LINCOLN
UNIVERSITY COLLEGE

BACH[illegible]AL AND ELECTRONICS ENGINEERING
[illegible]OGY WITH HONOURS

LAB MANUAL (CO3, P3, PO4) (Simulation - mcq).

Experiment 1 : Identify the ratio of stimulated emission rate to the spontaneous emission rate
Experiment 2 : To show the characteristic curve for led.
Experiment 3: To calculate material dispersion at various wavelength of operation.
Experiment 4: To identify fiber parameters (dimensions, refractive index difference) for single mode operation
Experiment 5 : To identify the bending loss in the optical fiber in the link.
Experiment 6: To show power budgeting for the link for given parameters.
Experiment 7: Identify the numerical aperture and critical angle.

EXPERIMENT 1

IDENTIF[illegible] STIMULATED EMISSION RATE TO THE [illegible]OUS EMISSION RATE.

1) Objectiv[illegible]

To identify the r[illegible]n rate to the spontaneous emission rate.

2) Backgro[illegible]

Spontaneous Emission

Spontaneous emission is an energy conversion process in which an excited electron or molecule decays to an available lower energy level and in the process gives off a photon. This process occurs naturally and does not involve interaction of other photons. The average time for decay by spontaneous emission is called the spontaneous emission lifetime. For some excited energy levels this spontaneous decay occurs on average within nanoseconds while in other materials it occurs within a few seconds. As with absorption, this process can occur in isolated atoms, ionic compounds, molecules, and other types of materials, and it can occur in solids, liquids, and gases. Energy is conserved when the electron decays to the lower level, and that energy must go somewhere. The energy may be converted to heat, mechanical vibrations, or electromagnetic photons. If it is converted to photons, the process is called spontaneous emission, and the energy of the photon produced is equal to the energy difference between the electron energy levels involved. The emitted photon may have any direction, phase, and electromagnetic polarization.

There are many ways in which an electron can be excited to a higher energy level. Spontaneous emission processes may be classified based on the source of energy which excites the electrons, and these classes are listed in Table 1. If the initial source of energy for spontaneous emission is supplied optically, the process is called photoluminescence. Glow in the dark materials emit light by this process. If the initial form of energy is supplied by a chemical reaction, the process is called chemiluminescence. Glow sticks produce spontaneous emission by chemiluminescence. If the initial form of energy is supplied by a voltage, the process is called electroluminescence. LEDs emit light by electroluminescence. If the initial form of energy is caused by sound waves, the process is called sonoluminescence. If the initial form of energy is due to accelerated electrons hitting a target, this process is called cathodoluminescence. If spontaneous emission occurs in a living organism, such a firefly, the process is called bioluminescence.

	Spontaneous emission energy source
Photoluminescence	Optical electromagnetic waves
Chemiluminescence	Chemical reactions
Electroluminescence	Applied voltages
Sonoluminescence	Sound waves
Bioluminescence	Biological processes

Table 1 : Spontaneous emission is classified based on the source of energy.

At temperatures above absolute zero, some electrons in atoms are thermally excited to energy levels above the ground state. These electrons decay and emit a photon by spontaneous emission. Any object at a tem[illegible] zero naturally emits photons by spontaneous emission, and this process is [illegible]ation. In 1900, Max Planck derived a formula for the energy density per [illegible]lackbody radiator by making the assumption that only discrete energies a[illegible]greed with known experimental data, and it is one of the fundamental ideas [illegible]. More specifically, the spectral energy density per unit bandwidth, u in u[illegible]y

[illegible] $\frac{\pi f^2}{c^3} \cdot \frac{hf}{e^{(hf/k_B T)-1}}.$

Equation above includes a number of constants including c the speed of light in free space, h the Planck constant, and kB the Boltzmann constant. Additionally, f is frequency in Hz, and T is temperature in kelvins. From the derivation, The first term represents the number of modes per unit frequency per unit volume while the second term represents the average energy per mode. The expression can be written as a function of wavelength instead of frequency with the substitution $f=c/\lambda$.

Photons emitted by a blackbody radiator have a relatively wide range of wavelengths, and this bandwidth depends on temperature. Figure 7.1.1 plots the energy density per unit bandwidth for blackbody radiators as a function of wavelength at temperatures 3000, 4000, and 5000 K. Room temperature corresponds to around 300 K. Visible photons have wavelengths between 400 nm $<\lambda<$ 650 nm. From the figure, we can see that black body radiators at higher temperatures emit both more photons and have a larger fraction of photons emitted fall in the visible range.

