Department of Electrical and Electronic Engineering (EEE)
Bangladesh University of Engineering and Technology (BUET)

EEE 310: Communication Laboratory

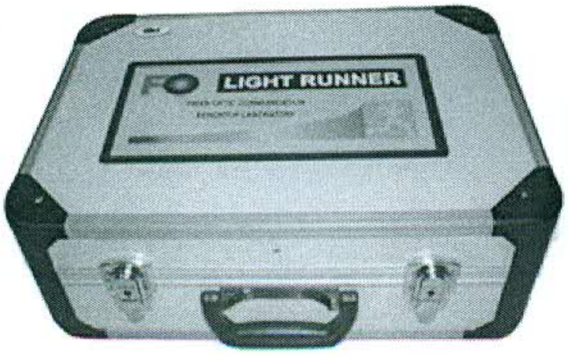
EXPERIMENT NO: 8
Study of Optical Fiber Characteristics – Attenuation and Dispersion

Optical Fiber Communication is a communication technology that uses fiber optic cables for data transmission. Optical carrier frequency lies in the range 10^{13} to 10^{16} Hz (generally in the near infrared around 10^{14} Hz or 10^{5} GHz) and thus yields a far greater potential transmission bandwidth over a much longer transmission distance.

An optical fiber is typically a circular cross-section dielectric waveguide consisting of a dielectric material (core) surrounded by another dielectric material (cladding) with a lower refractive index. Light rays impinging on the core-cladding interface at an angle greater than the critical angle get total internally reflected and propagate through a very long distance. Although total internal reflection at the core-cladding interface is lossless, long distance transmission gets affected due to attenuation and dispersion.

Familiarization with the trainer kit:

'Light Runner', a fiber optic communication, bench top laboratory with WDM is a standalone solution for fiber optic communication labs and does not require any external instruments/devices/components such as oscilloscopes, function generators, or power meters.



LIGHT RUNNER is controlled and monitored by pre-installed software on the computer which has two parts: LIGHT RUNNER Software and DSO Software. Each of these two softwares can be opened by double-clicking on their respective icons on the desktop. Due to its PC based Graphical user interface, LIGHT RUNNER shows a great flexibility and ease of use.

For the proper working of this software, LIGHT RUNNER should be switched ON first and then connected to the host computer through USB cables.

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LASER sources: There are 6 laser sources on LIGHT RUNNER. Each LASER source on LIGHT RUNNER can be enabled by selecting a designated checkbox in the interaction window of LIGHT RUNNER software. All the lasers have soft controls (digital controls) for their optical power regulation. However, for ease of operation and fine adjustments, the 1550 nm and 980 nm pump laser have manual controls in addition to the digital controls. For the 1550 nm laser, the user can select the type of control by the "MODULATION CONTROL" switch. When the switch is in "DIGITAL" position, 1550 nm laser power is controlled by internal digital control i.e. by software setting. It is not affected by the 1550 power control knob on LIGHT RUNNER. When the switch is in "MANUAL" position, 1550 nm laser power is controlled by 1550 power control knob on LIGHT RUNNER and internal digital control setting has no effect on laser power.

Photodetectors: For each laser source, there is a dedicated photodetector (PD1–PD5 and PD6) on the LIGHT RUNNER. Once the "Start" button in the interaction window on LIGHT RUNNER software is pressed, the box in front of labels (PD1-PD5) will display the value of the arbitrary power seen by these detectors. There are BNC connectors near each photodetector that give the electrical equivalent signals of the optical signals detected by the photodetectors. These electrical equivalent signals can be connected to CH-1 or CH-2 and monitored on DSO software. While operating LIGHT RUNNER, if detector is fed with high optical power (a few hundreds of μW) it will be saturated and will not give correct readings or waveforms (on DSO) due to saturation. This is identified by non changing amplitude on DSO (around 4V in DC mode). For reliable results, optical power fed to detector is to be kept below the saturation limit. This can be achieved by adjusting source power in LIGHT RUNNER software or using the VOA (variable optical attenuator) block on the LIGHT RUNNER.

50-50 Coupler/Splitter: It is a three-port device which splits the light fed at "COM" port equally and delivers at two different ports labeled as "50" and "50". If light from two different sources are fed to the 50-50 ports, the device will behave as a coupler and the combined light will appear at the COM port.

WDM Coupler (980/15xx coupler): This is a bidirectional three port device whose output port is COM and the input ports are named as 980nm and 1500nm. The input and output ports are interchangeable. This device can be used either as combiner or a splitter.

Patch Connectors: To make optical connections between various blocks yellow patch cords are used. Blue color at the terminals represents SC/PC and while green color at the terminals represents SC/APC connectors.

