC connector adjacent to PD2 to other channel (CH2) of the DSO with the help of BNC cable (CH2 will display the amplified1550nm output signal).

NOTE: Before starting the experiment, set the VOA and manual power knob of 980nm laser to minimum position.

SIGNAL GAIN SATURATION

1. Enable the 1550nm laser source by using stylus and set the following parameters:
For example - (a) Frequency = 50 KHz
(b) Duty cycle = 50%
(c) Laser power = 100%
2. Enable the 980nm laser source and set the 0% power for the pump laser with the help of stylus.
3. Click on the 'Start' button, a waveform will appear on the CH1 corresponding to 1550nm laser input signal.
4. Now by observing the waveform increase the attenuation by rotating the VOA knob in clock wise direction to 20mV.
5. Measure the input power using power meter (set at 1550nm) and note it down as Pi.
6. Disconnect the patch chord from 980nm port of WDM coupler and connect it to optical power meter.
7. Switch ON the optical power meter and keep it in 980nm wavelength.
8. Now increase the power level of 980nm laser by rotating manual power knob in clockwise direction and set the power level to 10mW.
9. Disconnect the patch chord from optical power meter and connect it back to 980nm port of WDM coupler.
10. After connecting it back to WDM coupler, waveform will appear on the CH2 of the DSO.
11. Now measure this output power using power meter (set at 1550nm) and note it down as Po.
12. From the above measured values of the power, calculate the gain by using the given formula.

13. Now without changing the 980nm laser power (set at 10mW), increase the input power by rotating the VOA knob in counter clockwise direction and observe the changes in input/output power using power meter & tabulate the readings for plotting graph.
14. Repeat the above procedure for different power level of the pump laser source (say 20mW, 30mW, 40mW etc.)

NOTE: Repeat the above steps with other C band lasers and calculate the gain in different conditions.

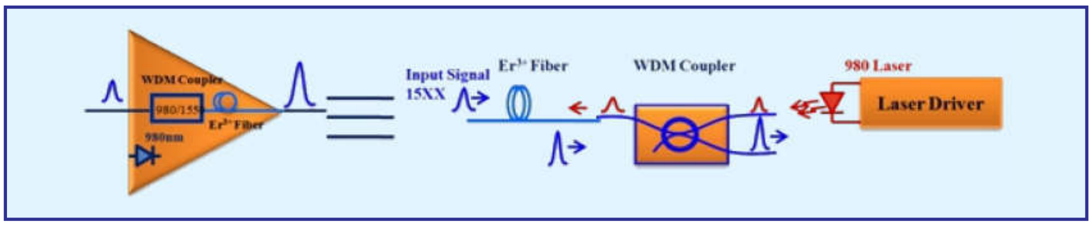


Fig 10.2: Backward Pumping in Erbium Doped Fiber Amplifier

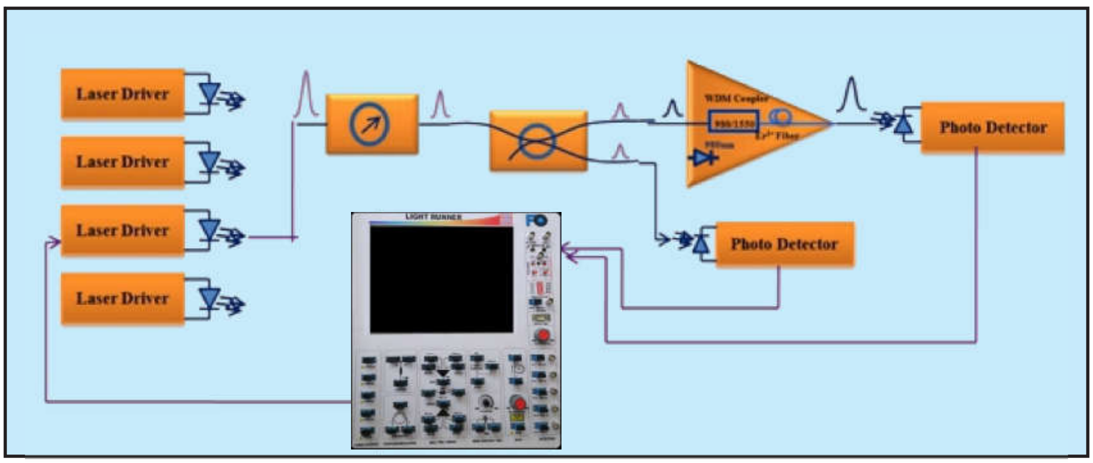


Fig 10.3: Experimental setup for study of Erbium Doped Fiber Amplifier

PUMP GAIN SATURATION

1. Enable the 1550nm laser source by using stylus and set the following parameters:

For example - (a) Frequency = 50 KHz

(b) Duty cycle = 50%

(c) Laser power = 100%

2. Enable the 980nm laser source and set the 0% power for the pump laser with the help of stylus.

3. Click on the 'Start' button, a waveform will appear on the CH1 corresponding to 1550nm laser input signal.

4. Now by observing the waveform increase the attenuation by rotating the VOA knob in clock wise direction to 20mV.

5. Measure the input power using power meter (set at 1550nm) and note it down as Pi.

6. Disconnect the patch chord from 980nm port of WDM coupler and connect it to optical power meter.

7. Switch ON the optical power meter and keep it in 980nm wavelength.

8. Now increase the power level of 980nm laser by rotating manual power knob in clockwise direction and set the power level to 10mW.

9. Disconnect the patch chord from optical power meter and connect it back to 980nm port of WDM coupler.

10. After connecting it back to WDM coupler, waveform will appear on the CH2 of the DSO.

11. Now measure this output power using power meter (set at 1550nm) and note it down as Po.

12. From the above measured values of the power, calculate the gain by using the given formula.

13. Now without changing the input signal, increase 980nm laser power to different values like 20mW, 30mW, 40mW etc. by rotating the 980 manual power knob in clockwise direction and observe the changes in input/output power using power meter & tabulate the readings for plotting graph.

14. Now instead of 20mV to 1550nm laser, set some other power level like 50mV, 100mV, 200mV etc and follow the same procedure to calculate the Gain.

NOTE: Repeat the above steps with other C band lasers and calculate the gain in different conditions.

OBSERVATION

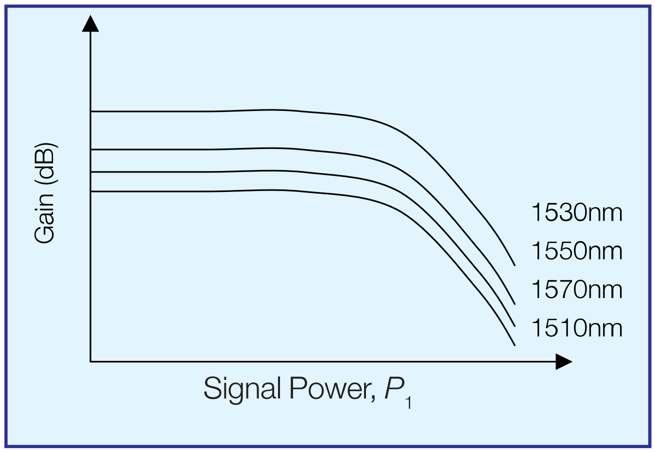
Laser wavelength (nm)	Pump Power, PP (mW)	Input Signal Power P_1 (μW)	Output Signal Power, P_2 (μW)	Gain in dB = 10 log (P_2/P_1)
1550	20 mW			
	30 mW			
	40 mW			
1510				
1530				
1570				

RESULT

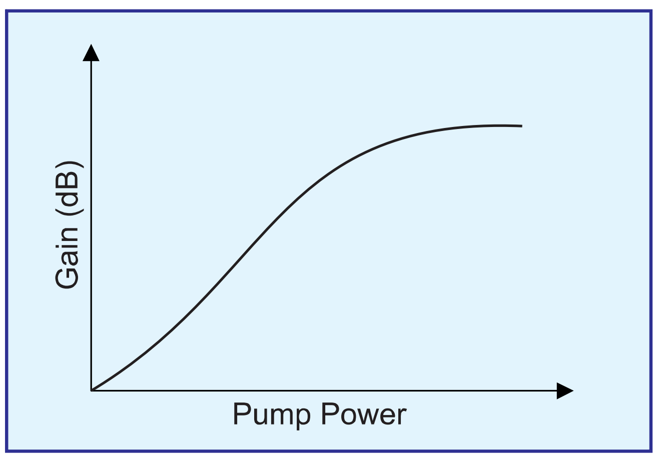
EDFA gain characteristics are varying in accordance with signal power, pump power and signal wavelength.

SIGNAL - GAIN SATURATION FOR VARIOUS WAVELENGTHS

Pump Power, *PP*



PUMP - GAIN SATURATION FOR SMALL SIGNAL



FURTHER EXPLORATION

1. Send in a signal at a certain wavelength, and measure the power exiting the fiber at the input wavelength as well as other wavelengths. Study the mechanism leading to power at wavelengths other than the signal wavelength.

2. Measure the gain at a given signal wavelength in the presence and absence of other wavelengths and interpret the results obtained.

11 Analog and Digital Fiber Optic Links

Introduction to Signal Communication

Communication signals can be transmitted in two fundamentally different forms, viz. continuous analog signals and discrete digital signals. Traditionally, signal communication involving telephone and video signals has been in analog form due to its compliance with natural objects such as eye and ear. On the other hand, digital signals are far easier to process with electronics and fiber optics. Moreover, digital signals are less prone to distortion and digital circuits are simpler and cheaper to design because they are supposed to just check the presence or absence of signal. When an analog signal goes through a system that does not reproduce it exactly, the result is garbled signal that may be unintelligible (see Fig 11.1). However, even when a digital signal is not reproduced exactly, it is still possible to clearly distinguish an OFF state from an ON state. Hence, the basic advantage with digital signals over analog signals is their immunity to noise and system response changes.