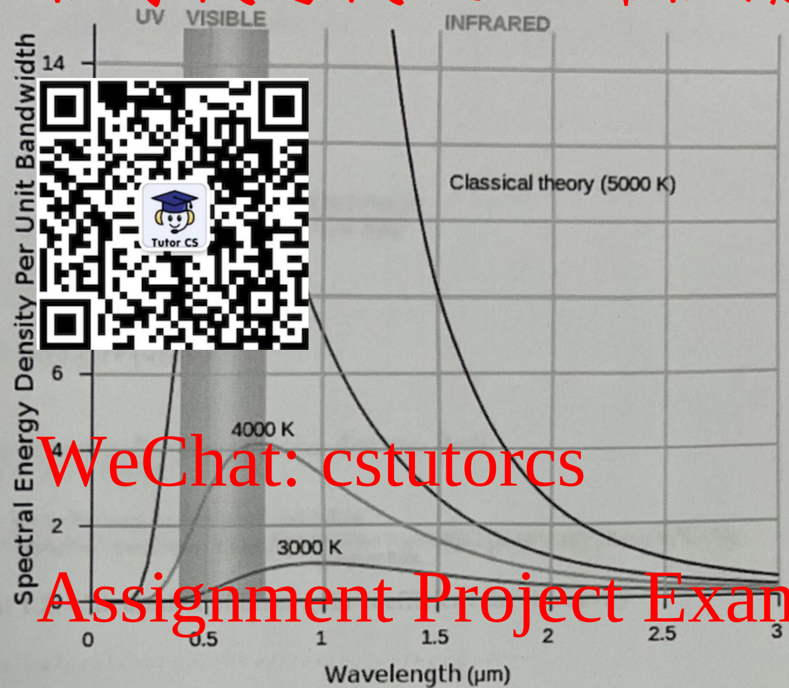


Figure 1 : Spectral energy density of a blackbody radiator. This figure is in the public domain

Stimulated Emission

Stimulated emission is the process in which an excited electron or molecule interacts with a photon, decays to an available lower energy level, and in the process gives o a photon. As with the other processes, this process can occur in isolated atoms, ionic compounds, organic molecules, and other types of materials, and it can occur in solids, liquids, and gases. If an incoming photon, with energy equal to the difference between allowed energy levels, interacts with an electron in an excited state, stimulated emission can occur. The energy of the excited electron will be converted to the energy of a photon. The stimulated photon will have the same frequency, direction, phase, and electromagnetic polarization as the incoming photon which initiated the process.

3) **Scilab Codes:**

- Write a Scilab code as follows:

```
clear;
clc;
close;

//Given data
Lambda=0.5*10^-6 ... WAVELENGTH
k=1.381*10^(-23) ... CONSTANT
c=2.998*10^8; //m ...
h=6.626*10^(-34) ...
T=1000; //Kelvin

//Average operating frequency

f= c / Lambda ;

//Stimulated Emission Rate/Spontaneous Emission Rate
Ratio=1/(exp(h* f/(k*T))-1);

//Displaying the Result in Command Window
printf("\n\n\t Stimulated Emission Rate/Spontaneous Emission Rate =%0.1f X 10^(-13)", Ratio/10^(-13));
```


Experiment 1.2: Calculation of laser gain coefficient for the cavity


```
//Program to calculate laser gain coefficient for the cavity
clear ;
clc ;
close ;
// Given data
L =600*10^-4; //cm − CAVITY LENGTH
r =0.3; // *100 p e r c e n t − REFLECTIVITY
alpha_bar = 30; // p e r cm − LOSSES

// L a s e r Gain C o e f f i c i e n t
gth_bar= alpha_bar+1/L*log(1/r);

printf("\n\n\t Laser Gain Coefficient is %0.1f percm",gth_bar);
```


- Display the result and write a conclusion.

EXPERIMENT 2

TO SHOW THE CHARACTERISTIC CURVE FOR LED.

1) Object

To show the cha

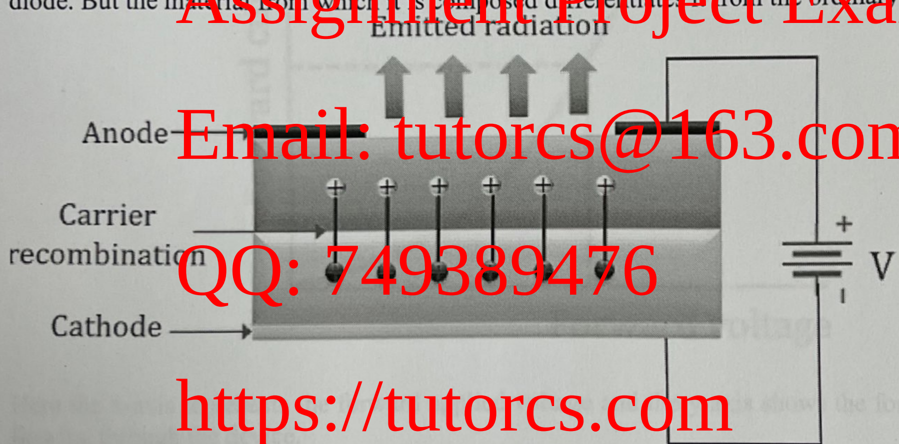
2) Backg

LED is a PN jun ht when a certain potential is provided to the diode. LED is the short form e and is a forward biased device. This means it operates only when a forward voltage is applied to it.

It is a semiconductor device whose operating principle is electro-luminance. By which LED changes electrical energy into its light equivalent.

Working of Light Emitting Diode

In LED, the p and n regions are forward biased. It operates like any other forward biased junction diode. But the material from which it is composed differentiates it from the ordinary one



When a forward voltage is applied to the PN junction diode. Then, the electrons start diffusing into the p region by experiencing repulsion from the battery. So, the electrons move from conduction band to valence band in order to combine with the holes.