BNC Connectors: BNC connectors are black colored electrical cables, which can be used for monitoring different signals on LIGHT RUNNER with the DSO software.

Power Meter: 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.

Safety Precautions:

- It is advisable to avoid direct looking into any of the laser beams.
- LIGHT RUNNER is an optoelectronic instrument and therefore should be handled with extreme care for its smooth operation. Even a modest shock or vibration can destroy some of the components of LIGHT RUNNER. All the knobs and switches should be operated gently.

Part A: Determination of Attenuation in an Optical Fiber

Objectives:

- To familiarize with attenuation in optical fiber
- To study the wavelength and length dependence of attenuation in the given optical fiber

Components to be used:

- Two Laser sources (1550 nm and 850 nm)
- Two Photodetectors (PD3 and PD5)
- Fiber spools (0.5 km and 1km)
- Patch connectors
- Power Meter

Theory:

Attenuation determines the maximum distance that the light wave can propagate before becoming undetectable at the output end by a receiver. Attenuation is a function of wavelength and minimum attenuation of silica fibers occurs at a wavelength of 1.55 μm. Typically optical fiber losses are in the range of 0.25 dB/km at 1.55 μm.

The loss in an optical fiber is measured in terms of attenuation coefficient defined as

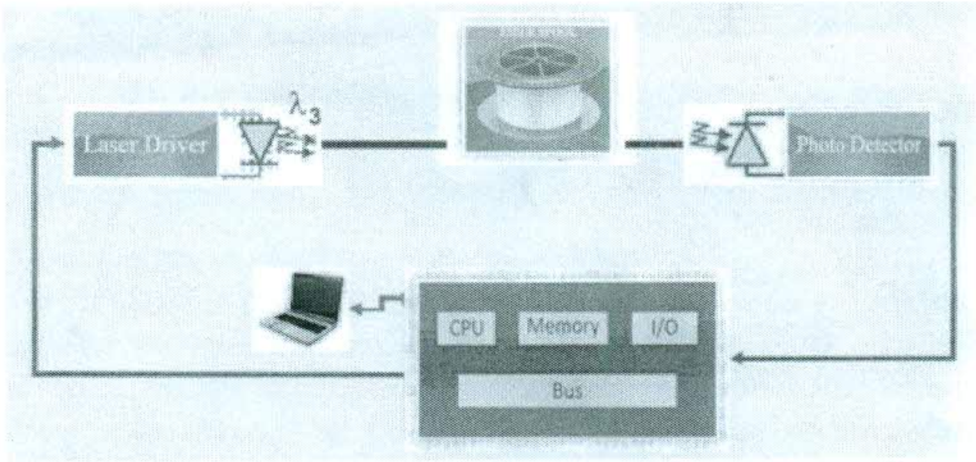
$$\alpha = \frac{10}{L} log\left(\frac{P(0)}{P(L)}\right)\ dB/km$$

where $P(0)$ is the optical power at the input and $P(L)$ is the optical power at the output (L km away from the input end).

Procedure:

- Setup the Light Runner.
- Using the LIGHT RUNNER software, start the experiment.
- Switch on the 850 nm laser and connect to the Si photodiode (PD5) using a patch cord. Adjust the laser power using the manual or soft control to keep it below the photodetector saturation and note this reading as P_1
- Disconnect the patch cord from the detector and connect to the given fiber spool of known length L. Connect the output end of the fiber spool to the Si photodetector and record the optical power output from the spool as P_2
- For estimating attenuation coefficient, consider 0.5 dB loss for each connector.
- Repeat the experiment for 1550 nm laser and InGaAs photodetector (PD3) with a fiber length of 1 km.
- Plot a graph with *Attenuation vs Distance* and calculate the attenuation coefficient from the slope. Compare the attenuation coefficient between two observed wavelengths.
- Insert an additional patch cord and estimate the losses due to the connectors. Since the patch cord length is very small, the additional loss is primarily due to the connectors.
- Gently bend the patch cord to some extent and observe how attenuation changes due to bending.

Experimental Setup:



Observation:

Wave-length λ (nm)	Fiber Length L (km)	Fiber input Power P_1 (mW)	Fiber Output Power P_2 (mW)	Total Attenuation $A=10\log(P_1/P_2)$ (dB)	Number of Connec-tors	Attenuation after accounting for connector loss, A_{eff} (dB)	Fiber attenuation coefficient $A= A_{eff}/L$ (dB/km)
850	0.5						
	1.0						
	1.5						
1550							

Part B: Determination of Dispersion in an Optical Fiber

Objectives:

- To observe the effect of group velocity dispersion on the propagation delay of optical signals at two wavelengths.
- To compare the experimental result with the theoretical prediction due to Sellemeier equation.