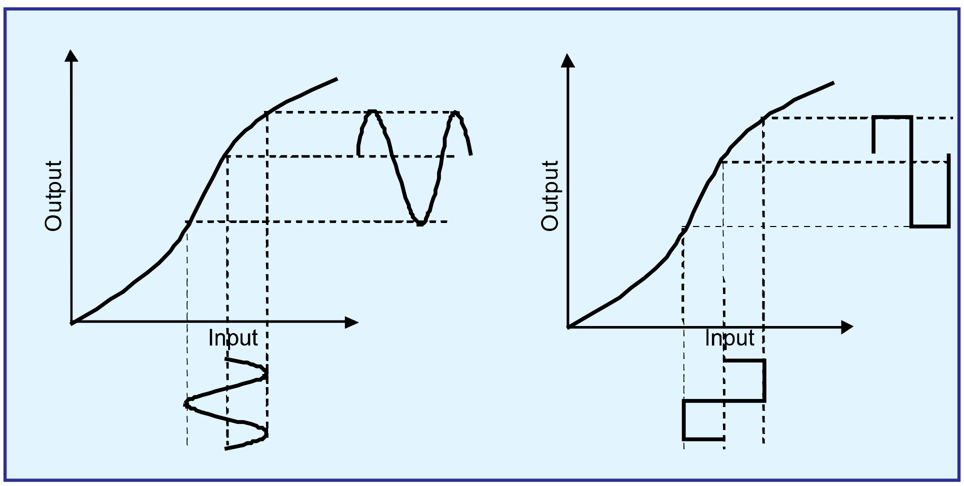


Fig 11.1: Effect of Distortion on Analog signal and Digital signal

Plain Old Telephone Service (POTS) with Public Switched Telephone Network (PSTN) started with analog communication techniques which later gave way for more advanced digital communication techniques during the 1960's. The advent of digital communication reduced the number of physical channels required. Employment of digital technique in telephony was fueled by the developments in digital electronics, IC technology, Digital Signal Processing etc. However, the change from analog to digital techniques is not apparent to most telephone users because digital signals are yet to reach homes. Even, most of the modern technologies such as DSL and ADSL use analog techniques for data and voice transmission. On the contrary, Integrated Services Digital Network (ISDN) employs digital signals for data and voice transmission. Therefore modern optical fiber communication mostly utilizes digital techniques.

EXPERIMENT

AIM

1. To setup an analog link for voice communication and digital link for data communication and observe analog and digital transmission.
2. To determine the range of laser power required for a clear voice transmission and that for a faithful digital transmission.

COMPONENTS USED

1. InGaAs Photodetector-1 (PD3)
2. C-Band Laser - 1 (1550nm)
3. Microphone
4. Speaker
5. VOA
6. DB-9 Cable for digital link

PROCEDURE

Analog Fiber Optic Link:- 1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Connect the microphone and speaker in the given slots of analog section for voice transmission.
3. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
4. Connect 1550nm laser source to the photo detector PD3 through a VOA with the help of patch cords (Refer the connections shown in Fig 11.2).
5. Set the manual power knob to its max position and VOA to the minimum position.
6. Run the experiment by clicking on the 'Analog Link' button given in the experimental window.

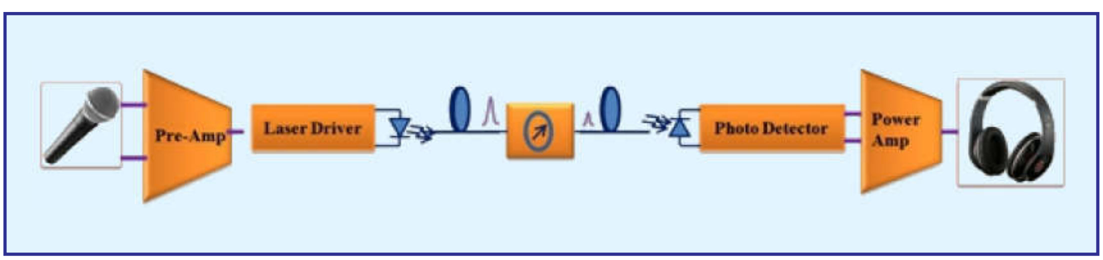


Fig 11.2: Schematic arrangement for analog fiber optic link

7. Send the voice signal through the fiber link by using microphone and check it for fidelity at receiver (Speaker).
8. Adjust the laser power through VOA to get a clear voice transmission.
9. Stop rotating the VOA knob, where voice transmission is achieved .with less noise
10. Disconnect the patch cord from PD3 and connect it to optical power meter for the power measurement.
11. Set the power meter in 1550nm range and determine the minimum and maximum laser power required to transmit the voice.

Digital Fiber Optic Link:- 1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Connect a keyboard to the USB port provided on the backside of the LIGHT RUNNER.
3. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
4. Connect 1550nm laser source to the photo detector PD3 with the help of patch cords.

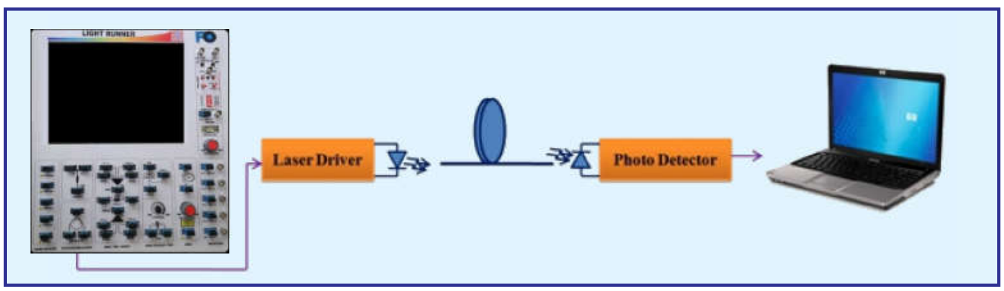
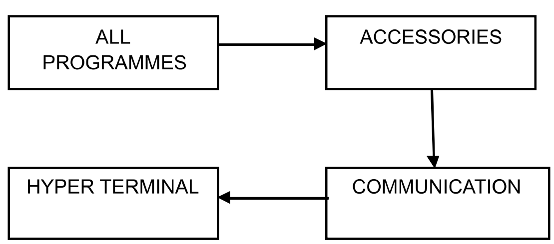


Fig 11.3: Schematic arrangement for digital fiber optic link

5. Run the experiment by clicking on the 'Digital Link' button.
6. Power on the PC and open the "Hyper Terminal". (Go to the "Hyper Terminal" from the desktop by clicking on all the tabs which are shown below in the block diagram).



NOTE: Hyperterminal is not pre installed in Windows-7

7. Type any message for the connection and click OK to come to next window.

8. Select 'COM1' and go to the next window by clicking on OK button.

9. Make all the default settings by clicking on the "Apply Default Settings" and select 115200 bits per second.

10. Click on the 'Apply' and OK button to apply all the settings.

11. Connect RS 232 port of LIGHT RUNNER to the RS 232 port of the external PC by using a DB-9 cable.

12. Enter some data in the allotted space with the help of keyboard.

13. Use stylus and click on transmit button, one message that 'Connect the Rs232 cable'. will display on the screen. Click OK to transmit the message.

14. Adjust the laser power through soft control till the data entered on the screen correctly appears on the External PC.

15. Disconnect the patch cord from PD3 and connect it to optical power meter for the power measurement.

16. Set the power meter in 1550nm range and determine the minimum and maximum laser power required for data transmission.

OBSERVATION

Minimum laser power for a clear voice transmission =

Maximum laser power for a clear voice transmission =

Minimum laser power for digital transmission =

Maximum laser power for digital transmission =

RESULT

The analog and digital links are setup and the minimum and the maximum laser power requirement for clear voice transmission and digital transmission are determined.

12

Time Division Multiplexing of Digital Signals

Introduction to Time Division Multiplexing

Time Division Multiplexing (TDM), used mostly with digital signals, is the time interleaving of samples from several sources so that the information from these sources can be transmitted serially over a single communication link as shown in Fig 12.1. TDM of multiple signals is possible only when the available data rate of the channel exceeds the data rate of the total number of users. Analog telephone signal is digitized at a rate of 64 kbps and is known as the DS0 rate. TDM of 24 DS0 signals results in DS1 signal with a speed of 1.544 Mbps and multiplexing of 4 DS1 signals make DS2 signal with a speed of 6.912 Mbps and so on. TDM is classified as bit interleaved multiplexing (in Plesiochronous Digital Hierarchy) and byte interleaved multiplexing (in Synchronous Digital Hierarchy). Statistical TDM has dynamic channel width allotment as against fixed channel width in general TDM.

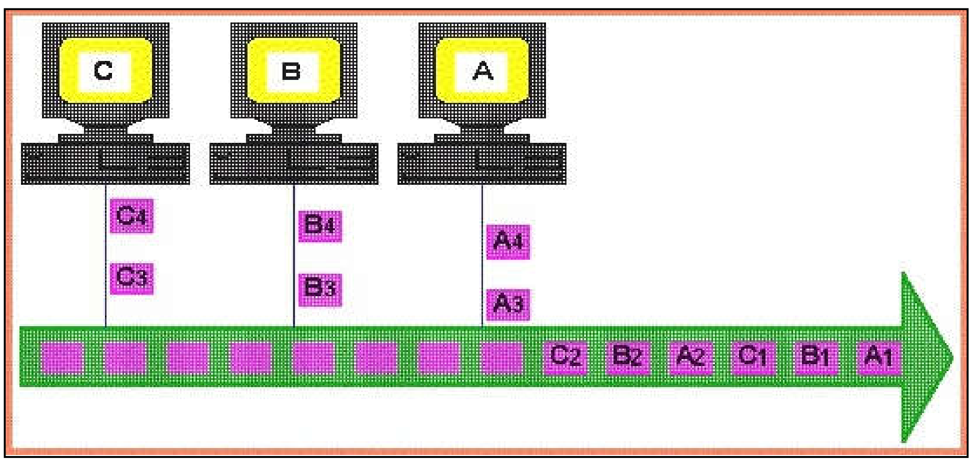


Fig 12.1: Time Division Multiplexing employed for data transmission

EXPERIMENT

AIM

To understand the concept of Time Division Multiplexing of digital signals and observe it on the computer screen. Determine minimum laser power for faithful reproduction of time division multiplexed signals. From the multiplexed signals identify the ASCII equivalent of the data entered on LIGHT RUNNER screen.

COMPONENTS USED

1. 1550nm Laser
2. InGaAs Photodetector – 1 (PD3)
3. VOA

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Connect a keyboard to the USB port given on the backside of the LR.
3. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
4. Connect 1550nm laser source to the photo detector PD3 through a VOA with the help of patch cords (Refer the connections shown in Fig 12.2).
5. Set VOA to its minimum position by rotating it into anticlockwise direction.
6. Enter the data in all the streams by using keyboard.
7. Set laser power and frequency with the help of stylus.
8. Click on the 'Start' button, the multiplexed data bit stream will appear on the LIGHT RUNNER screen.
9. Reduce the 1550nm laser power level with help of VOA, till the laser power is insufficient to reproduce the bit stream on LIGHT RUNNER screen.
10. Now fix the laser power at the next higher power level where the sent data stream can be retrieved.

