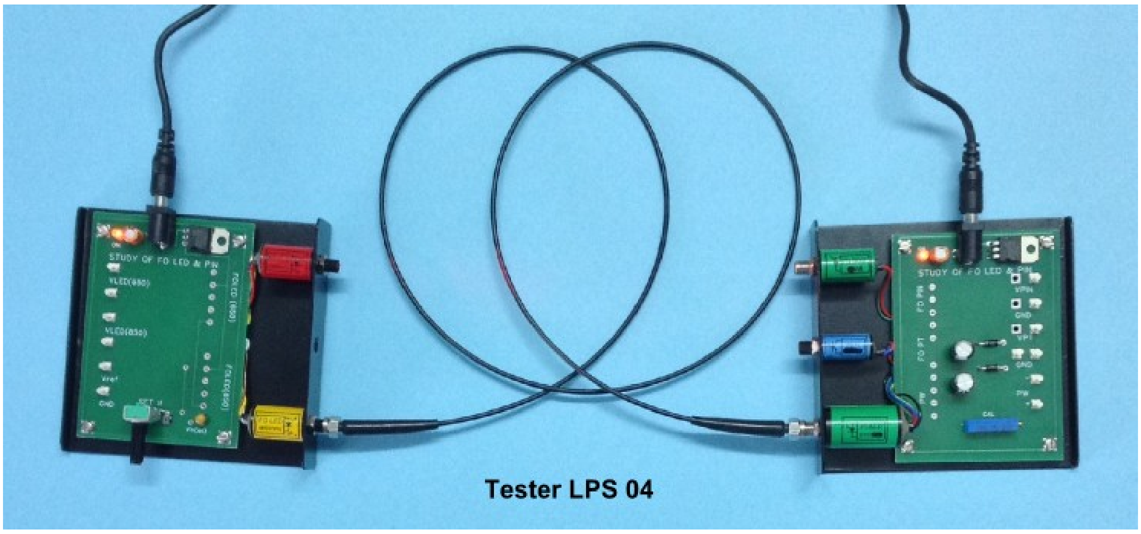
Numerical Aperture, Attenuation, Bending & Connector Losses in Optical Fibers

LABORATORY MANUAL: TESTER LPS04



TELENET SYSTEMS,
203, Mehtab Arcade,
TARNAKA,
Secunderabad 500017
Email: info@telenet-systems.com

0. Introduction

0.1 Tester LPS04 for Study of Optical Fibers and Optical Fiber Cables

Tester LPS04 described here is an optimized set-up to *primarily* conduct a comprehensive study of all DC parameters of a set of fiber optic sources and detectors commonly used in optical fiber communication systems. In this Lab Manual, the applications of Tester LPS04 have been extended to study optical properties of fibers and cables. The experiments include (a) measurement fiber numerical aperture (NA) (b) attenuation per unit length of fiber (c) bending loss in fibers (d) losses in patch cords and connectors. For these studies we employ some parts of Tester LPS04. These are (a) optical power source at 660nm (b) optical power source at 850nm (c) built-in optical power meter that measures power losses in decibels directly. Apart from Tester LPS04, the accessories required are (a) Cable1: SMA-SMA connectorised 1-meter PMMA cable (b) (a) Cable2: SMA-SMA connectorised 3-meter PMMA cable (c) SMA-SMA In-Line-Adaptor (d) Numerical Aperture Jig (e) Mandrel (e) one 31/2-digit digital multi-meter

0.2 Optical Fibers and Cables Studied

Tester LPS04 is designed to study optical properties of all types of plastic optical fibers terminated with SMA connectors at both ends. Please refer to Annexure I for detailed specifications of the PMMA type of plastic fibers and cables. The optical sources at 660nm & 850nm and the power meter have been specially designed to provide simple and repeatable coupling with these entry level optical fibers and cables. The other accessories such as the In-Line Adaptor (ILA) and the Numerical Aperture Jig are also designed to match the cables.