As we know, the conduction band is the higher energy level and valence band is the lower energy level. Hence, during this recombination, some energy is emitted by the electrons.

We have already discussed that it is made of GaAs, GaAsP, GaP. As these materials exhibit the property of releasing energy in the form of radiation. While in Si or Ge diodes, energy liberation is done in the form of heat. Therefore, LED emits the energy in the form of photons, thereby producing light.

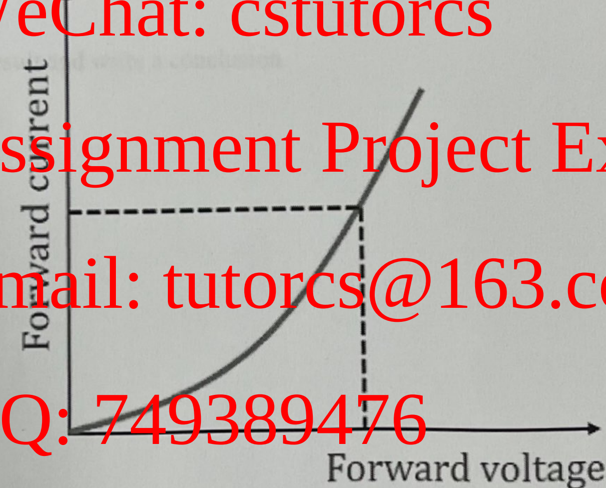
The reason for possessing this special property by these materials is that these semiconductor materials have a direct band gap. This means a direct recombination is seen between electrons and holes and the e[...] the form of light.

LED is not ope[...]de as it cannot tolerate reverse bias voltage and can lead to its destructio[...]

Characteristic[...]g Diode

As the device s[...] which means when certain current flows through it, then only radiation [...]o, the intensity of light emitted by the device varies in proportion wit[...]ing through it.

The figure below represents the VI characteristics of LED:



Here the x-axis represents the forward applied voltage and the y-axis shows the forward current flowing through the device.

A thing is to be kept in mind while connecting LED to the power supply, which is, that a resistor is to be placed in series with the whole circuit. This is done so as to secure the circuit from excess current.

Usually, during operation low dc voltage is provided to the LED and around 5mA current is to be provided to it. This is maintained by the limiting resistor.

3) Scilab Codes:

- Write a Scilab code as follows:

```
clear ;
close ;
clc ;
h =6.626e-34; // planks constan
c=3e8; //velocity of light
e =1.6e-19; //charge of electro
lambda =0.87e-6 // wavelength
tr =60e-9; // regenerative recon
tnr =100e-9; // non regenerati
t=tr*tnr /( tr+ tnr );
Nint =t/tnr // internal quantum efficiency
for i= 1:40
L(i)=i;
pint (i)= Nint *i*h*c*1e-3/( e* lambda ); // i is current in ampers
end
plot2d (L, pint );
xtitle ( ' Characteristics of LED ' , ' Current ( Amperes ) ' ,' Power (Watts ) ' );
```

- Display the result and write a conclusion.

EXPERIMENT 3

TO IDENTIFY MATERIAL DISPERSION AT VARIOUS WAVELENGTH OF OPERATION.

1) Objec

To identify mate wavelength of operation.

2) Backg

In digital communication systems, information is encoded in the form of pulses and then these light pulses are transmitted from the transmitter to the receiver. The larger the number of pulses that can be sent per unit time and still be resolvable at the receiver end, the larger is the capacity of the system.

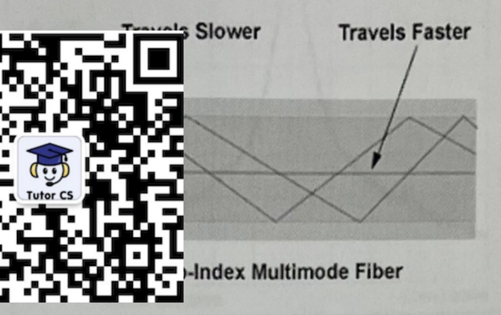
However, when the light pulses travel down the fiber, the pulses spread out, and this phenomenon is called Pulse Dispersion. Pulse dispersion is shown in the following figure

Pulse dispersion is one of the two most important factors that limit a fiber's capacity (the other is fiber's losses). Pulse dispersion happens because of four main reasons:

A) Intermodal Dispersion (also called Modal Dispersion or Group Delay)

Modal dispersion is only important in multimode fibers.

Many different modes propagate in a multimode fiber. Each of these modes takes a different path and thus different length when traveling down the fiber.



Another factor is the differing propagation constants associated with each mode (each mode's group velocity).

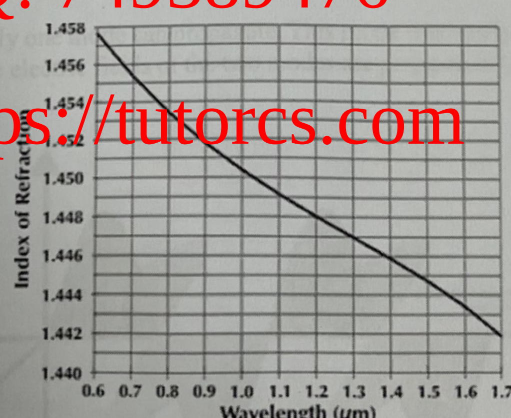
Both factors contribute to modal dispersion.