11. Disconnect the patch cord from PD3 and connect it to optical power meter for the power measurement.
12. Set the power meter in 1550nm range and measure the corresponding laser

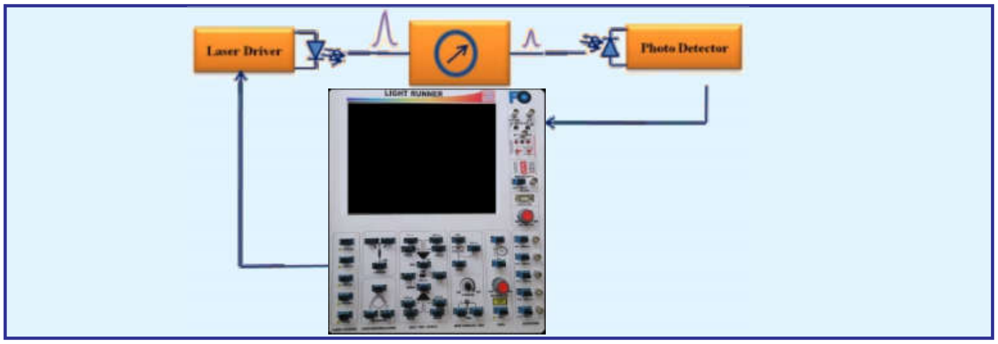


Fig 12.2 : Schematic arrangement for Time Division Multiplexing

OBSERVATION

The minimum laser power for faithful reproduction of TDM bits =

Laser Power	Laser Frequency	Data Entered	Minimum Laser Power required (mw)
100%	1.2 M Hz	Channel 1	
		Channel 2	
		Channel 3	
		Channel 4	

RESULT

The minimum laser power for faithful reproduction of time division multiplexed signals is determined. From the multiplexed signals, the ASCII equivalent of the data entered on screen is identified.

★ ★ ★

13

WDM Fiber Optic Link

WDM Fiber Optic Link

Wavelength division multiplexing is a technique where optical signals with different wavelengths are combined, transmitted together, and separated again. It is mostly used for optical fiber communications to transmit data in several (or even many) channels with slightly different wavelengths. In this way, the transmission capacities of fiber-optic links can be increased strongly, so that most efficient use is made not only of the fibers themselves but also of the active components such as fiber amplifiers.

EXPERIMENT

AIM

To setup a WDM link with the given components and determine the total loss present in the system for each wavelength.

COMPONENTS USED

1. C-Band Lasers-4
2. 4 Channel Mux
3. 4 Channel Demux
4. Optical Power meter

FORMULA USED

If P_1 is the optical power of the laser at wavelength λ_1 and P_2 is the power from the output port of Demux at same wavelength in WDM link then insertion loss is given by the following formula,

Insertion Loss = $10 \log (P_1 / P_2)$

If P_3 is the power at other port of the WDM link due to laser at wavelength λ_1 then cross talk is given by the following formula,

Cross Talk = $10 \log (P_3 / P_1)$

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Now connect all 4 C-band lasers to the respective photodetectors (1510 to PD1, 1530 to PD2, 1550 to PD3, 1570 to PD4) with the help of patch cords.

4. Connect the BNC connector adjacent to PD1 to anyone of the DSO channel with the help of BNC cable.

5. Enable the 1510nm laser (one laser at a time) by using stylus and set the following parameters :

For example - (a) Frequency = 50 KHz
(b) Duty cycle = 50%
(c) Laser power = 100%

6. Click on the 'Start' button, a waveform will appear on the screen corresponding to 1510nm laser source.
7. In case of detector saturation, reduce the power level below the saturation level (Refer the note given on pg xii) and measure the power with the help of optical power meter.
8. Similarly repeat the above given steps from 5 to 7 for other remaining laser also, by enabling them one by one and measure the power of each laser with the help of power meter and note down each laser's power level as P_1 .
9. Stop the running experiment by clicking on 'Stop' button and disconnect the one end of all the patch cords from photodetectors.
10. Connect the other end of all the patchcords to the respective port of the MUX as shown in the Fig 17.1 (1510nm laser to 1510 port..etc.).
11. Connect the 'OUT' port of the MUX to the 'IN' port of the DEMUX.
12. Now connect all the four channels of the DEMUX to the optical power meter one by one and measure the optical power for each of the C-band laser by switching on one laser at a time.
13. Make a note of each laser's power level as P_2 .
14. By using the given formula , calculate the insertion loss for each of the channel in WDM link.

CROSS TALK MEASUREMENT

1. Without disturbing their power levels, enable all the laser sources except 1550nm.
2. Measure the optical power at 1550 port of the DEMUX and consider it as P_3 which is used to determine the cross talk in WDM link.
3. Follow the above steps to determine the cross talk at other ports of the DEMUX also.

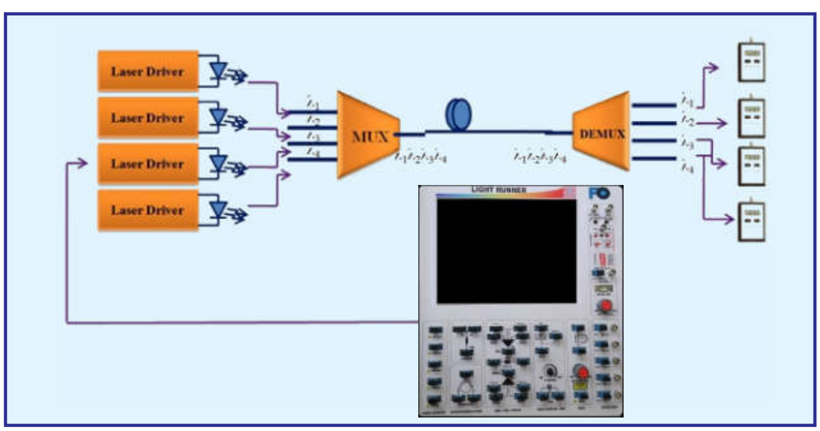


Fig 13.1: Schematic of the setup of a WDM Link.

OBSERVATION

Insertion Loss

Channel Wavelength (nm)	Input optical power, P_1(μW)	Output optical power, P_2 (μW)	Total Loss = 10log(P_1/P_2)	Output Power due to other Lasers, P_3(μW)	Cross Talk = 10log(P_3/ P)
1510					
1530					
1550					
1570					

RESULTS

The WDM link is setup and the total insertion loss for each wavelength is measured.

Experiment 13

★ ★ ★

14

Optical Amplification in a WDM Link

Optical Amplification in WDM link

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier. The 980 nm pump is generally used where low-noise performance is required.

Basic principle of EDFA

The input signal and the 980nm pump light are guided into a section of fiber with erbium ions included in the core. This high-powered light beam excites the erbium ions to their higher-energy state. When the photons belonging to the signal at a different wavelength from the pump light meet the excited erbium atoms, the erbium atoms give up some of their energy to the signal and return to their lower-energy state. A significant point is that the erbium gives up its energy in the form of additional photons which are exactly in the same phase and direction as the signal being amplified. So the signal is amplified along its direction of travel only.

Note

For more information on EDFA check the experiment **Characterization of a Erbium Doped Fiber Amplifier**

EXPERIMENT

AIM

To realise optical amplification in a WDM link having EDFA and measure the overall gain in the system for different wavelength combination in the C-band.

COMPONENTS USED

1. C-Band Lasers-4

2. 4 Channels Mux

3. 4 Channel Demux

4. InGaAs photodetectors-4

5. Erbium doped fiber amplifier

6. VOA

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Now connect 1530 and 1550nm laser sources to respective ports of the MUX by using SC/PC patch cords as shown in the Fig 14.1 (1530 laser to 1530 port of the MUX and 1550 laser to 1550 port of the MUX).

4. Connect the OUT port of the MUX to VOA by using a patch cord.

5. Connect the other port of the VOA to PD3 detector with the help of other patch cord.

6. Connect the BNC connector which is adjacent to the PD3 to one of the channel located at the top right corner of LR by using a BNC cable.

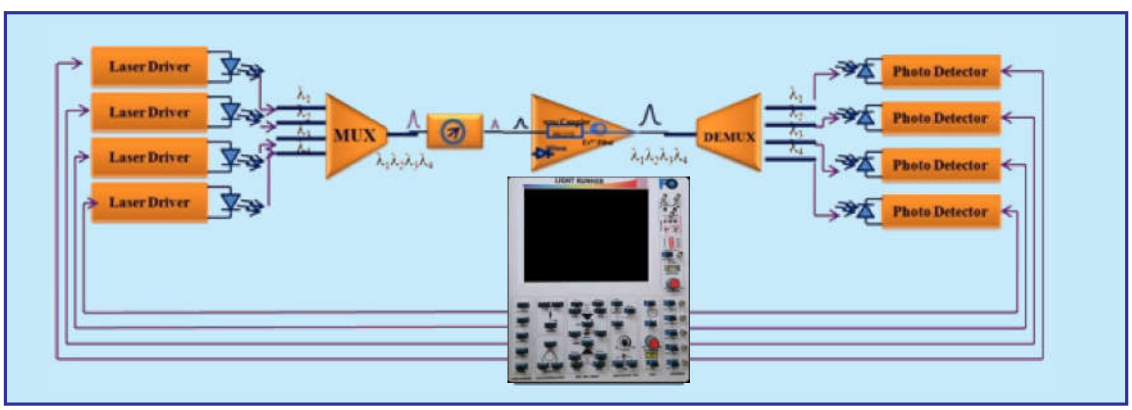


Fig 14.1: WDM Fiber Optic Link with EDFA

7. Enable the 1530nm laser (one laser at a time) by using stylus and set the following parameters :

For example - (a) Frequency = 50 KHz

(b) Duty cycle = 50%

(c) Laser power = 100%

8. Click on the 'Start' button, a waveform will appear on the screen corresponding to 1530nm laser source.

9. Set the voltage level of signal at a very low value (less than 50 mV on DSO) with the help of VOA knob.

10. Measure the signal power with the help of the optical power meter and note it down as P_1 .

11. Now stop the experiment by clicking on the 'Stop' button and disable the 1530nm laser source with the help of stylus.

12. Enable the 1550nm laser source and repeat the above steps from 7 to 10 to set the voltage level of the signal (less than 50mV) and note down the signal power as P_2.