0.3 ST Connectorised Glass Optical Fiber Cables ,FO LEDs, PIN Diodes

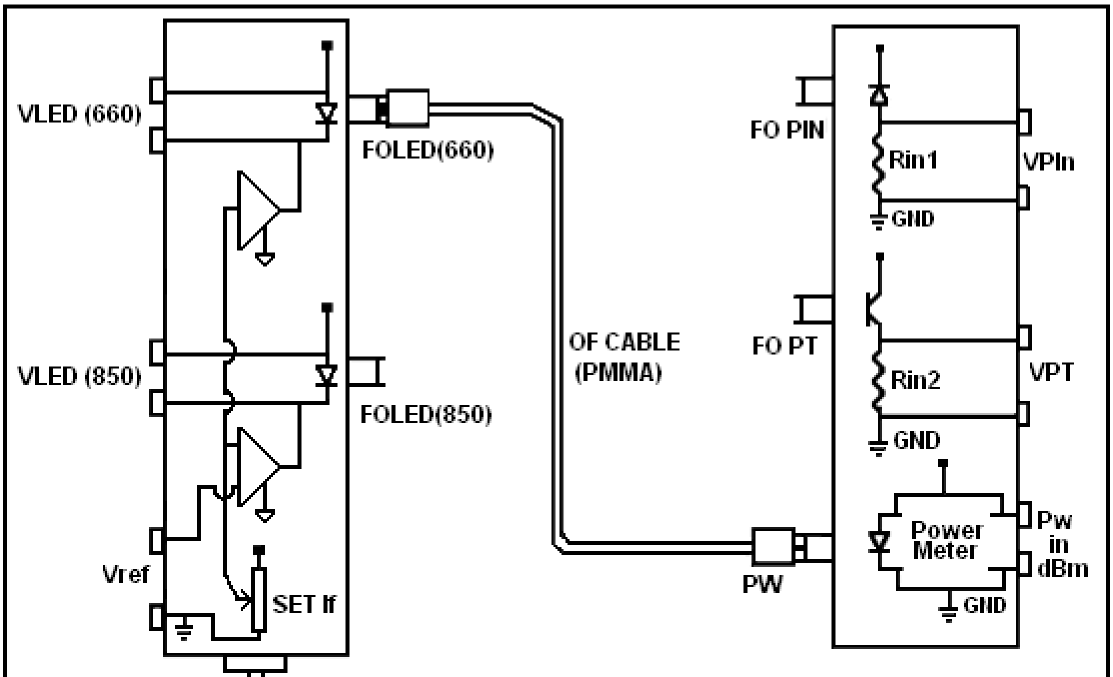
We source a full range of ST connectorised optical fiber patch cords, FO LEDs (660nm and 850nm) and FO PIN diodes. The patch cords are ST connectorised glass multimode graded index and single mode optical fiber cables. It must be mentioned that the glass fiber losses are very high at 660nm.

0.4 Data Sheets on Optical Fibers/ FO Components/ Cables/ Power meter Module

These are included in Annexure I and Annexure II of this laboratory manual for ready reference and use. It may be noted that actual results may vary from those shown in the data sheets due to (a) component tolerance (b) wear and tear (c) accumulation of dirt at the terminals.

1. Experimental Set-up for Tester LSP04

The experimental set-up for LPS04 comprises 2 parts (a) transmitter section and (b) the receiver section. The two sections are linked by the optical fiber cable. These are explained in greater length below.

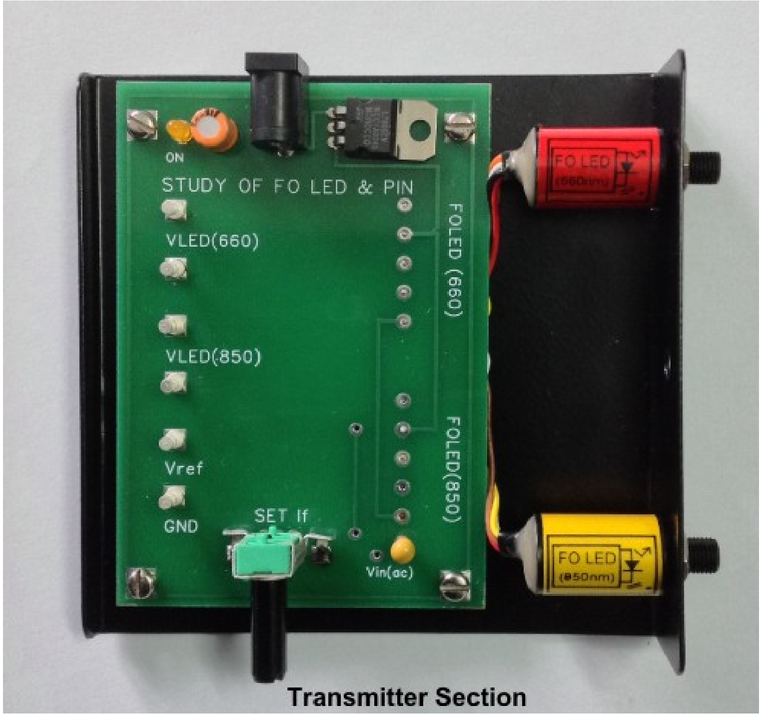


Schematic of Experimental Set-Up

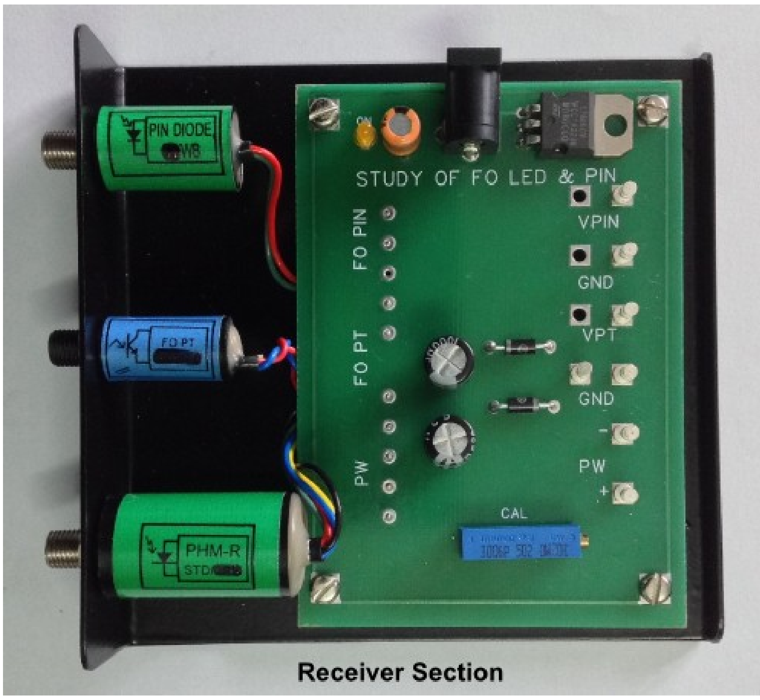
1.1 Transmitter Section This section has two SMA terminated fiber optic LEDs with wavelengths 660nm and 850nm. The LEDs, designated as, **FOLED (660nm)** and **FOLED (850)** are driven by identical linear current drivers that are controlled by the **SET If** potentiometer. The LED forward current, If, is given by Vref/ 50. If is settable in the range 0 to 25 mA. **Vref** is measured with a DMM. The voltage drop between the anode and the cathode of the forward biased FOLEDs are measured across the terminals marked **VLED (660nm)** and **VLED (850nm).** It may be mentioned that the optical output from FOLED (850) will not be visible. The section is powered by a separate 9 Vdc power pack. The regulated supply is 6Vdc.