Components to be used:

- Two Laser sources (1550 nm and 850 nm)
- Two Photodetectors (PD3 and PD5)
- Fiber spools (0.5 km and 1km)
- Patch connectors
- 50/50 Coupler and 980/15xx Coupler

Theory:

Most optical fiber communication systems employ digital communication techniques i.e. information is sent as a string of 1s and 0s. Each 1 is represented by the presence of a light pulse and each 0 is represented by its absence. Since each pulse carries information, in order to receive the information at the output with minimal errors, adjacent pulses should not overlap in time. In an optical fiber system, as the optical pulses propagate through the fiber, they broaden in the time domain. This is known as pulse broadening or pulse dispersion. Due to pulse dispersion, successive pulses may overlap in time and lead to intersymbol interference.

Input pulses　　Optical fiber　　Output pulses

A pulse of light contains many optical frequencies (wavelengths) and these wavelengths travel at different velocities. This experiment uses two very different wavelengths so that the time difference is measurable using simple instrumentation.

The difference in delay between two pulses at different wavelengths (one at 0.85 μm and the other at 1.55 μm) after propagating a distance of L km

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

where

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

$v_g(\lambda)$ is the group velocity and $n_g(\lambda)$ is the group refractive index of the fiber at a wavelength λ

The group refractive index for pure silica is described by the Sellemeier relation as given below.

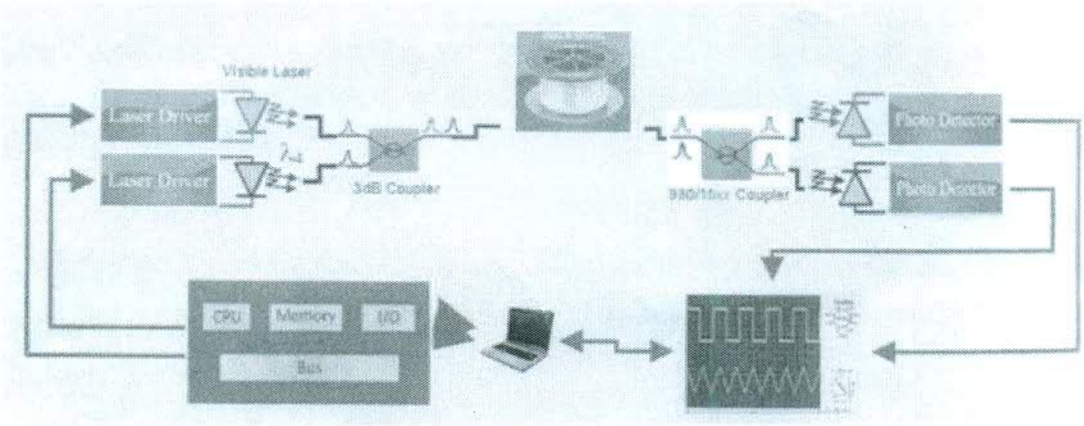
$$n_g(\lambda) = 1.451 + 0.003\left(\lambda^2 + \frac{3}{\lambda^2}\right)$$

Procedure:

- Switch on the 1550 nm and 850 nm lasers with equal frequency, power and duty cycle.
- Connect patch cords to the two laser sources and multiplex the optical signals through a 3 dB coupler.
- Connect a 980/15xx coupler to separate out the different wavelengths from the combined beam.
- Connect the separated wavelengths 1550 nm and 850 nm to Si and InGaAs photodetectotrs respectively.
- Connect the output of the photodetectors to the Channels 1 and 2 of DSO. Measure the delay between the optical pulses from the two laser sources.

- Replace the patch cord connecting 980/15xx coupler and 50/50 coupler with a spool of known fiber length and measure the delay between two laser pulses again.
- Use spools of different fiber lengths and measure the delay between the two wavelengths as a function of frequency.
- Plot a graph with *difference in delay vs distance* and calculate the dispersion from the slope.
- Use Sellemeier equation to find the group velocities at 1.55 μm and 0.85 μm and hence find the delay between the two wavelengths.
- Compare the experimental values with the theoretical ones.

Experimental Setup:



Observation:

Fiber Length (km)	Position of 0.85 μm pulse (ms)	Position of 1.55 μm pulse (ms)	Difference between positions of two light sources (ms)
0			
0.5			
1.0			
1.5			

Report:

Answer the following questions:

- Draw the block diagram of a long-haul fiber optic communication system.
- What is the range of wavelengths suitable for optical fiber communication? Draw the attenuation vs wavelength graph for lightwave systems and identify the suitable low loss windows. State the range of C, L, and S band.
- Explain the following terms: DSF, DCF,DFF
- Why fiber loss increases due to bending?

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