13. Disconnect the patch cord from PD3 and connect this end to the port2 of the erbium doped fiber.

14. Connect the port 1 of the erbium doped fiber to the 'COM' port of the WDM coupler.

15. Connect the 980nm laser to the 980 port of the WDM coupler with the help of the patch cord.

16. Connect the 15XX port of the WDM coupler to the input port of DEMUX.

17. The 1530nm and 1550nm outputs of DEMUX are fed to the photodetector PD2 and PD3 by using patch cords.

18. Now connect the BNC connectors adjacent to the PD2 and PD3 to the CH1 and CH2 of DSO with the help of BNC cables.

19. Set the manual power knob of 980nm laser source to minimum position before running the software.

20. Now enable the both 1530nm and 1550nm laser source and do not change the laser parameters what you had set earlier.

21. Now enable the 980nm laser source and set 0% power for the laser (To make digital power control off).

22. Click on the 'Start' button, you will see the waveforms on both the channels corresponding to 1530 and 1550nm laser sources.

23. Now start increasing the power of 980nm laser source with the help of knob and observe the waveforms on the screen.

24. Set the 980 power control knob to a position where we can get the maximum gain (below the saturation level).

25. Now the amplified power level for both 1530nm and 1550nm lasers is measured with the help of power meter.

26. Knowing the initial power level (measured initially), the gain for both wavelengths can be determined.

27. The whole experiment can be extended for 2 wavelength combinations such as 1550-1570 and 1530-1570.

OBSERVATION

Two-channel Configuration

Channel Wavelength (nm)	Input optical power $P_1(\mu W)$	Output optical power $P_2(\mu W)$	Total Gain in dB = 10 log (P_2/P_1)
1530			
1550			
1530			
1570			
1550			
1570			

RESULTS

WDM link with EDFA is setup and overall gain in the system is measured for various wavelength combinations. It shows that it is possible to simultaneously amplify multiple wavelength channels in a single fiber optic link with EDFA.

FURTHER EXPLORATION

Connect fiber spools of different lengths after the EDFA and measure the exiting power at different wavelengths.

15

Adding and Dropping of Channels in a WDM link

Optical Add Drop Multiplexer

Optical Add Drop Multiplexer (OADM), mainly deployed in wide area and metro area network, is used for adding and dropping of optical channels in a fiber link while preserving the integrity of other channels. Several kinds of OADMs which uses a Mach-Zehnder interferometer. However, grating assisted directional coupler, arrayed waveguide grating (AWG) based OADM and optical circulator based OADM are widely used. In the present experiment optical circulator based OADM is employed whose basic architecture is detailed in Fig 15.1.

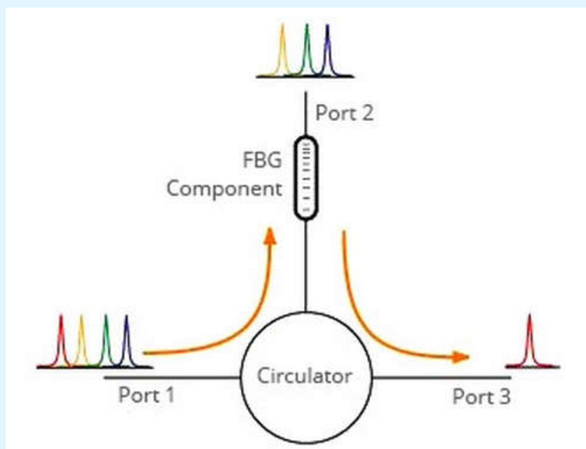


Fig 15.1: OADM architecture using FBG and Optical Circulator

EXPERIMENT

AIM

(a) To setup an Optical Add Drop Multiplexer (OADM) using Fiber Bragg Grating and circulator.
(b) Determine adding and dropping efficiencies of OADM.

COMPONENTS REQUIRED

1. C band Lasers - 4
2. InGaAs Photodetectors
3. Fiber Bragg Grating (1550nm)
4. 4 Channel Mux
5. Optical Circulator

FORMULA USED

Transmission, dropping/adding efficiency in dB = 10 log (P_2 / P_1)Where P_1 and P_2 are the input and output optical power at the dropper/adder respectively.

PROCEDURE

Dropping of channels in WDM link:-
The optical channel dropping is achieved by using a FBG and circulator as shown in Fig 15.2. The procedure for dropping of the channels in WDM link is explained below.
1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect the 1550nm laser source and any other C-band laser source (say 1530nm) to the respective ports of the MUX by using Patch cords.
4. Connect the OUT port of the MUX to anyone of the InGaAs (say PD3) photodetector with the help of the patchcord.
5. Now connect the BNC connector adjacent to PD3 to anyone channel (say CH1) of the DSO with the help of BNC cable.

6. Enable both the lasers and set the different parameters for both the lasers (say for 1550nm laser :- frequency = 50%, duty cycle = 10%, power = 85% and for 1530nm laser :- frequency = 50%, duty cycle = 50%, power = 40%) for their identification purpose.

7. Click on the 'Start' button, a multiplexed waveform will appear on the screen.

8. In case of detector saturation, set the laser power level below the saturation level. (Refer the note given on pg no. xii).

9. Determine the optical power of each signal with the help of power meter and consider it as P_1 .

10. Now connect the 'OUT' port of the multiplexer to the port 1 of the circulator. The combined laser light at Port 1 comes out at Port 2 which is fed to FBG through patch cord (see Fig 15.2).

11. Since FBG has a characteristic reflection wavelength at 1550nm (see Expt.9), therefore the 1550nm light reflected from the FBG comes back into Port 2 and is dropped by the circulator at Port 3.

12. Connect the port 3 of circulator to PD3. The dropped signal can be seen on the screen by making connection through BNC cable to CH1 of the DSO.

13. Disconnect the patch cord from PD3 and measure the optical power of the dropped signal with the power meter, consider it as P_2 .

14. From the above two measurements, determine the dropping efficiency of the signal by using the given formula.

15. The 1530nm light at one end of FBG, instead of reflecting back like 1550nm, passes through the FBG and appears at its other end which can be measured using same PD3 and DSO.

16. Connect the other end of FBG to PD3. The transmitted signal can be seen on the screen by making connection through BNC cable to CH1 of the DSO.

17. Disconnect the patch cord from PD3 and measure the optical power of the transmitted signal with the power meter, consider it as P_2 .

18. From the above two measurements, determine the transmission efficiency of the signal by using the given formula.

19. Repeat the above experiment for other combinations (1510-1550 and 1550-1570) also.

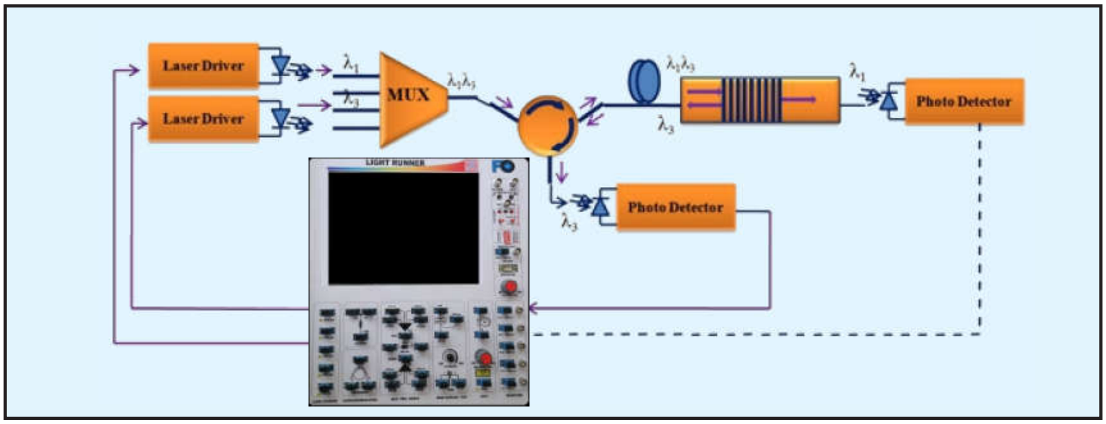


Fig 15.2: Schematic of experimental setup for Dropping of Channels in an OADM. Solid lines represent current use and the dotted line later use.

Adding of channels in WDM link:-

The optical channel adding is achieved by using a FBG and circulator as shown in Fig 15.3. The procedure for adding of the channels in WDM link is given below.

1. Setup the LIGHT RUNNER as per the instructions given in the manual. (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect the 1550nm laser source and any other C-band laser source (say 1530nm) to the photodetectors respectively (say PD2 and PD3) by using Patch cords.

4. Make connections through BNC cables from the adjacent connectors of PD2 and PD3 to both the channels of DSO.

5. Enable both the lasers and set the different parameters for both the lasers (say for 1550nm laser :- frequency = 50%, duty cycle = 10%, power = 85% and for 1530nm laser :- frequency = 50%, duty cycle = 50%, power = 40%) for their identification purpose.

6. Click on the 'Start' button, waveform will appear on the screen for both the signals.

7. In case of detector saturation, set the laser power level below the saturation level. (Refer the note given on pg no. xii).

8. Determine the optical power of each signal with the help of power meter and consider it as P_1 .

9. Stop the experiment by clicking on 'Stop' button and disconnect the patchcords from the photodetectors PD2 and PD3. Connect the 1530nm laser to one port of the FBG and 1550nm laser to port 1 of the circulator with patchcords.

10. Connect the free port of FBG to the port2 of the circulator with the help of patchcords.

11. The 1530nm light passes through the grating and arrives at port 2 and similarly the 1550nm light gets reflected at FBG and arrives at port 2 of the circulator too.

12. This circulator will pass the combined signal of 1530nm and 1550nm from port 2 to the port 3 of the circulator which can be seen on the screen by connecting the port 3 of the circulator to anyone of the detector (say PD3) by using patchcord and BNC cable.

13. Run the experiment without disturbing the power level of both the lasers, combined waveform of both 1530nm and 1550nm laser light will appear on the DSO screen from which the individual power P_2 of both lasers can be measured.