Single mode fiber doesn't have modal dispersion since there is only one mode propagating in the fiber. As we shall see, single mode fiber's bandwidth is mainly limited by material dispersion, waveguide dispersion and PMD (polarization mode dispersion).

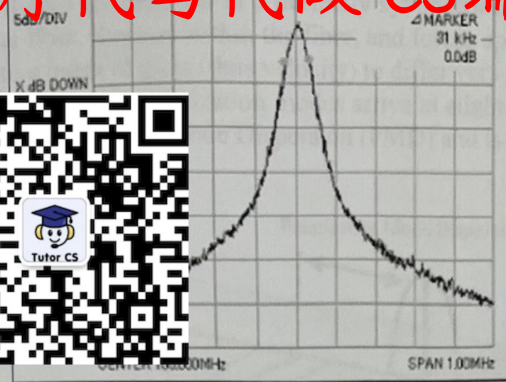
B) Material Dispersion (also called Chromatic Dispersion)

Material dispersion is caused by the velocity of light (or its refractive index) being a function of wavelength. Each wavelength takes different amounts of time to propagate the same path.

The following figure shows refractive index versus wavelength in silica.



Any given light source (even a laser) emits over a range of wavelengths as shown below.



C) Waveguide Dispersion

Waveguide dispersion is a type of dispersion attributable to the relationship of the physical dimensions of the waveguide and the optical signal.

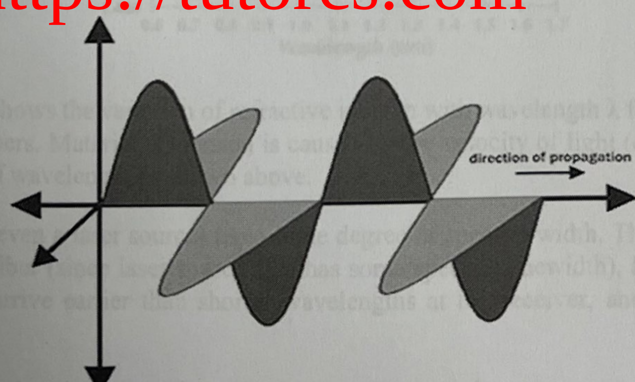
In optical fibers, this shows as the propagation constant of a mode (and, hence, its velocity) being a function of a/λ. Where a is the core radius and λ is the wavelength.

Unlike material dispersion, even if the refractive indexes of the core and cladding are independent of wavelength, we will still have waveguide dispersion.

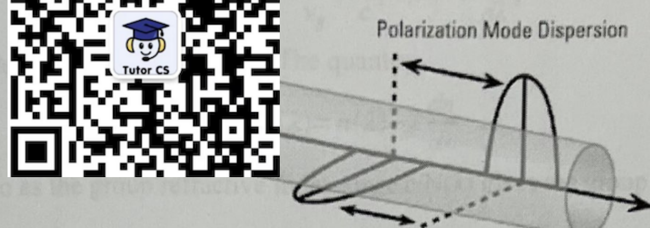
C) Polarization Mode Dispersion (PMD)

PMD is only important in single mode fibers.

In single mode fiber, only one mode can propagate. This mode is actually composed of two distinct polarization modes. The electric fields of the two modes are perpendicular to each other. As shown below.

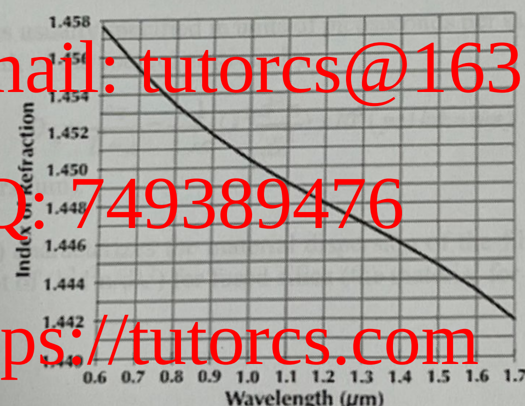


These two polarization modes are identical in a perfectly symmetric fiber. However, in reality there is no perfect optical fiber. Stresses within the fiber, and forces applied to it from the outside world, causes the refractive index of glass (thus velocity) to differ very slightly for light in the two polarization mo[illegible] Thus these two polarization modes arrive at slightly different time at the end of the fiber. Thi[illegible] Mode Dispersion (PMD) and is shown below.



Polarization Mode Dispersion is smaller in magnitude than material dispersion, so it hasn't been a problem until recently high speed long distance single mode fiber systems becomes popular. PMD is a serious problem when data rate exceeds 2.5 Gb/s.

Material Dispersion



The above figure shows the variation of refractive index n with wavelength λ for fused silica used in current glass fibers. Material dispersion is caused by the velocity of light (or refractive index) being a function of wavelength as shown above.

All light sources (even a laser source) have some degree of spectral width. This means that even in a single mode fiber (since laser source also has some spectral linewidth), longer wavelengths travel faster and arrive earlier than shorter wavelengths at the receiver, and this causes pulse spreading.