1.2 Receiver Section This section has three SMA-terminated optoelectronic devices (a) fiber optic PIN photodiode, **FO PIN**, (b) fiber optic phototransistor, **FO PT** and (c) optical power meter marked **Pw**.

1.2.1 Power Measurement The optical port, **Pw**, facilitates measurement of optical power decibels, **dBm** (referred to **1mw**). The voltage (in mV) at the **electrical terminals Pw** divided by 10, directly gives Pw in dBm
As an example, **-100 mV** measured across Pw is equivalent to **-10.0 dBm** of optical power. This when converted to a linear value corresponds to **0.1 mw** or **100 uW** of optical power. It is to be noted that the optical power meter has been calibrated at **660nm**. The power meter readings for other wavelengths will have to be corrected manually, as described later.



Transmitter Section



Receiver Section

***All optical connections may please be done with extreme care as improper use can damage the cable as well the devices, permanently*.**

2. Determination of Numerical Aperture ih Fibers with Tester LPS04

2.1 Aim of the Experiment The aim of the experiment is to determine the numerical aperture of a PMMA fiber cable.

2.2 Basic Definitions Numerical aperture of any optical fiber is a measure of how much light can be collected by the optical system. It is the product of the refractive index of the incident medium and the sine of the maximum ray angle.

$$\mathbf{NA= n_i.\sin\theta_{max}};\qquad n_i \text{ for air is 1, hence NA} = \sin\theta_{max}$$

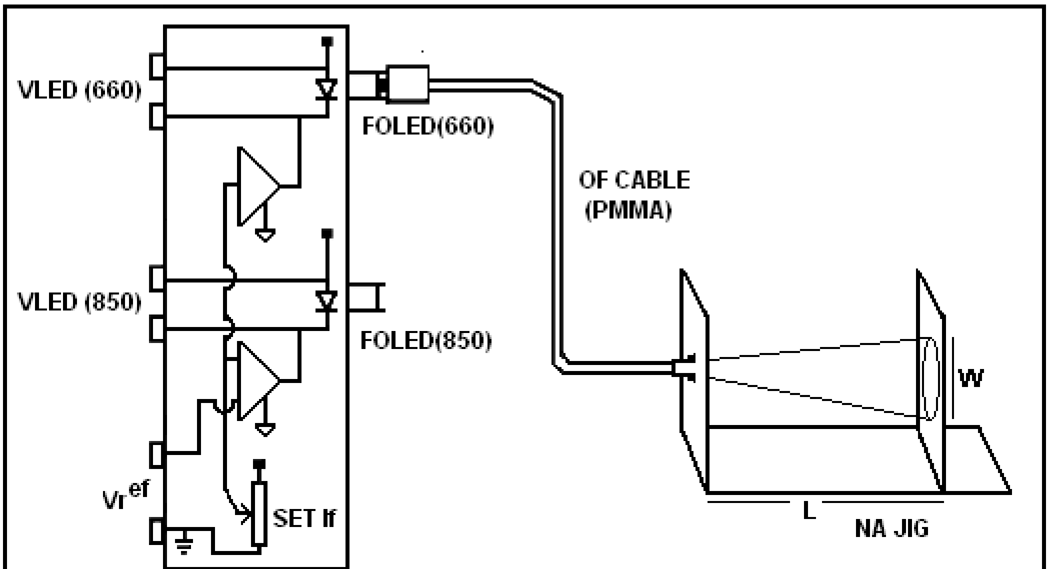
For a step-index fiber, as in the present case, the numerical aperture is given by

$$\mathbf{N= \sqrt{(n_{core}{}^2 - n_{cladding}{}^2)}}$$

For very small differences in refractive indices the equation reduces to

$$NA= n_{core}\sqrt{(2\Delta)},$$ where Δ is the fractional difference in refractive indices.

The schematic diagram of the numerical aperture measurement system is shown below and is self explanatory.



Numerical Aperture Measurement without Mandrel

2.3 Procedure For determination of numerical aperture only the transmitter section of Tester LPS04 will be employed along with the cable and the Numerical Aperture Jig as shown above.