14. From the above two measurements, determine the adding efficiency by using the given formula.

15. Repeat the above experiment for other combinations (1510-1550, 1550-1570) also.

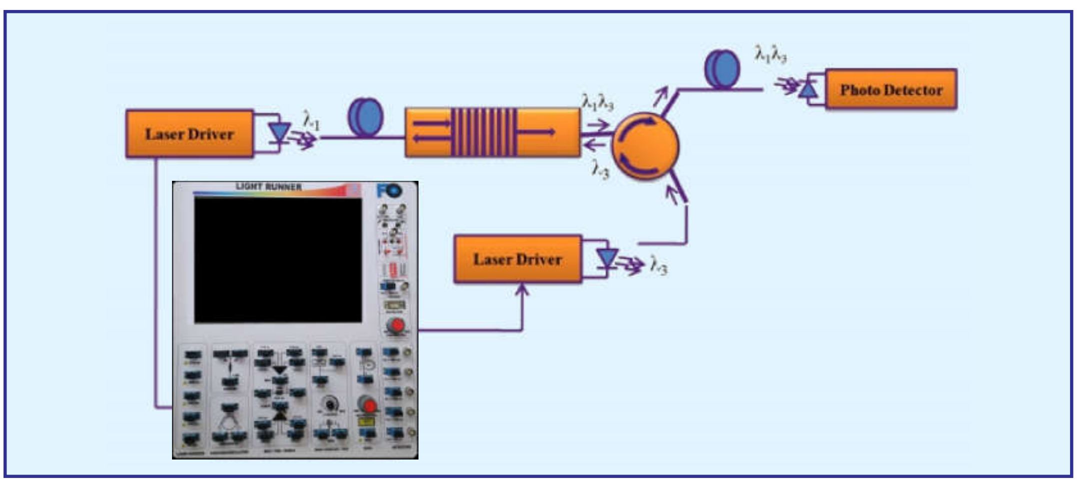


Fig 15.3: Schematic of experimental setup for Adding of Optical Channels

OBSERVATION

Estimation of dropping and Transmission Efficiency

Channel Wavelength (nm)	Optical power before OADM, P_1 (µW)	Optical power after OADM, P_2 (µW)	Dropping Efficiency for λ_3 (1550nm) in dB = 10 log (P_2/P_1)	Transmission Efficiency for λ_1, λ_2 and λ_4 in dB, = 10 log (P_2/P_1)
1550 (λ_3)				
1510 (λ_1)				
1530 (λ_2)				
1570 (λ_4)				

Estimation of adding Efficiency

Channel Wavelength (nm)	Optical power before OADM, P_1 (µW)	Optical power after OADM, P_2 (µW)	Adding Efficiency for λ_3 (1550nm) in dB = 10 log (P_2/P_1)	Transmission Efficiency for λ_1, λ_2 and λ_4 in dB, = 10 log (P_2/P_1)
1550 (λ_3)				
1510 (λ_1)				
1530 (λ_2)				
1570 (λ_4)				

RESULTS

Optical Add Drop Multiplexer (OADM) is setup using Fiber Bragg Grating and Circulator. The adding, dropping and transmission efficiencies of OADM are determined.

FURTHER EXPLORATION

Construct an Add/Drop Multiplexer which can simultaneously add and drop channels using the FBG-Circulator combination (for dropping) and Fiber Optic Coupler (for adding).

16

Optical Time Domain Reflectometer (OTDR)

Introduction

Apart from scattering, whenever there is a break in the optical fiber, then the light pulse suffers Fresnel reflection and about 4% of the incident light gets coupled back into the fiber and it propagates towards the input end of the fiber (assuming that the fiber break is perfect and is at right angles to the axis of the fiber, if the fiber break is not good or if the break is not perpendicular to the axis, then the fractional power coupled back would be smaller). This is much larger than Rayleigh scattered power in a fiber and is easily measurable. If we know the speed of light pulse within the optical fiber, by knowing the time taken between the launch of the pulse and the detection of the reflected pulse it is possible to estimate the distance of the fiber break (see Fig 16.1).

One of the main considerations in locating the break is the resolution of the distance of the break from the input end. If we consider a pulse of duration t, and if v is the speed of light in the optical fiber, then the physical length of the pulse would be v*t. For example if the speed of the pulse is assumed to be $2.052*10^5$ km/s (see Expt. 5), and if the pulse duration is 150 ns then the pulse length would be about 30.8 m. Now if the fiber has two breaks which are separated by a distance shorter than 30.8 m then it would not be possible to resolve them as separate breaks. Thus the spatial resolution of the technique would be about 30.8 m. Pulse with shorter duration are smaller in length and correspondingly would give a better spatial resolution. In the following experiment, the possibility of measuring the fiber length using this technique and the effect of pulse duration on measurement are demonstrated.

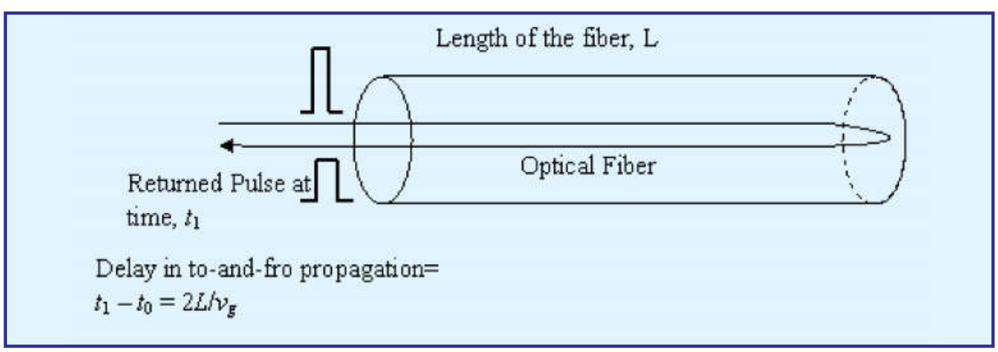


Fig 16.1: Principle of operation of OTDR

Experiment 16

EXPERIMENT

AIM

(a) To determine the position of the fault in fiber optic link.
(b) Study the effect of pulse width on spatial resolution.

COMPONENTS USED

1.C-Band Laser -1550nm
2.Photodetector –PD3
3.Optical Circulator
4.Fiber spools

FORMULA USED

Length of an optical pulse of width (τ),

$$L = V_g . \tau$$

v_g is the group velocity of light pulse in the medium.

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect 1550nm laser source to the port1 of the optical circulator with the help of patch cord (Refer the connections shown in Fig 16.2).
4. Connect the port2 of the circulator with a patch cord. The other end of the patch cord remains free (Assume that the fiber patch cord is having a break at the end).
5. Connect the port3 of the circulator to the photo detector PD3 by using a patch cord.
6. Connect the BNC connector adjacent to PD3 to CH2 of the DSO only with the help of BNC cable.
7. Now set the pulse width as 1μs with the help of stylus and run the experiment by clicking on the 'Start' button.
8. After clicking on the 'Start' button, CH2 will display the pulse due to light reflected from the port 2 of the circulator (reflected light comes due to mismatch of the refractive index between fiber core and surrounding medium (air))

9. Connect a BNC cable from OTDR CLK to CH1/TRG of the DSO for input reference clock (NOTE: Keep the toggle switch under EXT MOD to DIGITAL/OTDR CLK).
10. Set the CH2 voltage from the control panel given on right side in software window (In case if the amplitude of the signal is very less).
11. Measure the time delay between the rising edge of reference clock pulse at CH1 and rising edge of reflected pulse (2^{nd} pulse for the measurement purpose).
12. The time delay between both the pulses the patch cord so replace the patch cord connected at port2 of the circulator with a fiber spool of unknown length L.
13. Observe the shifting of the reflected pulse in time domain at CH2, coming from the end of the fiber spool.
14. Measure the time delay between of both the pulses (For DSO measurement, please refer the instructions given on pg. xi).

Calculation of Spool length L / Location of fiber break:-

Knowing the speed of light in the fiber with core refractive index 1.46, the total length covered by the light pulse (twice the length of the fiber) can be calculated.

For example:-

If time delay (τ) = 20 μs = $20*10^{-6}$ s
Speed of the light in the fiber with core refractive index of 1.46 (V) = $2.05X10^{5}$ Km/s
Total length covered by the light pulse (twice the length of the fiber) will be,
$2L = V*\tau$ So $L = (20 * 10^{-6} * 2.05 \times 10^{5}) / 2 = 2$ Km (approx.)

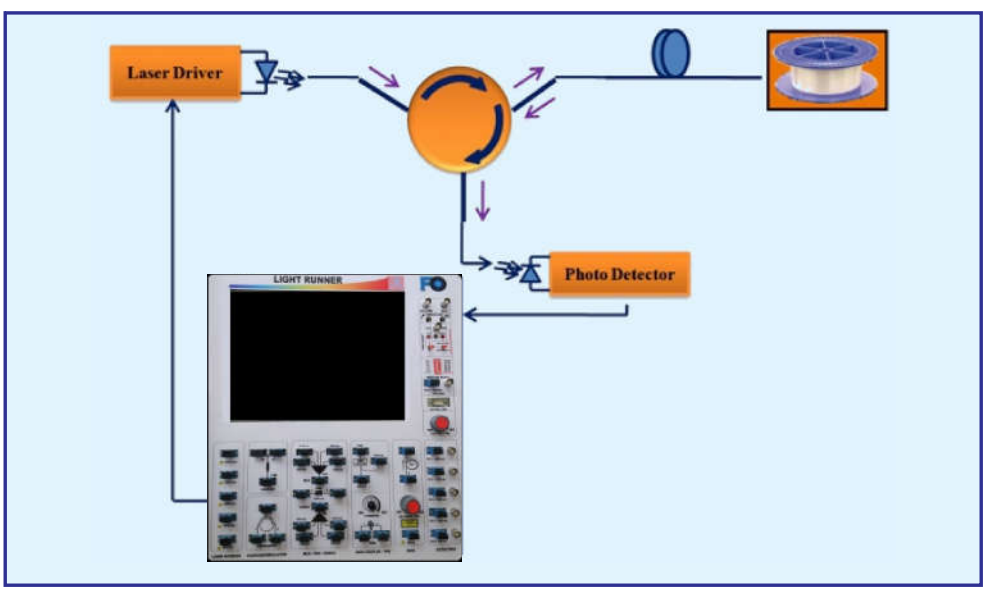


Fig 16.2: OTDR setup

Experiment 16

OBSERVATION

Pulse width in time (μs)	Fiber Length (km)	Time delay between the pulses, t (μs)	Fiber Length = $v_g t/2$ (km)
1	1		
	2		
	3		
	4		
	5		
	6		
2			

RESULT

The length of the given fiber is determined. The effect of pulse width on spatial resolution is observed.

FURTHER EXPLORATION

(1) Setup experiment and show that for a given pulse length the spatial resolution is limited.
(2) Study the role of wavelength in OTDR measurement.

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17

Bit Error Rate and Eye Pattern Analysis

Introduction to Bit Error Rate

In a digital communication system information is coded in the form of bits represented by 1s and 0s. In optical fiber communication each 1 is represented by a light pulse and each 0 is represented by the absence of light. In order to decode the information, the detector identifies the 1s and 0s in the incoming pulse sequence using a threshold level. Now as the light pulse propagates through the fiber, it gets affected by different mechanisms such as pulse broadening due to dispersion, attenuation, nonlinear effects etc. This results in the distortion of the received optical pulses and could result in wrong identification of the 1s and 0s in the received pulses. Thus the receiver can commit errors if the power is too low or if adjacent pulses start to overlap too much and the information gets corrupted. This effect is termed as the Bit Error Rate (BER).