When a temporal pulse propagates through a homogeneous medium, its group velocity v_g is given by

$$\frac{1}{v_g}=\frac{1}{c}[n(\lambda)-\lambda\frac{dn}{d\lambda}]$$

Thus, the time tak... length L of fiber is given by

$$...=\frac{L}{v_g}=\frac{L}{c}[n(\lambda)-\lambda\frac{dn}{d\lambda}]$$

which is dependen... The quantity

$$...(\lambda)=n(\lambda)-\lambda\frac{dn}{d\lambda}$$

is also referred to as the group refractive index since c/N(λ) gives the group velocity.

If the source is characterized by spectral width Δλ, then each wavelength component will traverse with a different group velocity, resulting in temporal broadening of the pulse. This broadening is given by

$$\Delta\tau=\frac{d\tau}{d\lambda}\Delta\lambda=-\frac{L}{c}(\lambda^2\frac{d^2n}{d\lambda^2})(\frac{\Delta\lambda}{\lambda})$$

The quantity $(\lambda^2 d^2n/d\lambda^2)$ is a dimensionless quantity. The above pulse broadening is referred to as material dispersion and occurs when a pulse propagates through any dispersive medium.

Material dispersion D_m is usually specified in units of picoseconds per kilometer (fiber length) per nanometer (spectral width of the source) as given by

$$D_m=\frac{\Delta\tau}{L\Delta\lambda}=-\frac{1}{\lambda c}(\lambda^2\frac{d^2n}{d\lambda^2})x10^9(ps/km*nm)$$

where λ is in micrometers (μm).

The quantity $(\lambda^2 d^2n/d\lambda^2)$ characterizes the material dispersion of the fiber and is grouped in the equation. Here is the plot of $(\lambda^2 d^2n/d\lambda^2)$ for fused silica (the material for current glass fibers).

From the above figure, we can see that with $\lambda \approx 1.27$um, $d^2n/d\lambda^2 \approx 0$. This means that at $\lambda \approx 1.27$um the material dispersion of fused silica changes sign. For $\lambda \approx 1.27$um the material dispersion is zero. This wavelength is referred to as Zero Material Dispersion Wavelength (ZMDW). However we will see that the other sources of dispersion move the wavelength for zero total dispersion to 1300nm.

3) Scilab Codes:

- Write a Scilab code as follows:


```
// Experiment no . 5 To calculate material dispersion at various wavelength of operation .
// OS=Windows XP sp3
// Scilab version 5.4.0
// sample values
// L0=1.3 ( zero dispersion wavelength psnm-2km-1)
// S0=0.095(Sl ope at zero dispersion wavelength in psnm-1km-1)

clear ;
close ;
clc ;
L0= input (" enter the value of zero dispersion waveleng thin um")
S0= input (" enter the value of Slope at zero dispersion wavelength ")
lambda =0.7:0.1:1.7 // wave l eng th o f l i g h t
MD =( lambda .* S0 /4) .*(1 -( L0 ./ lambda ) .^4) ; // Material Dispersion
plot2d (lambda ,MD);
xtitle ( ' Material Dispersion at various wavelength ' , ' wavelength ( meters ) ' , ' Material Dispersion ( psnm-1 km-1) ' );
```


- Display the result and write a conclusion.

EXPERIMENT 4

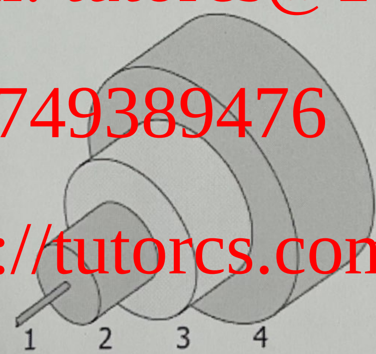
TO IDENT ... TERS (DIMENSIONS, REFRACTIVE INDEX ... R SINGLE MODE OPERATION

1) Objective:

To identify fiber ... refractive index difference) for single mode operation

2) Backgrou...

In fiber-optic communication, a single-mode optical fiber (SMF) is an optical fiber designed to carry only a single mode of light - the transverse mode. Modes are the possible solutions of the Helmholtz equation for waves, which is obtained by combining Maxwell's equations and the boundary conditions. These modes define the way the wave travels through space, i.e. how the wave is distributed in space. Waves can have the same mode but have different frequencies. This is the case in single-mode fibers, where we can have waves with different frequencies, but of the same mode, which means that they are distributed in space in the same way, and that gives us a single ray of light. Although the ray travels parallel to the length of the fiber, it is often called transverse mode since its electromagnetic oscillations occur perpendicular (transverse) to the length of the fiber. The 2009 Nobel Prize in Physics was awarded to Charles K. Kao for his theoretical work on the single-mode optical fiber. The standard G.652 defines the most widely used form of single-mode optical fiber.