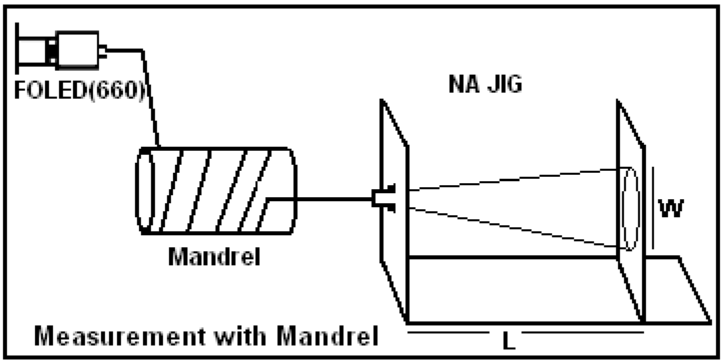
Step1: Connect one end of the Cable to **FO LED(660)** and the other end to the NA Jig, as shown.

Step2: Plug the AC mains. Light should appear at the end of the fiber on the NA Jig. Turn the **Set If** knob clockwise to increase intensity of the optical output at the far end of the optical fiber cable.

Step3. Hold the white screen with the concentric circles (10, 15, 20 and 25 mm diameter) vertically at a suitable distance to make the red spot from the emitting fiber coincide with the 10 mm circle. Note that the circumference of the spot (outermost) must coincide with the circle. A dark room will facilitate good contrast. Record L, the distance of the screen from the fiber end and note the diameter (W) of the spot. You may measure the diameter of the circle accurately with a suitable scale.

Step4 Compute NA from the formula NA = $\sin\theta_{max} = W/(4L^2 + W^2)^{1/2}$. Tabulate the reading and repeat the experiment for 15mm, 20mm and 25 mm diameters too.

Step5: In case the fiber is under-filled, the intensity within the spot may not be evenly distributed. To ensure even distribution of light in the fiber, first remove twists on the fiber and then wind 5 turns of the fiber on to the mandrel as shown. Now, view the spot. The intensity will be more evenly distributed within the core.



2.4 Table of Readings

Sl No	L (mm)	W(mm)	NA	θ (degrees)	Acceptance Angle =2θ (deg)
1	10	10	0.447	26.5	
2	16	15	0.423	25.0	
3	20	20	0.447	26.5	
4	26	25	0.432	25.64	
5	30	-	-	-	

3. Fiber Attenuation and Bending Loss with Tester LPS04

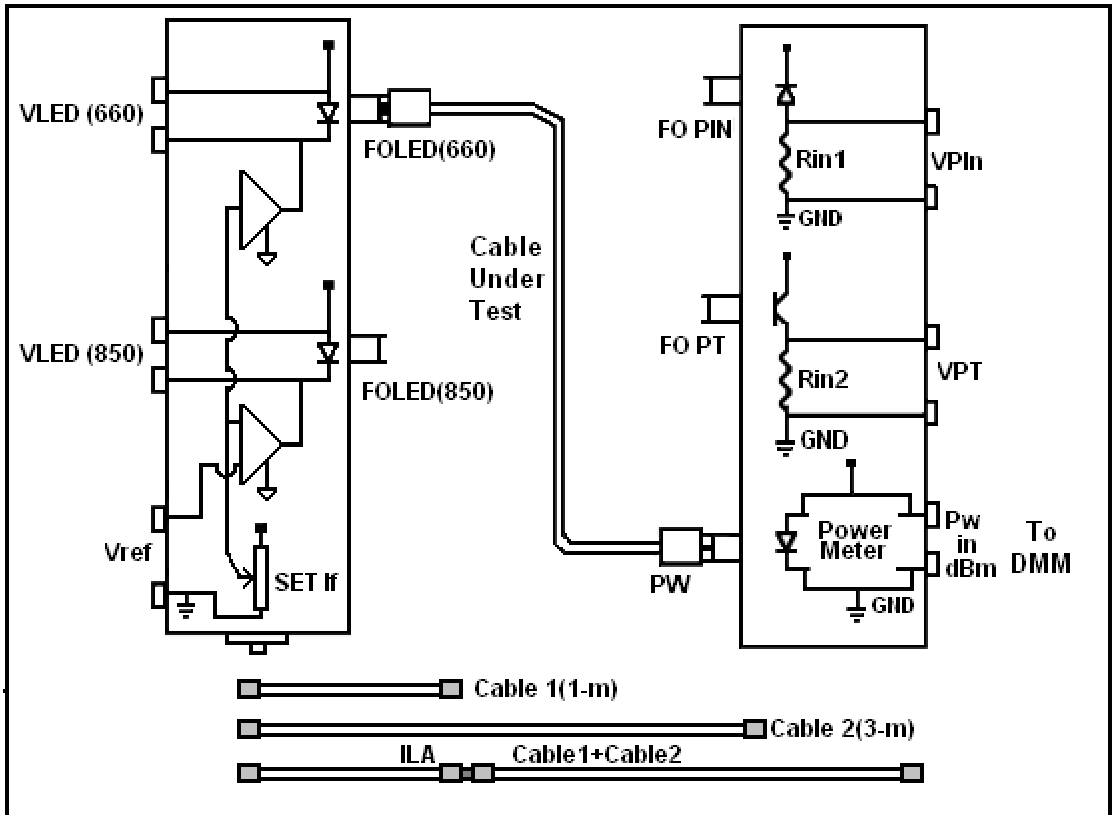
3.1 Aim of the Experiment

The aim of the experiment is to study loss in (a) fibers due to bending (b) loss per meter of fiber employing two patch cords (c) loss in patch cords. The measurements will be conducted initially at 660nm and then repeated at 850nm.