If the receiver makes n errors in receiving N bits, then the bit error rate is defined by the ratio n/N. For example, out of a total number of 10^{12} bits received 3 errors are committed, and then the bit error rate becomes 3×10^{-12}. With this bit error rate in a communication system at a bit rate of 10 Gb/s the number of errors committed per second would be 3×10^{-2}, thus an average of 3 errors will be committed in a period of 100 seconds.

Errors come randomly and sometime in bursts. Thus to measure BER it is necessary to count the errors committed over a period of time and then average the rate of errors. An incorrect estimate of BER may take place if short periods of time are chosen. If the BER is expected to be 10^{-10} when communication is taking place at a rate of 100 Mb/s, then the expected number of errors in a second would be 10. Thus in order to accumulate some errors, measurements has to be performed over at least 1000 seconds so that at least 10 errors would have been committed (as an average). The larger the sample of measurements, the better would be the estimation.

Eye Pattern

In the non return to zero (NRZ) scheme, each '1' is represented by a pulse of duration equal to the bit period and each '0' is represented by the absence of a pulse. Each time slot can randomly have a value of 1 or a value of 0. If we consider a sequence of three pulses then the following eight combinations are possible:000, 001, 010, 011, 100, 101, 110, 111

Now if we superimpose these on an oscilloscope display then the output would appear as shown in fig 17.1.

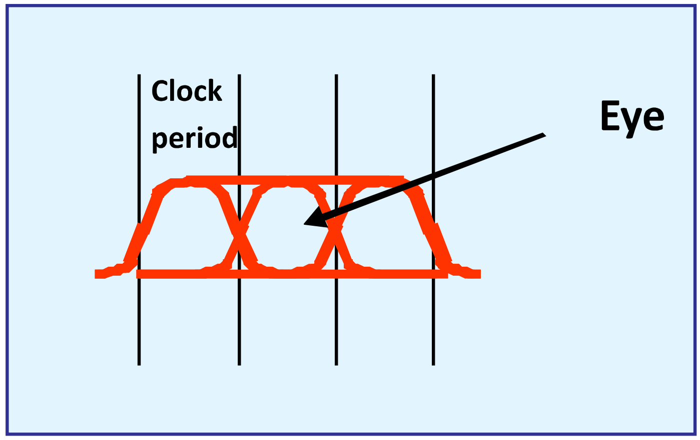


Fig 17.1: Clean Eye Pattern

The above pattern is called an eye pattern and gives an indication of the performance of the system. Now in the above figure we have just superimposed the eight combinations assuming that there is no jitter, no broadening and no noise. In general as the pulses propagate through the fiber link then they will accumulate dispersion, jitter and loss. Thus the detected signal would suffer from these imperfections and the eye pattern would not look like that shown in Fig 17.1. For example you may get an eye pattern as shown in fig 17.2.

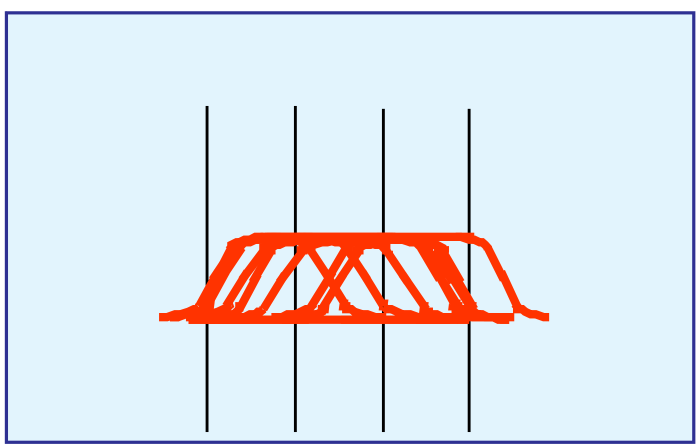


Fig 17.2: Distorted eye pattern

The above figure shows the eye pattern when the pulses suffer from dispersion, jitter etc. and as can be seen the pattern has its eye closed. From the eye pattern it is possible to measure Bit Length, Suitable Sampling Period, Jitter and Noise of a fiber optical communication system (given in Fig 17.3). Eye pattern analysis is a very useful tool in the performance evaluation of the system, and an open eye is an indication of good performance of the system.

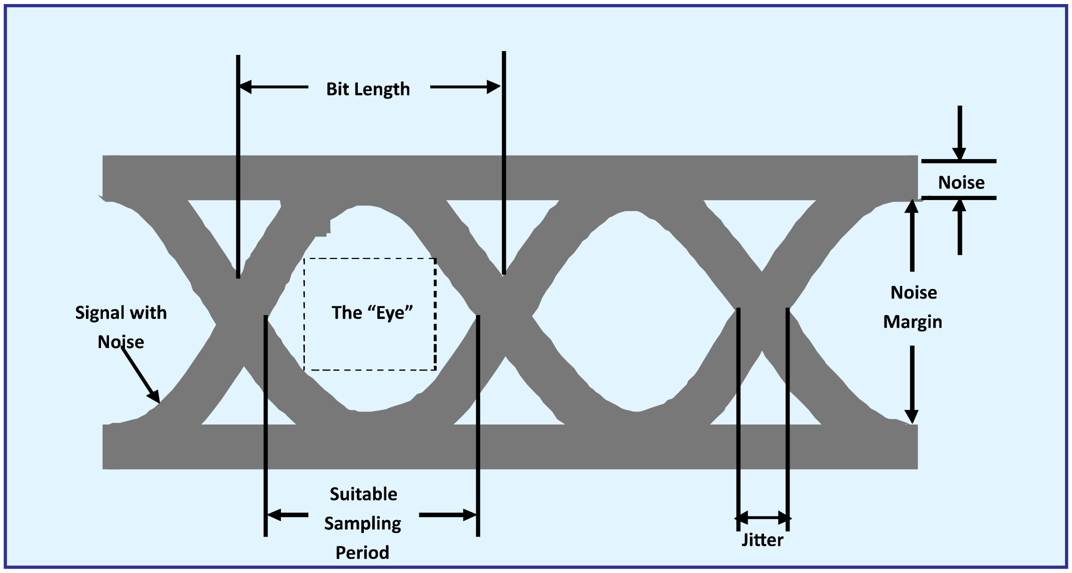


Fig 17.3: Eye Pattern Diagram and its parameters

EXPERIMENT

AIM

To determine BER as a function of the laser transmitted power. To calculate bit length, noise, noise margin, jitter, suitable sampling period for various optical powers.

COMPONENTS USED

1. C-Band Laser - 1 (1550nm)
2. InGaAs photodetector - 1 (PD3)
3. VOA

FORMULA USED

Bit error rate = n/N
Where N is number of data bits transmitted and n is number of error bits produced.

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect 1550nm laser source to the photo detector PD3 through a VOA with the help of patch cords (Refer the connections shown in Fig 17.4).
4. Set the manual power knob and VOA to its minimum position by rotating it in anticlockwise direction.
5. Set the1550nm laser power with the help of stylus.
6. Select any 'Pattern' and 'No. of repetitions' from the drop down menu given in experimental window.
7. Click on the 'Start' button, the number of error bits with the number of iterations will display on the screen which is given on the right side in the experimental window.
8. If the number of error bits is 0, means the laser power is sufficient for data transmission and if error bits are there, shows that the laser power is insufficient to transmit the data.

9. In case, if no error bits are there, reduce the 1550nm laser power level with help of VOA (or) manual control knob, till the laser power is insufficient for data transmission and displays error bits .

10. Consider the last iteration to get an accurate value of the no. of error bits, noted on the software screen.

11. Disconnect the patch cord from PD3 and connect it to optical power meter for the power measurement.

12. Set the power meter in 1550nm range and measure the corresponding laser power.

13. Repeat the above experiment for various laser power levels.

14. With the help of above measurement, calculate the 'Bit Error Rate' by using the given formula.

Calculation of 'Bit Error Rate':- To calculate the BER, total number of bits should be known. The total no. of bits can be calculated by using the following method.

(a) Convert the selected pattern into HEX using ASCII table and then to its binary equivalent.

(b) Count the total no. of 1's from its binary equivalent and consider it as total no. of bits.

For example:- Selected pattern- 0

HEX Equivalent- 30

Binary Equivalent- 00110000

Total no. of bits (N) = (no. of 1's in binary equivalent) = 2

(c) Use the total no. of bits in the given formula to calculate the BER.

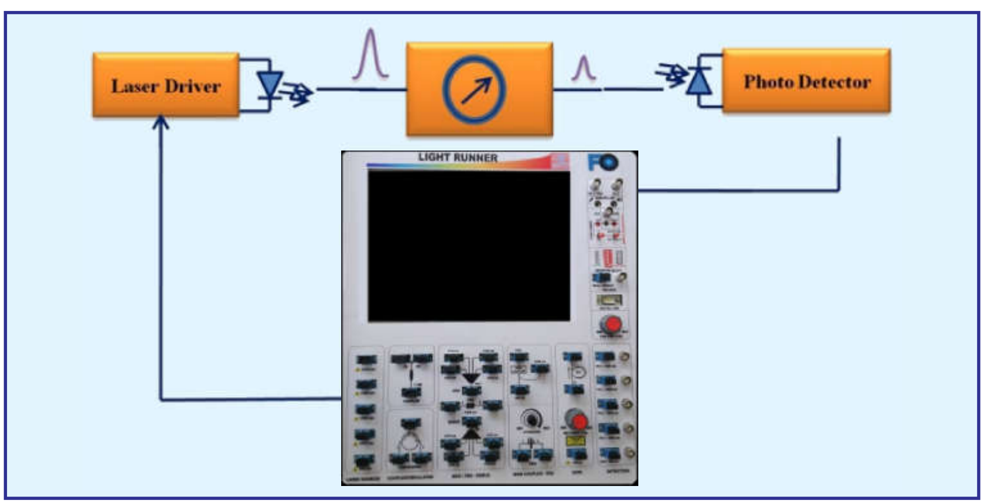


Fig 17.4: Bit Error Rate Setup

Eye Pattern

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 1550nm laser source to the photo detector PD3 with the help of patch cords (Refer the connections shown in Fig 17.5).