The structure of a typical single-mode fiber.
1. Core 8 - 9 μm diameter
2. Cladding 125 μm diameter
3. Buffer 250 μm diameter
4. Jacket 900 μm diameter

3) Scilab Codes:

- Write a Scila[illegible]

```
//ric=1.45(refract[illegible]
//V=2.405(V mumber)
//delta=0.003(refr[illegible]e)

clear ;
close ;
clc ;
lambda=0.8e-6:0.1e-6:1.7e-6;
ric = input ('refractive index of core=');
V= input ('V mumber for single mode transmission=');
delta = input (' refractive index difference=');
for i =1:10
a(i)=V* lambda (i) /(2*3.14* ric* sqrt (2* delta ))
end
plot2d (lambda ,a);
xtitle ( ' Core daimeter versus wavelength of transmission', 'Wavelength (lambda) (m)', 'Core diameter (m)' );
```

- Display the result and write a conclusion.

EXPERIMENT 5

TO IDENTIFY THE BENDING LOSS IN THE OPTICAL FIBER IN THE LINK.

1) Object

To identify the b fiber in the link.

2) Backg

Radiative losses cal 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.

Let us examine large–curvature radiation losses, which are known as macrobending losses. For slight bend the excess loss is extremely small and is essentially unobservable. As the radius of curvature decreases the loss increases exponentially until at a certain critical radius the curvature loss becomes observable. A sharp bend in a fiber can cause significant losses as **well as the** possibility of mechanical failure. The ray shown in Fig.(1-a) is safely outside of the critical angle and is therefore propagated correctly. Now, if the core bends, as in Fig.(1-b), the normal will follow it and the ray will now find itself on the wrong side of the critical angle and will escape. The tighter the bend cause the worse the losses. Therefore; the critical radius determined by attached instruments indicated a loss of over 6 dB. If bending radius is smaller than critical radius causes damage in optical fiber.

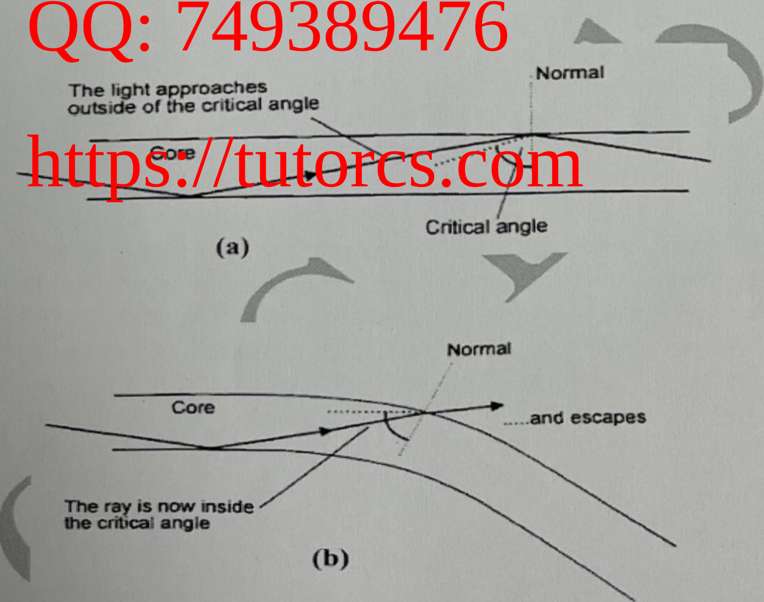


Fig. 1

3) Scilab Codes:

- Write a Scilab

```
// n1 =1.50
// n2 =1.47
//R=1e-2
// lambda =0.82
clear ;
close ;
clc ;
n1 = input ('enter the value of core refractive index=')
n2 = input ('enter the value of cladding refractive index=')
R = input ('enter the value of radius of curvature of bending m=') // c u r v a t u r e of bend
lambda = input ('enter the value wavelength in micrometer=')
c1 =1.2; // c o n s t a n t
c2 =0.5 // c o n s t a n t
delta =( n1^2-n2^2) /(2*n1^2) ;
Rc =(3*lambda*1e-6)/(4*3.14*2*delta);
alpha=c1*exp(-c2*R);
alphadb=10*log(alpha)
disp (alphadb ,'Bending loss in db=') ;
disp ( Rc ,'critical radius in m=') ;
```

- Display the result and write a conclusion.

EXPERIMENT 6

TO SHOW POWER BUDGETING FOR THE LINK FOR GIVEN PARAMETERS.

1) Object[illegible]

To show power [illegible] given parameters.

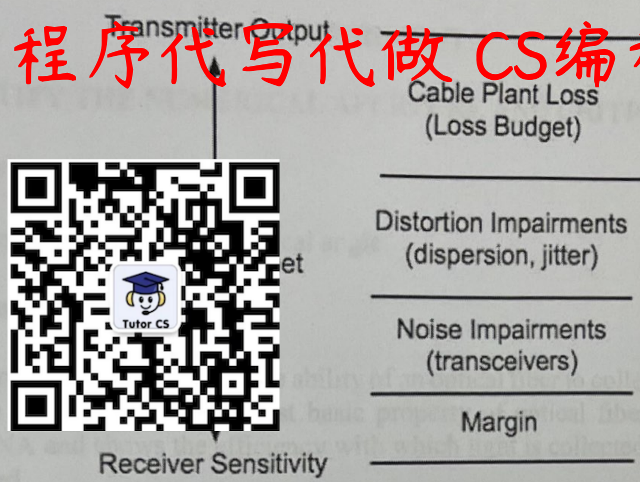
2) Backg[illegible]

The power budg[illegible]f fiber optic cable plant loss that a datalink (transmitter to receiver) can tolerate in order to operate properly. Sometimes the power budget has both a minimum and maximum value, which means it needs at least a minimum value of loss so that it does not overload the receiver and a maximum value of loss to ensure the receiver has sufficient signal to operate properly.