3.2 Basic Definitions

Attenuation in an optical fiber is a result of a number of effects. This aspect is well covered in the text books.

The optical power at a distance, L, in an optical fiber is given by $P_L = P_O\,10^{(-\alpha L/10)}$ where P_O is the launched power and α is the attenuation coefficient in decibels per unit length at a given wavelength. The typical attenuation coefficient value for the fiber under consideration here is 0.15 to 0.2 dB per meter at a wavelength of 660nm. Loss in fibers expressed in decibels is given by -10log(P_O/P_W) where, P_O is the launched power and P_W is power at the far end of the fiber. Typical losses at connector junctions may vary from 0.3 dB to 0.5 dB.



Scheme for Attenuation and Loss Measurements

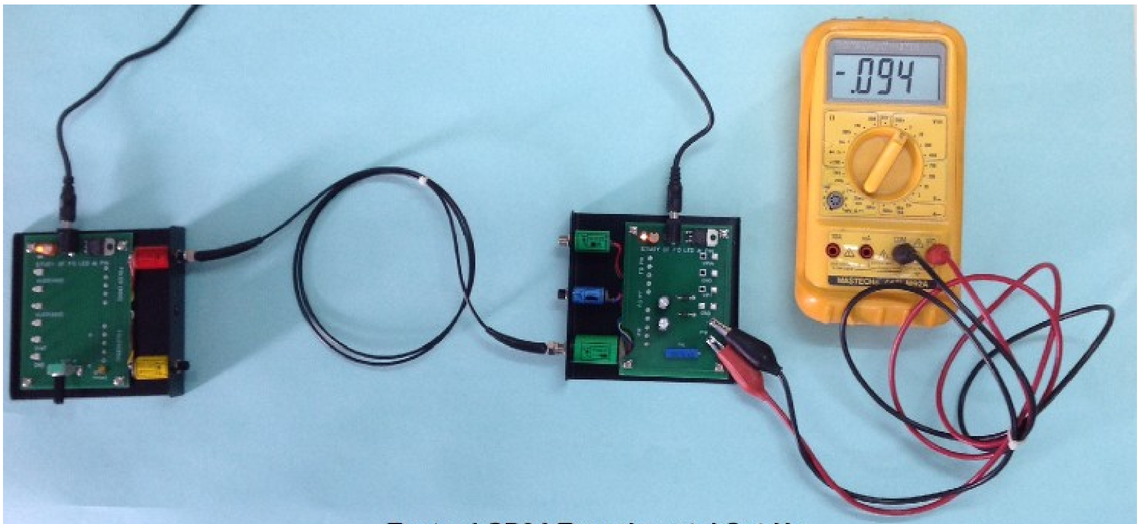
Losses in fibers occur at fiber-fiber joints or splices due to axial displacement, angular displacement, separation (air-gap), mismatch of cores diameters, mismatch of numerical apertures, improper cleaving and polishing at the ends. Losses in fiber also occur due to bending. The loss equation for a simple fiber optic link is given as:

Pin (dBm)-Pout(dBm)= $L_{J1}+L_{FIB1}+L_{J2}+L_{FIB2}+L_{J3}$ (db): where, L_{J1}(db) is the loss at the LED-connector junction, L_{FIB1} (dB) is the loss in cable1, L_{J2} (dB) is the insertion loss at a splice or in-line adaptor, L_{FIB2} (dB) is the loss in cable2 and L_{J3} (dB) is the loss at the connector-detector junction.

3.3. Procedure with Block Schematic

The schematic diagram of the optical fiber loss measurement system is shown above and is self explanatory. We will first conduct measurements with FOLED (660nm) and repeat measurements with FOLED (850nm) employing the transmitter section of Tester LPS04. For measurement of power in decibels directly, we will use the optical power meter provided in the receiver section of Tester LPS04.

Tester LPS04: Numerical Aperture, Attenuation, Bending/Connector Losses in Fibers



Tester LSP04 Experimental Set-Up

Step1: Connect one end of FO Cable1 to the **FO LED (660)** of Trainer ALS04.

Step2: Set the DMM to the 2000 mV range and connect to **Pw**. Turn the DMM on The power meter is now ready for use.

Step3: Plug the AC mains. Connect the Cable1 securely, as shown, after relieving all twists and strains on the fiber. Adjust the **Set If** knob to set **Po** to a suitable value, say, -15.0dBm (the DMM will read 150 mV). Note this as $\mathbf{P_{o1}}$

Step 4 Wind one turn of the fiber on the mandrel, as shown in the first experiment and note the new reading of the power meter $\mathbf{P_{o2}}$. Now the **loss due to bending** and strain on the plastic fiber is $\mathbf{P_{o1}-P_{o2}}$ dB. For more accurate readout set the DMM to the 200.0mV range and take the measurement. Typically the loss due to the strain and bending the fiber is 0.3 to 0.8 db for several turns on the mandrel.

Step5: Next remove the mandrel and relieve the cable of all twists and strains. Note the reading **Po1** for Cable1 (1-metre cable). Repeat the measurement with the Cable2 (3-metre cable) and note the reading **Po2**. Use the in-line SMA adaptor and connect the cables in series as shown. Note the measurement **Po3**.