4. Set the manual power knob to its minimum position by rotating it into anticlockwise direction.

5. Connect the BNC connector adjacent to PD3 to CH1 of the DSO only with the help of BNC cable.

6. Enable the 'Eye pattern experiment' with the help of stylus and observe the 'Eye Pattern' on the DSO screen.

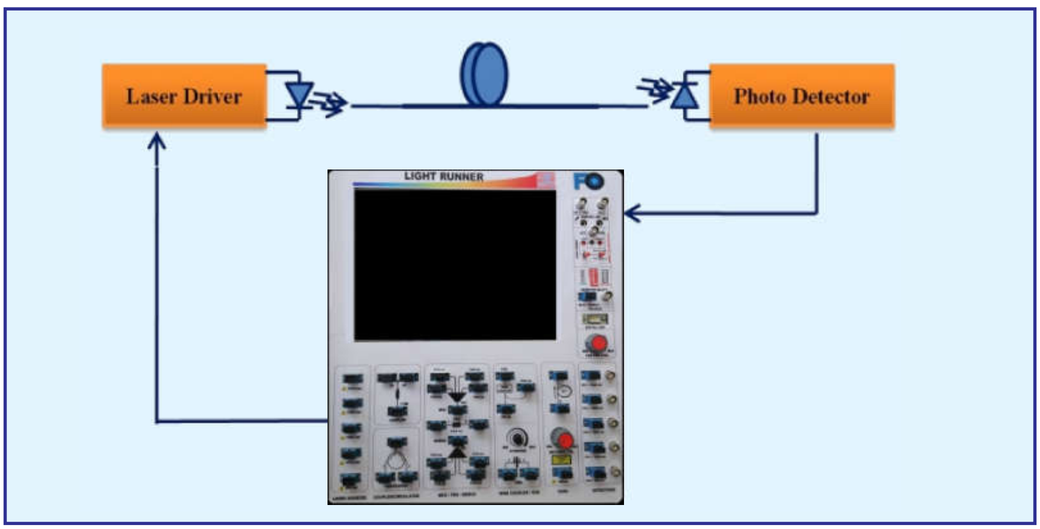


Fig 17.5: Eye Pattern set up

OBSERVATION

Transmitted power vs BER

Laser Power (μW)	Total no. of bits, N (bits/sec)	Errors Generated, n (bits/sec)	Bit Error Rate n/N

Eye pattern vs signal level and Modulation frequency

Laser Power (mW)	Frequency (kHz)	Noise Level on the DSO (mV)	Noise Margin on the DSO (mV)	Bit Length (ms)	Suitable Sampling Period (ms)	Jitter (ms)

RESULT

BER as a function of optical power is determined. Bit length, noise, noise margin, jitter and suitable sampling period for modulation frequencies are determined.

FURTHER EXPLORATION

Set up the WDM link and look at the eye at a signal wavelength in the absence and presence of power at other signal wavelengths. See the effect of the presence of additional channels on the eye of the signal.

★ ★ ★

18

Power Budgeting of an Optical Fiber Link

Introduction

A fiber optic communication link is specified in terms of the distance between the transmitter and receiver and the bit rate at which communication is to take place. The two primary effects that determine the maximum distance and maximum bit rate possible for a given BER are the attenuation and pulse dispersion in the link. Attenuation leads to drop in power at the receiver and thus the receiver would start to commit errors in identifying the bits as a 1 or a 0. Pulse dispersion would result in overlap of adjacent pulses of light and leading to inter pulse interference and thus an increase of errors. Power budgeting and rise time budgeting are two procedures that can help us in designing of a communication link.

Power Budgeting

As we have discussed in the previous experiment, for achieving a certain BER the power received by the photodetector must be greater than a certain value. For example, for a system operating at a bit rate of 2.5 Gb/s, the minimum power received should be about 5 mW (-23 dBm). Given the power that is available at the transmitter, it is then possible to estimate the maximum loss that can be allowed between the transmitter and the receiver. This would then give us an estimate of the maximum distance permissible.

Let P_r be the power at the receiver, P_0 be the power of the transmitter, L_c the loss at each connector, L_s the loss of every splice and let α be the attenuation coefficient (in dB/km) of the fiber. If there are N_c number of connectors and N_s number of splices, then for a length L (in km) of the fiber we have,

$$P_o = P_r + N_c L_c + N_s L_s + \alpha L$$

Here all power levels are measured in units of dBm and loss in units of dB. Now for a given BER the receiver should receive a certain minimum power say P_{min} . Usually a power margin P_m is also provided in the power during the design. Thus $P_r > P_{min} + P_m$, this would give us the maximum length of the fiber link permissible with the components.

As an example if the transmitter power is 0dBm (1mW) and if the minimum received power is -23dBm then with a margin of 3dBm, the maximum permissible loss would be 20 dB. If there are two connectors each with a loss of 0.5 dB and if there are three splices each with a loss of 0.1 dB, then the maximum permissible loss in transmission fiber would be 18.7 dB. If the attenuation constant of the fiber is 0.3dB/km, the maximum permissible distance estimated from power considerations would be 62.3 km.

EXPERIMENT

AIM

Determine the length of the fiber that can be used with the given optical power level to get a signal to noise ratio (SNR) of 3 (= 5 dB). Perform the experiment with various fiber lengths and validate the theoretical prediction.

COMPONENTS USED

1. 1550nm laser
2. InGaAs photo detector PD3
3. VOA
4. Fiber spools-3

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manual (Refer pg no. vi).

2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.

3. Connect 1550nm laser source to the photo detector PD3 through a VOA with the help of patch cords (Refer the connections shown in Fig 18.1).

4. Connect the BNC connector adjacent to PD3 to anyone channel (say CH1) of the DSO with the help of BNC cable.

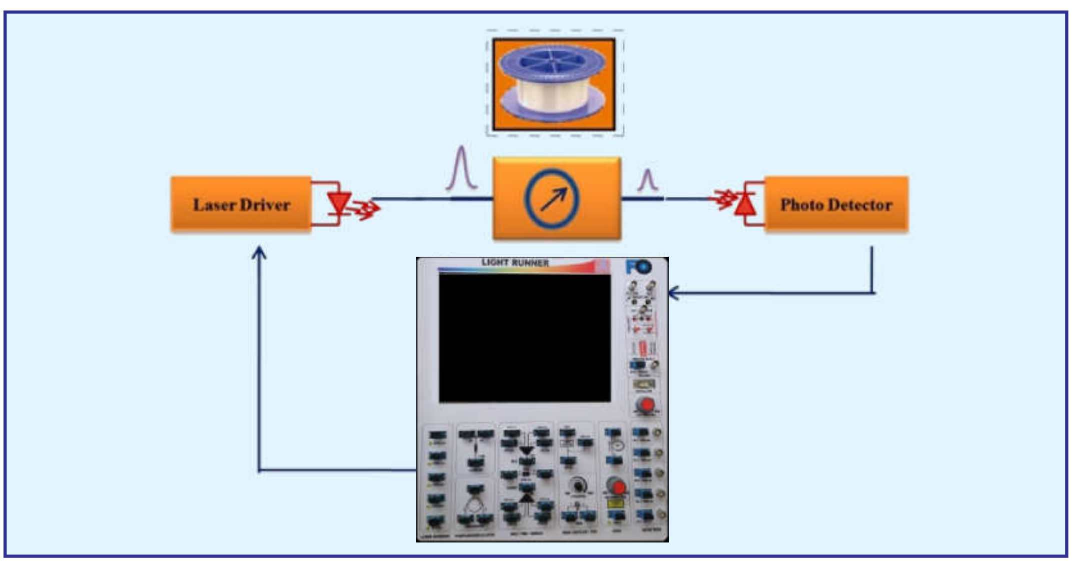


Fig 18.1: Power Budgeting Setup

5. Without enabling the 1550nm laser, click on the 'START' button and measure the noise level on DSO screen.

6. Since the noise level of Light Runner is very low, noise will not appear on the DSO screen so click on the ' STOP' button and assume the noise value as 10mV.

7. For SNR= 3, Noise Level V_2= 3*10mV = 30mV (SNR = Signal power/Noise).

8. In order to maintain the SNR value as 3, the minimum voltage V_1=100mV at the DSO .

9. Now adjust the laser power through VOA to get 100mV signal on DSO screen.

10. From the above measured voltage levels, calculate the value of dynamic range and used fiber length by using the following formula,

$$\text{Dynamic range (R)} = 20\log(V_1/V_2) \text{ (or) } 10\log(P_1/P_2)$$

$$\text{Length of the used fiber} = R / \alpha$$

Where α is the attenuation coefficient of the fiber (Fiber attenuation is assumed to be 4.5 - 6.0 dB/Km at 850nm and 0.2 - 0.3 dB/Km at 1550nm).

11. Now introduce the fiber spools of length L between laser and photo detector PD3 and measure the output power using PD3-DSO combination.

12. Note down the maximum length of the fiber at which signal to noise ratio (SNR) comes equal to (or) above 3 (corresponding signal on DSO screen is 30mV).

13. Use this value of length to prove the theoretical prediction.

14. Repeat the above experiment for various power levels of the 1550nm laser source.

OBSERVATION

Attenuation coefficient of the fiber, α = 0.2-0.3 dB/km at 1550nm

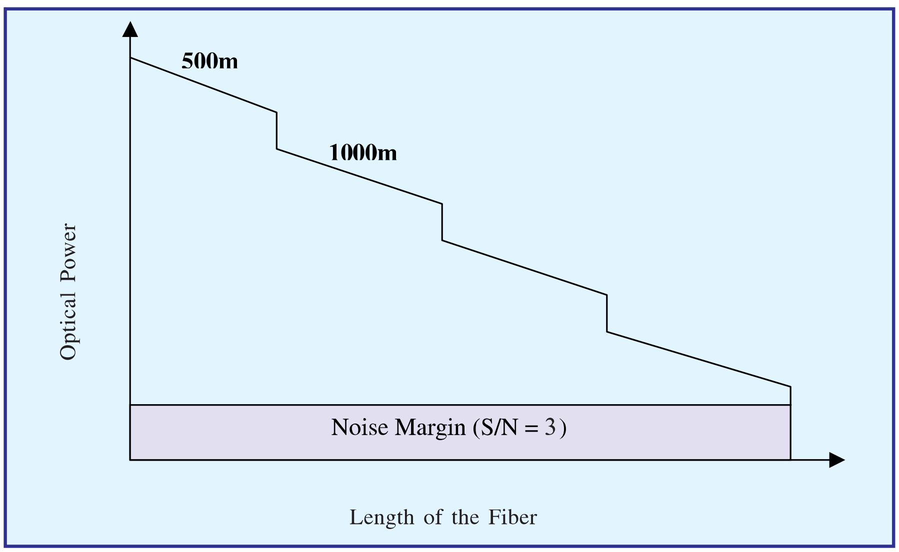
Noise at detector, N = ____mV

Minimum signal, V_2 for SNR of 3, = ____mV

Signal level at the detector without fiber, P_1 (V)	Dynamic Range, R = 20log (V_1/V_2)	Length of the usable Fiber = R/α (km)	Length of the fiber (km)	Output at the end of the fiber
0.1			1.0	
			2.0	
			3.0	
			4.0	
			5.0	
			6.0	
0.3				

RESULT

The length of the fiber that can be used with the given optical power level to get a signal to noise ratio of 3 is determined. Signal power coming out of various fibers is measured and the theoretical prediction validated.