All datalinks are limited by the power budget of the link. The power budget is the difference between the output power of the transmitter and the input power requirements of the receiver, both of which are defined as power coupled into or out of optical fiber of a type specified by the link. The power budget is not just a straightforward determinant of the maximum loss in the cable plant that the link can tolerate. As shown below, cable plant loss is only a part of the power budget. Distortion impairments, for example from dispersion (modal and chromatic dispersion in MM fiber, chromatic and polarization mode dispersion in SM fiber), reduce the power budget. In multimode gigabit Ethernet networks, for example, transceivers have a dynamic range (transmitter output to receiver sensitivity) of about 5-6 dB before dispersion is factored in, leaving a power budget of about 2 dB.

Noise in transceivers, mainly in the receiver, affect the power budget also. The receiver has an operating range determined by the signal-to-noise ratio (S/N) in the receiver. The S/N ratio is generally quoted for analog links while the bit-error-rate (BER) is used for digital links. BER is practically an inverse function of S/N. Transceivers may also be affected by the distortion of the transmitted signal as it goes down the fiber, a big problem with multimode links at high speeds or very long OSP singlemode links.

When testing a fiber in a cable plant to determine if the cable plant will allow a specific link to operate over it, the test should be made from transceiver to transceiver, e.g. the cable plant with patchcords installed on either end that would be used to connect the transceivers to the cable plant. When doing a link loss budget (below) for the cabling to be used with a given link to determine if the link will operate over that link, the loss of the patchcords may also be included.



3) Scilab Codes:

- Write a Scilab code as follows:


```
//Ps=13 ( input power in dBm)
//Pr=-31(sensitivityofreceiver)
//L=80(Link lengthin Km)
//Loss =0.35(fiberlossin dB/Km)
//SL=0.1(SpliceLossindB)
//CL=0.5(couplinglossindB)
//EL=1.5(excessloss)

clear ;
close ;
clc ;
Ps= input ('Power from source in dBm=');
Pr= input ('sensitivity of receiver in dBm=');
L= input ('Link length in Km=');
Loss = input ('fiber lossin dB/Km=');
SL= input ('Splice Loss in dB/Km=');
CL= input ('coupling loss in dB=');
EL= input ('excess loss in dB=');
Pt=Ps-Pr;
SM=Pt-(2* CL+ Loss *L+SL*L)
disp ('system margin=',SM,'dB');
```


- Display the result and write a conclusion.

EXPERIMENT 7

IDENTIFY THE NUMERICAL APERTURE AND CRITICAL ANGLE.

1) Objectiv[illegible]

Identify the num[illegible]cal angle.

2) Backgro[illegible]

Numerical Apert[illegible] ability of an optical fiber to collect or confine the incident light ray inside [illegible]t basic property of optical fiber. Numerical aperture is abbreviated as NA and shows the efficiency with which light is collected inside the fiber in order to get propagated.

We know light through an optical fiber is propagated through total internal reflection. Or we can say multiple TIR takes place inside the optical fiber for the light ray to get transmitted from an end to another through an optical fiber.

Basically when the light is emitted from an optical source then the fiber must be highly efficient so as to collect the maximal emitted radiation inside it.

Thus we can say that the light gathering efficiency of an optical fiber is the key characteristic while transmitting a signal through an optical fiber.

NA is related to acceptance angle. As acceptance angle is that max angle through which light enters the fiber. Hence the acceptance angle and numerical aperture are related to each other.

Propagation through Optical fiber

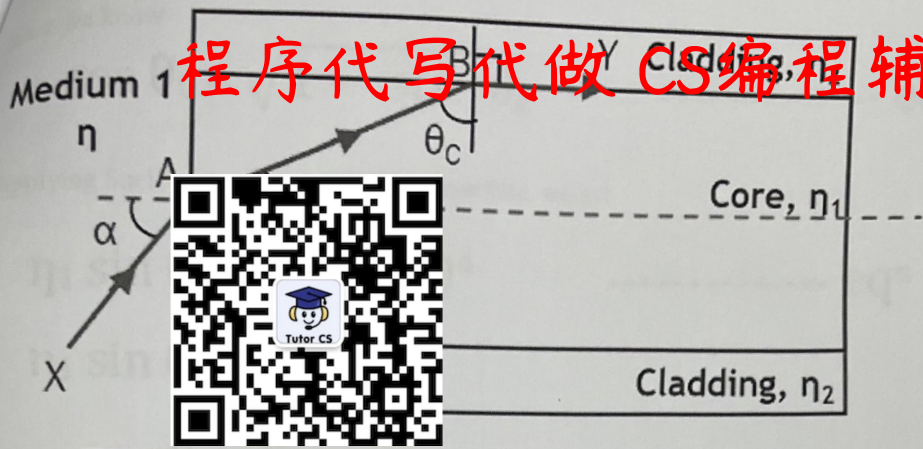
As we have already discussed that light through an optical fiber is propagated by several continuous total internal reflections.