Po3-Po1 gives loss in the Cable2 + Loss in IL.
Po3-Po2 gives loss in the Cable1+Loss in IL.
Assuming a loss of 1.0dB in the in-line adaptor, we obtain the loss in each cable.
The loss per meter of fiber may be then computed from (Po2-Po1)/2

The experiment may be repeated at 850nm as well. The losses is much higher at this wavelength.

3.4. Table of Readings

SI No	Po1 (dBm)	Po2 (dBm)	Po3 (dBm)	Loss in Cable1 (dB)	Loss in Cable2 (dB)	Loss /meter (db)
12.0						
15/0						
18.0						

4. Connector Loss Due to Air Gap with Tester LPS04

4.1 Aim of the Experiment

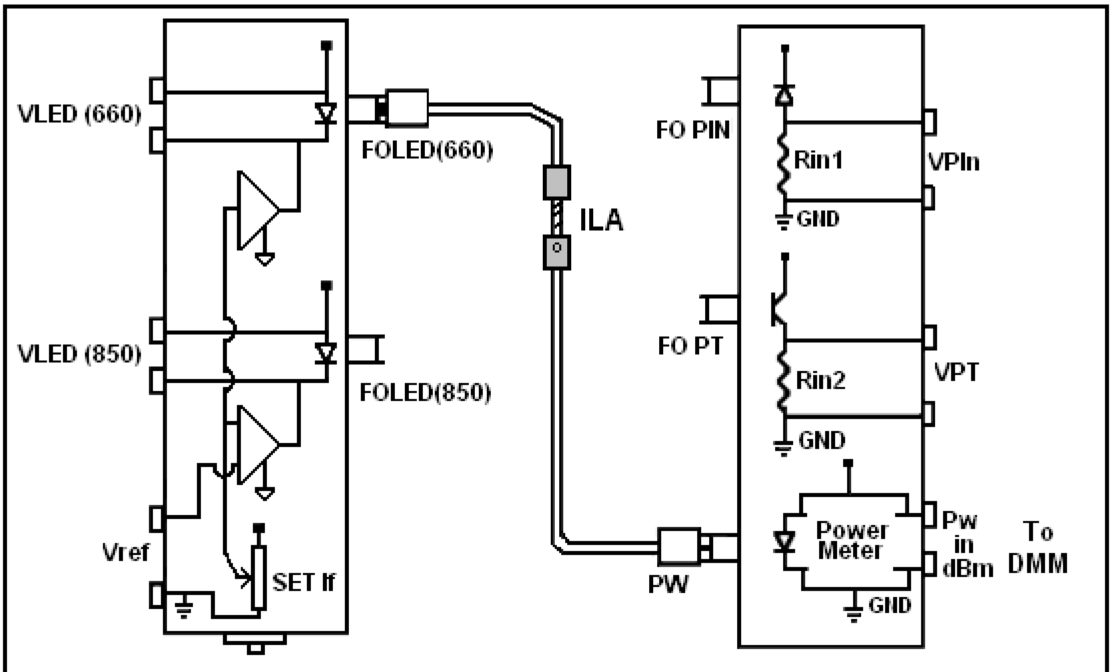
The aim of the experiment is to study losses at fiber junctions with an in-line SMA-SMA adaptor by creating known air gaps.

4.2 Basic Definitions

In-line adaptors are mechanical components, with which two optical fiber cables may be connected in series. These find application in all fiber optic systems. In-line adaptors without air-gap facilitate low loss connectivity. The loss arising out of such a connector may be limited to 0.5 to 1.0 dB. A number of other mechanical connectorisation methods are available. However for reliable permanent connections between one fiber and another, fusion splices would be the solution.
Many fiber optic communication systems require attenuators in the optical path to ensure proper matching of signals between the source and the detector. In case of too large a signal from the transmitter, the receiver may be driven to saturation. To facilitate adjustments of optical signal levels in optical fiber networks, attenuators are used. Attenuators are based on a variety of methods. Variable attenuators are also essential fiber optic accessories.

One simple and popular way to attenuate optical power at fiber junctions is to create a known (fixed or variable) air-gap at the junction. All the light exiting from the transmitting side is not coupled to the receiving fiber, resulting in attenuation.

In the present experiment we shall be studying the loss difference arising out of a lateral air gap created in the in-line adaptor.



Scheme for Connector/ Air Gap Loss

4.3 Procedure with Block Schematic

The schematic diagram to measure connector loss due to an air gap using an in-line-adaptor is shown.

Step1: **Mark one face of the hexagonal lock nut with a pen**. Connect one end of Cable1 (1-meter) to **FO LED (660nm)** of Tester LPS04, keeping the connector with the marking on the hexagonal lock-nut free. Connect one end of the Cbale2 (3-meter) to **Pw** of Tester LPS04.

Step2: Next connect the free end of Cable1 (with the marking) to the in-line adaptor (ILA) by rotating it. Connect the free end of Cable2 to the other side of the in-line adaptor tightly, but without force.

Step3: Set the power meter to read a convenient value, say -15.0dBm...P1.

Step4: Next loosen the lock-nut with the marking by one turn. Pull the cables gently apart so as to create an air gap in the ILA that corresponds to one thread of the connector (=0.7mm). Note the meter reading as P2. Unwind another full thread of Cable1 and pull the cables apart gently to create an air gap of 1.4mm. Note the meter reading as P3. Do not disturb Cable2 position in the in-line adaptor.