FURTHER EXPLORATION

The user can similarly do power budgeting with optical amplifier also. Moreover, if LIGHT RUNNER has EDFA, then it can be introduced into the fiber link to increase its length.

★★★

19

Rise Time Budgeting of an Optical Fiber Link

Introduction

Apart from attenuation, the other important factor that determines the repeater spacing is the pulse dispersion. In order to ensure that adjacent pulses do not overlap, for a given bit rate there is a maximum distance over which the pulses can propagate and are still resolvable. This is ensured through the rise time budgeting. Rise time of a device is defined as the time taken for the response of the device to increase from 10% to 90 % of the final output value, when the input is changed abruptly in a step like fashion. The total rise time of a fiber optic system is given by a combination of the rise times of the transmitter, the receiver and most importantly the dispersion of the fiber. If t_t, t_r and t_f represent the rise times of the transmitter, the receiver and the fiber, then the total system rise time is given by,

$$t_s = \sqrt{\left(t_t^2 + t_r^2 + t_f^2\right)} \qquad (1)$$

The rise time of the fiber is approximated by the pulse dispersion of the fiber. The overall bandwidth of the system is related to the system rise time by the following formula (for non return to zero or NRZ schemes),

$$\Delta f = \frac{0.70}{t_s} \qquad (2)$$

Knowing the rise time of the transmitter and the receiver and knowing the dispersion coefficient of the fiber, we can use Eq. (1) to estimate the maximum repeater less distance from the rise time budgeting point of view.

As an e.g. we consider a 1 Gb/s NRZ system, the bandwidth required is 500MHz. This gives an overall system rise time of 1.4 ns. If we use a transmitter and a receiver with rise times of 0.6 ns each, the rise time of the fiber must be less than 1.1 ns. If the fiber dispersion coefficient is 17 ps/km-nm (a typical G652 fiber dispersion at 1550 nm), and if the laser has a spectral width of 1nm, then the maximum permissible distance from the rise time point of view would be about 65 km.

The above rise time budgeting analysis can be used for estimating the maximum bit rate for a given system or the maximum repeater less distance for a given bit rate.

EXPERIMENT

AIM

Determine the length of the fiber that can be used with the given Total Rise Time, Source and Detector Rise Times for a 50 kHz bandwidth fiber link.

COMPONENTS USED

1. Laser Source - 1 (850nm)
2. Photo diode with resistor array - 1 (PD6)

DATA

Total Bandwidth of the Fiber Optic System = 50 kHz
Total system rise time = 14 μs (micro seconds)
Optical Source Rise Time = 5 ns (nano seconds)
Dispersion coefficient (D) at 850 nm = +37ns /nm-km
Spectral width of 850nm laser source (Δλ) = 1 nm

PROCEDURE

1. Setup the LIGHT RUNNER as per the instructions given in the manua (Refer pg no. vi).
2. Select the corresponding experiment from the experiment drop down menu with the help of stylus and the experimental window will appear on the screen.
3. Connect 850nm laser source to the photo detector PD6 through a fiber spool of length L with the help of patch cord (Refer the connections shown in the Fig 19.1)
4. Connect the BNC connector adjacent to PD6 to anyone channel (say CH1) of the DSO with the help of BNC cable.
5. Set the two way switch in photoconductive mode located at the 'PD CHARACTERIZATION' block.
6. Enable the 850nm laser by using stylus and set the following parameters :
(a) Frequency = 50 KHz
(b) Duty cycle = 50%
(c) Laser power = Below saturation

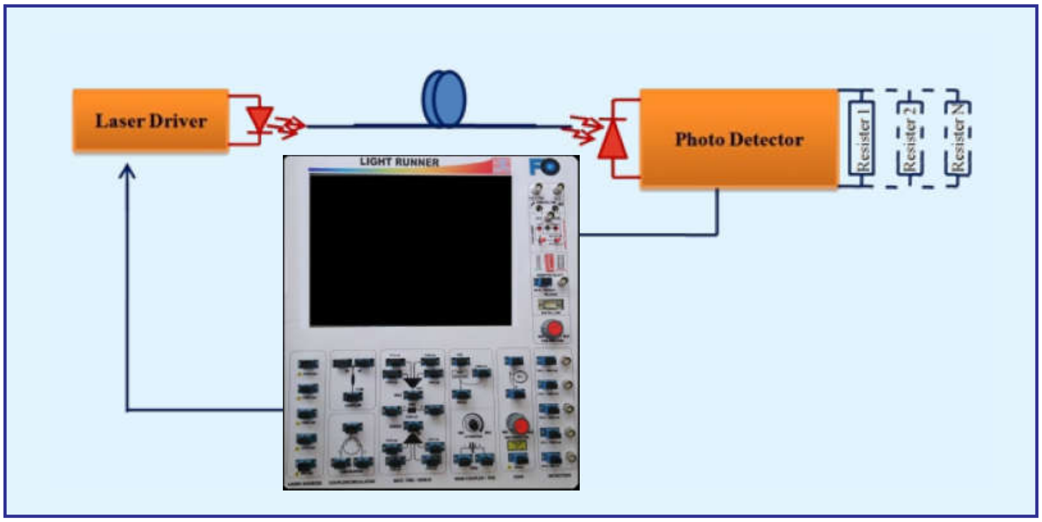


Fig 19.1: Schematic arrangement for Rise Time Budgeting

7. Click on the 'Start' button, a waveform will appear on the screen corresponding to 850nm laser source.

8. In case of detector saturation, reduce the power level below the saturation level (Refer the note no.6 given on pg xii).

9. For clear view of waveform, channel voltage and time base can be increased or decreased by using the control panel option given in the software on the right side.

10. Measure the rise-time of the photo detector from the DSO (Refer the instructions given on the pg no. x for DSO software).

11. From the above measurement, calculate the length of the fiber by using the given data and the formula.

OBSERVATION

Resistance (KΩ)	Receiver Rise Time μs	Total Rise Time μs	Transmitter Rise Time μs	Fiber Dispersion t_f (ns)= $\left(t_s^2 - t_r^2 - t_t^2\right)^{1/2}$	Length of Fiber $\frac{t_f}{D\Delta\lambda}$ (km)
		14	5		
		14	5		
		14	5		

RESULTS

The length of the fiber that can be used with the given Total Rise Time, Source and Detector Rise Times is determined.

FURTHER EXPLORATION

For 850nm laser with 100 μW power, find out the maximum distance of transmission for rise time budgeting with a bit rate of 100 Kb/s, 1Mb/s and 10Mb/s.

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REFERENCE:

1. Introduction to Fiber Optics - A.Ghatak and K.Thyagarajan, Cambridge University Press, Cambridge, UK - 1998.

2. Optical Fiber Communications - 3rd Edition Gred Keiser, McGrawHill Inc, 2000.

3. Guided Wave Optics - Anurag Sharma, Viva Books Private Ltd., New Delhi - 2006.

4. Understanding Fiber Optics, 2nd Edition - Jeff Hecht, SAMS Publishers, USA - 1997.

5. Fiber Optic Communication Systems, 3rd Edition, Govind P Agrawal, John Wiley Sons Inc - 2002.

6. Optical Fiber Communications Principles and Systems, A.Selvarajan, S.Kar and T.Sreenivas, Tata McGraw Hill Publishing Company Ltd., New Delhi - 2002.

Experimental List based on Further Exploration:

1. Attenuation in Optical Fiber.

2. Calculation of additional loss due to patch cord.

3. Determine the connector loss into the fiber path.

4. Measurement of bending loss in the fiber (with Bend diameters of 40 - 10 mm).

5. Dispersion in Optical Fiber

6. Measurement of distortion in the output at 850nm/1550 nm.

7. Measurement of delay between 850 nm and other C-band pulses

8. Observation of various mode patterns (by slightly bending the fiber at 850 nm).

9. Characterization of WDM Mux and Demux

10. Determine the insertion loss and cross talk at each port of Mux and Demux.

11. Characterization of FBG and Circulator

12. To explore FBG dependence on the direction of light launching to it.

13. To demonstrate Add/Drop filter using FBG/Circulator

14. Characterization of Erbium Doped Fiber Amplifier

15. Measurement of the power exiting the fiber for input wavelength as well as other wavelengths.

16. Measurement of gain at a given wavelength in the presence/absence of other wavelengths.

17. Diode Laser Characteristics

18. Photodiode Characteristics

19. Study the linearity of the photodetector in photoconductive modes.

20. Study the linearity of the photodetector in photovoltaic modes.

21. Analog and Digital Fiber Optic Links

22. Analyse laser power for the signal transmission of analog source.

23. Time Division Multiplexing of Digital Signals

24. WDM Fiber Optic Link

25. Optical Amplification in a WDM Link

26. Measurement of exiting power at different wavelengths.

27. Calculation of exiting power at different fiber length.

28. Adding and Dropping of Channels in a WDM link

29. Designs add / drop multiplexer

30. Optical Time Domain Reflectometer

31. Analysing spatial resolution technique through OTDR

32. Differentiate the OTDR signal by varying the Wavelength and study the trace

33. Bit Error Rate and Eye Pattern Analysis

34. Analyse the effect on eye pattern in the presence of additional channels.

35. Measurement of the additional noise introduced by EDFA into the system.

36. Power Budgeting of a Fiber Optic Link

37. Rise Time Budgeting of a Fiber Optic Link

38. Calculation of transmission distance with the given power and rise time budget for a bit rate of 100kb/s, 1Mb/s and 10Mb/s.

39. To study the Numerical Aperture of Optical Fiber (using 850nm visible LASER)

40. To study the V-number & Modes

External Modulation Select Block

External Modulation (with external source):

External modulation mode requires a compatible source. Connect a compatible source or signal or function generator to the External Modulation BNC connector.

When Switch is at "External" position (Up), the 1550 nm Laser accepts modulation input from compatible external source or signal/function generator. Modulation signal fed should have an Voltage range of **0 to 2.7 V AC / DC** and Frequency of around **10M Hz**.

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Further Exploration