As we know that an optical fiber is composed of a core which is made up of a very pure form of glass silica and is surrounded by a glass cladding. So, the light is propagated inside the fiber by performing continuous reflections from the cladding.

But the condition of total internal reflection for the propagation of light ray comes into action only when most of the light is collected inside the fiber. So, let us now understand the numerical aperture for optical fiber in detail.

Derivation for Numerical Aperture of Optical Fiber

Consider a light ray XA, that incident inside the optical fiber. The refractive index of the core is $\eta 1$ and that of cladding is $\eta 2$.



Ray propagation through Optical Fiber

The figure below shows an optical fiber inside which light ray is focused. So, the ray XA is launched from denser medium to rarer medium by making an angle α with the fiber axis. This angle α is known as the acceptance angle of the fiber.

This incident ray propagates inside the fiber and gets reflected completely by the core-cladding interface.

But for this, the angle of the incident should be more as compared to the critical angle. Otherwise, if the incident angle is less the critical angle then rather being reflected the ray gets refracted.

According to Snell's law, the incident and refracted ray propagate in the same plane. Hence, on applying Snell's law at medium 1 (usually air) and core interface. Then

$$\eta \sin\alpha = \eta_1 \sin\theta \qquad \text{--------------- eq}^n\ 1$$

From the above figure, we can write

$$\theta = \frac{\pi}{2} - \theta_C \qquad \text{--------------- eq}^n\ 2$$

On putting the value of θ from the above equation in equation 1, we get,

$$\eta \sin\alpha = \eta_1 \sin\left(\frac{\pi}{2} - \theta_C\right)$$

$$\eta \sin\alpha = \eta_1 \cos\theta_C \qquad \text{(by trigonometric identity)}$$

$$\sin\alpha = \frac{\eta_1}{\eta} \cos\theta_C \qquad \text{--------------- eq}^n\ 3$$

Since we know

$$\cos\theta_C = \sqrt{1 - \sin^2\theta_c} \text{ -------------- eq}^n\ 4$$

Applying Snell's [illegible] interface, we get

$$\eta_1 \sin ([illegible])^\circ \text{ -------------- eq}^n\ 5$$

$$\eta_1 \sin ([illegible]$$

$$\sin\theta_C = \frac{\eta_2}{\eta_1} \text{ -------------- eq}^n\ 6$$

Substituting the above value in equation 4

$$\cos\theta_C = \sqrt{1 - [\frac{\eta_2}{\eta_1}]^2}$$

Substituting the above value in equation 3, we get

$$\sin\alpha = \frac{\eta_1}{\eta}\sqrt{1 - [\frac{\eta_2}{\eta_1}]^2}$$

$$\sin\alpha = \sqrt{\frac{\eta_1^2 - \eta_2^2}{\eta}} \text{ -------------- eq}^n\ 7$$

As we have already discussed that medium 1 is air, thus refractive index i.e., η will be 1.

So more specifically we can say

$$\sin\alpha = \sqrt{\eta_1^2 - \eta_2^2}$$

$$NA = \sqrt{\eta_1^2 - \eta_2^2}$$

This is the expression for the numerical aperture of an optical fiber, having η1 as the refractive index of core and η2 as the refractive index of the cladding.

So we can conclude that as the numerical aperture shows the light collecting ability of the fiber thus its value must be high. As higher the value of NA, better will be the optical fiber.

However, the greater value of NA will be achieved only when the difference between the two refractive indices [illegible]er, η1 is to be high or η2 to be low.

But no such mate[illegible]r refractive index than 1. So, an option stands that if we remove the cladd[illegible]e then greater NA can be achieved.

While, for optical[illegible] only motive is not to have high accepting range but also to propagate the [illegible]imal attenuation.

This is so because an optical fiber that has the greatest light gathering efficiency but does not allow light propagation through it properly, is not of any use.

Thus several parameters must be taken into consideration for selecting the appropriate optical fiber for signal propagation.

3) Scilab Codes:

- Write a Scilab code as follows:

Experiment 7.1


```
clear ;
clc ;
delta = 1/100; //Relativerefractivedifferenceindex
n1 =1.46; //Corerefractiveindex(assumption)

NA = n1 * sqrt (2* delta ) ; //computingnumericalaperture
theta = 1 - delta ;
Critical_angle = asind ( theta ) ; //computingcriticalangle
printf ('\nNumerical aperture is %.2f \n Critical angle is %.1f degree.',NA, Critical_angle);
```


Experiment 7.2: Numerical aperture


```
//n1=1.50
//n2=1.47
clear ;
close ;
clc ;
n1= input ('enter the value of core refractive index ')
n2= input ('ent e r the value of cladding refractive index ')
delta =( n1 ^2- n2 ^2) /(2* n1 ^2)
NA=n1* sqrt (2* delta )
accept = asind (NA)
disp (NA ,'numerical aperture=');
disp ( accept ,' acceptance angle=');
```

- Display the result and write a conclusion.