Step 5: The losses due to the air-gaps are given by the P2-P1 and P3-P1 (in dB).

Step6: Repeat the experiment for other settings of optical power.

Step7 Repeat Experiment at 850nm as well.

4.4 Table of Readings

Sl No	P1(dBm)	P2(dBm)	P3 (dBm)	Loss for 0.7mm air-gap (dB)	Loss for 1.4mm air-gap (dB)
1.	-15.0				

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ANNEXURE I

SMA Connectorised Basic Optical Fiber Cables and Components

1. General Information

For 20 years, Telenet Systems have been manufacturing a wide range of affordable but professional SMA connectorised optical fiber cables, optical sources and optical detectors that cater to a number of industrial and educational applications. These well-documented products facilitate experimenters and professional users to design a variety of fiber optics systems on their own, that include laboratory trainers. Conversion of existing electrical systems to optical fiber systems is possible using these devices and cables. While the full range is low-priced, there is no compromise in the quality, reliability and standardisation. The cables / components covered in this data sheet are

- # SMA-SMA Connectorised PMMA Cable
- # SMA Connectorised Light Emitting Diode @ Wavelength of 660nm
- # SMA Connectorised Light Emitting Diode @ Wavelength of 850 nm
- # SMA Connectorised Light Emitting Diode @ Wavelength of 950 nm
- # SMA Connectorised Phototransistor (400nm to 1100nm)
- # SMA Connectorised Photo PIN Diode (400nm to 1100nm)

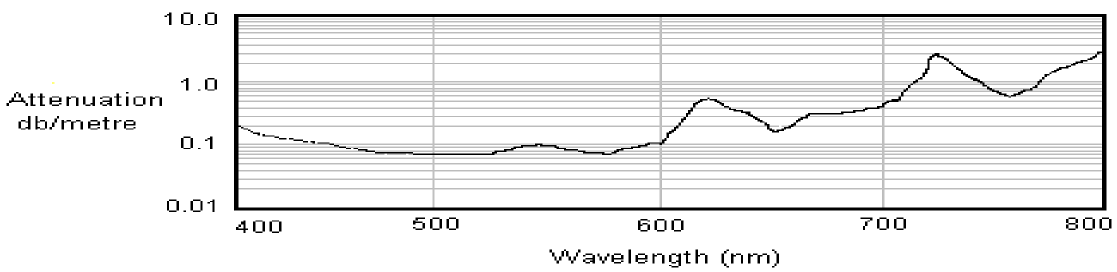
2.0 SMA-SMA Connectorised PMMA Cables

The SMA-SMA connectorised cable or patch cord, with PMMA fiber, finds application in short distance analog and digital signal transmission. The step index fiber has a large area of cross section and a high numerical aperture, facilitating easy coupling with transmitting and receiving devices. Light is guided along a fiber of one millimeter approximately to distances of a few tens of metres.

2.1 Specifications of PMMA Cable

#	Core Material:	polymethyl methacylate
#	Cladding Material:	Fluorinated polymer
#	Fiber Structure:	Step index type
#	Core/Cladding Diameter:	960u/1000u
#	Core Refractive Index:	1.492
#	Cladding Refractive Index:	1.405 to 1.417
#	Numerical Aperture:	0.5 (typical)
#	Acceptance Angle:	55 to 60 degrees
#	Attenuation at 660nm:	Typical 0.2-0.3dB/m
#	Jacket Material:	Polythene (black) 2.2mm OD

2.2 Spectral Attenuation of a PMMA Fiber



2.3 Cable Ordering Information:

#	OF Cable PMMA-0.5	Half metre PMMA cable/ SMA-SMA connector
#	OF Cable PMMA-1.0	One metre PMMA cable with SMA-SMA connector
#	OF Cable PMMA-2.0	Two metre PMMA cable with SMA-SMA connector
#	OF Cable PMMA-3.0	Three metre PMMA cable with SMA-SMA connect
#	OF Cable PMMA-5.0	Five metre PMMA cable with SMA-SMA connector

3.0 SMA Connectorised Light Emitting Diode with Wavelength of 660 nm

The optical fiber Light Emitting Diode (LED), operating at 660nm, couples around -10 to-13 dBm of optical power into a 1000 micron PMMA fiber. The LED is terminated with an optical SMA 905 connector made of glass-filled nylon and is panel mountable. The LED is suitable for speeds over 1MHz.

3.1 Specifications of FO LED(660nm)

#	Peak Wavelength	:	660nm with spectral width of 45nm
#	Forward Voltage (Vf)	;	1.9V at @If=10 ma
#	Reverse Voltage (Vr)	:	5 Volts
#	Forward Current (max)	:	20 ma (avg)
#	Coupled Optical Power	:	-10 to -13 dbm @ If=10ma into PMMA cable
#	Case Dimensions	:	Case of 11mm dia/20mm length
#	Electrical Leads	:	Black (CA)/Red(AN) /Teflon insulated
#	Ordering Code	:	Light Emitting Diode SMA/660

4.0 SMA Connectorised Light Emitting Diode with Wavelength of 850 nm

The SMA (905) connectorised Light Emitting Diode-850nm is an infrared light source operating at a wavelength of 850nm. The specifications are:

4.1 Specifications of FO LED(850nm)

#	Peak Wavelength	:	850 nm with spectral width of 50nm
#	Coupled Optical Power	:	-15 to -12 dbm @ If=10ma
#	Forward Voltage	:	1.7 Vdc (typical)
#	Reverse breakdown	:	5 Vdc
#.	Case Dimensions	:	Case of 11mm dia/20mm length
#.	Electrical Leads	:	Black (CA)/Green (AN) /Teflon
#	Ordering Code	:	Light Emitting Diode SMA/850

5.0 SMA Connectorised Light Emitting Diode with Wavelength of 950 nm

The SMA (905) connectorised Light Emitting Diode-950nm is an infrared light source operating at a wavelength of 950nm. The specifications are:

5.1 Specifications of FO LED(890nm)

#	Peak Wavelength	:	950 nm with spectral width of 50nm
#	Coupled Optical Power	:	-15 to -12 dbm @ If=10ma
#	Forward Voltage	:	1.5 Vdc (typical) @ If=10ma
#	Reverse breakdown	:	5 Vdc
#.	Case Dimensions	:	Case of 11mm dia/20mm length
#.	Electrical Leads	:	Black (CA)/Yellow (AN) /Teflon
#	Ordering Code	:	Light Emitting Diode SMA/950

6.0 SMA Connectorised Phototransistor (400nm to 1100nm)

The device is a wideband optical receiver with high responsivity at 660nm, when coupled to a 1 mm PMMA fiber. The device is terminated with an optical SMA connector made of glass-filled nylon. The phototransistor is suitable for speeds over 500kHz.

6.1 Specifications of FO Phototransistor

#	Peak Responsivity	:	850 nm
#	Spectral Range	:	400 to 1100 nm
#	Dark current	:	100 na (max)
#	Sensitivity @660nm	:	1.5 to 2 V @ -10dbm/ Rin=100 ohms
#	CE Breakdown Voltage	:	30 V (min)
#	EC Breakdown Voltage	:	5 V (min)
#	Rise/Fall Time (100ohms)	:	1 us (typ) for Rin=100 ohms
#	Case Dimensions	:	Case of 11mm dia/20mm length
#	Electrical Leads	:	Red(C)/ Blue (E) /Teflon insulated
#	Ordering Code	:	Phototransistor SMA/WB

7.0 SMA Connectorised Photo PIN Diode (400nm to 1100nm)

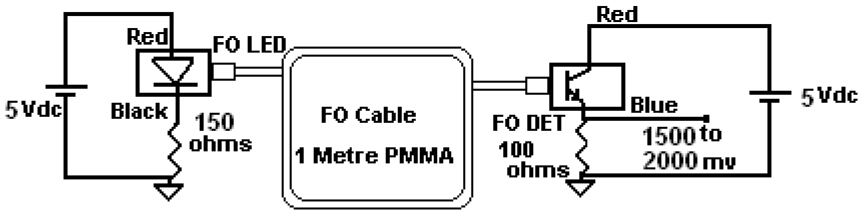
The fiber optic PIN photodiode is a high speed device with a metal SMA connector. The specifications are as given below:

7.1 Specifications of FO Photo PIN Diode

#	Sensitivity @ 660nm	:	40- 50 mV @ -10dbm/Rin=1kohm
#	Spectral range	:	400-1100 nm
#	Dark Current	:	2 na (typ)
#	Peak Response	:	850 nm
#	Rise Time and Fall Time	:	20ns
#.	Case Dimensions	:	Case of 11mm dia/20mm length
#.	Electrical Leads		Red (A)/Green(C) /Teflon insulated
#	Ordering Code	:	Photo PIN Diode SMA/WB

8.0 Typical Test Set-up

For the circuit given below, the output will be in the range shown. The readings are typical and will vary from piece to piece. This is given for a typical 660nm FO LED and FO phototransistor.



Quick Check Test Circuit

ANNEXURE II

Fiber Optic Micromodule for Optical Power Measurements, Mdel PHM-R/STD

1. General Information

The fiber optic micromodule, PHM-R/STD comprises an encapsulated panel mountable device that receives optical power through a multimode step index plastic fiber at 660nm (or other multimode GI glass fibers such as 50/125, 62.5/125, 100/140, 200/230 etc) and converts it into an electrical voltage that is equivalent to the optical power measured in dBm. The FO module employs SMD technology to achieve a high degree of reliability and compactness. Teflon leads (5 in all) provide for easy integration with other circuitry. The device requires only a few external components to realise desired functions. The industry standard fiber otpic SMA connector (optical terminal) provides for rugged and consistently repeatable operations. The power meter operates from a single 6Vdc source.

2 Specifications of PHM-R/STD

#	Wavelength Calibrated	:	660nm
#	Fiber Types	:	PMMA/Glass
#	Detector	:	Si PIN Diode
#	Wavelength Range	:	400 to 1100 nm
#	Optical Connector	:	SMA 905
#	Power Range	:	-5dbm--55.0
#	Accuracy	:	+/- 0.3 dB

(Note: 0 dBm corresponds to 1 milliwatt and -60dBm corresponds to 1nanowatt of optical power)

#	Power Supply	:	6Vdc
#	Vout(mV)/10	:	Power in dBm
#	Ordering Code	:	Micromodule PHM- R/STD

Note

PHM-R/STD is calibrated based on the device specifications provided by the device manufacturer. It is not calibrated against National/International standards. The user may recalibrate the module to any standard that he desires, setting the trimmer shown in the figure above.