fiber Optics Communication

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Date: 3-Jan-17

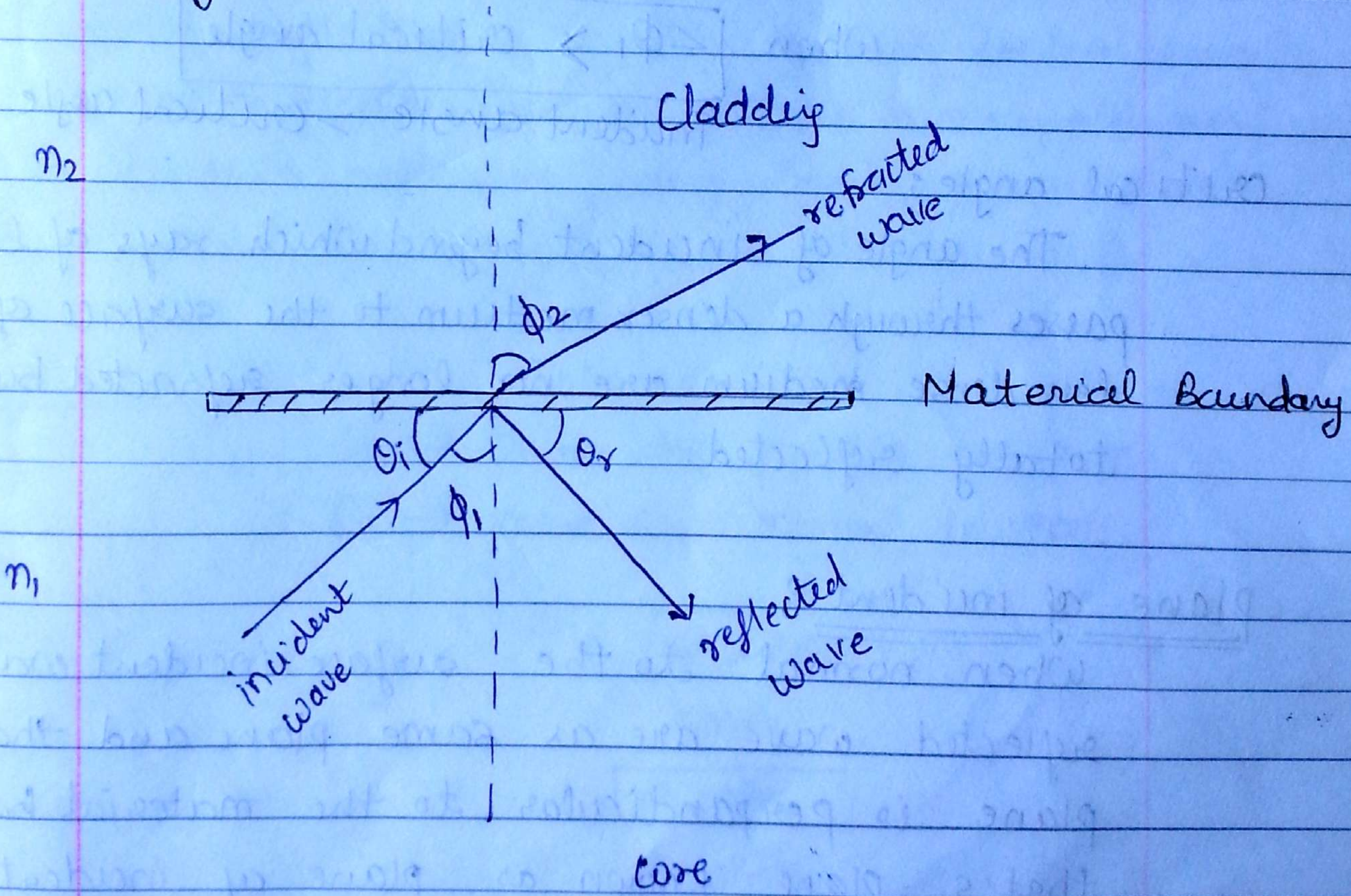
Pg NO 28
ch-2

Optics theory:

- Reflection / Refraction
- Refraction Index

$n = \frac{c}{v}$ $c \rightarrow$ free space velocity of light
$v \rightarrow$ velocity of light in medium

Ray model:



- $n_2 < n_1$
- $\phi_2 > \phi_1$

$\phi_1 \rightarrow$ angle of incident
$\phi_2 \rightarrow$ angle of refracted

Snell's law:

$$n_1 \sin\phi_1 = n_2 \sin\phi_2$$

- When light passes through denser to lighter medium velocity will ~~decreases~~ increases ($n_2 < n_1$)

<u>law of reflection:</u>

$$\angle\theta_i = \angle\theta_r$$

when $\boxed{\angle\phi_1 > \text{critical angle}}$

incident angle > critical angle

critical angle:

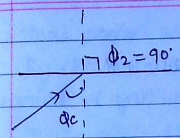
The angle of incident beyond which rays of light passes through a denser medium to the surface of a less dense medium are no longer refracted but totally reflected.

<u>Plane of incident:</u>

When normal to the surface incident wave and reflected wave are as same plane and that plane is perpandicular to the material boundary that's plane known as plane of incident.

critical angle of incident:

when $\phi_2 = 90^\circ$, then incident angle is θ_c.



- When $\phi_1 > \theta_c \longrightarrow$ then reflection is occur (TIR)

in eq^n (A) $\quad n_1 \sin\theta_c = n_2 \sin(90^\circ)$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

only reflection is when $n_2 < n_1$

- Internal reflection ($n_2 < n_1$ denser $\rightarrow$ less denser)
- external reflection ($n_2 > n_1$ less denser $\rightarrow$ denser)
  - Due to reflection energy and phase loss occur.

<u>Phase shift:</u>

$\delta_p \rightarrow$ phase shift parallel to POI
$\delta_n \rightarrow$ phase shift normal to POI

$$\tan\frac{\delta_p}{2} = \frac{n\sqrt{n^2\cos^2\theta_1 - 1}}{\sin\theta_1}$$

$n = n_1/n_2$

$\theta_1 = \pi/2 - \theta_c$

$$\tan\frac{\delta_n}{2} = \frac{\sqrt{n^2\cos^2\theta_1 - 1}}{n\sin\theta_1}$$

- phase shift is totally dependent on incident angle.

Date: 9-Jan

Characterization of light source's

- wavelength of light (transmitting the information at particular wavelength)
- intensity the light
- spectral width of source (optical source will be able to transmit the how much range of wavelength

wavelength = 660 nm

400 nm / 700 nm ⟶ spectral width

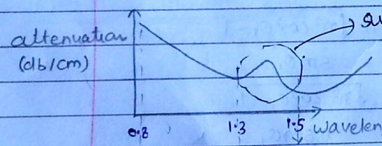
300 nm

Understanding the Behaviour of light :

- Ray model (Reflection, Refraction, TIR, Snell, POI, refractive index)
- Wave Model
- Quantum model

- 400 to 700 nm ⟶ Visible spectrum

Evolution of FOC :



Second gen^n (no. of repeater are less, repeater generates the information again after certain interval, bcoz of reflection, scatter information may loss so we req. Repeaters)

first gen^n 0.8 μm

1.3 μm freq. is ↓ ses

third generation (1.5 μm)

- By changing the signal wavelength or dimension and object dimension's are fixed, then reflection may differ or changeable. large amount of reflection occurs when wavelength of signal is less as compare to object dimension.

elements of an optical fiber transmission link :

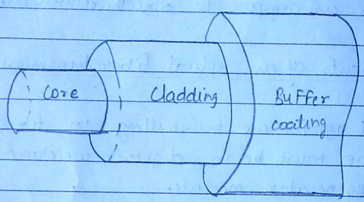
(From slide)

- all signals are transmitting in fiber transmission are must be in digital. we done this by using regenerator module.

Structure of optical fiber:

$n_{2\,cladding} < n_{1\,core}$

– working principal : TIR

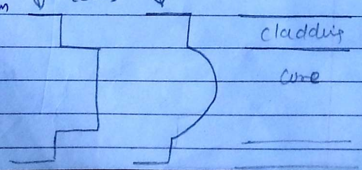


Why cladding is necessary ?
- To minimize the scattering loss occurred due to unequal surface of core and gives the mechanical strength also cladding is used.

Types of Fiber

Step index
- singlemode
  - core = 8 to 12 μm
  - cladding = 125 μm
  - BW = High
  - refraction index of core is constant
- multimode (LED)

graded index
- refraction index of core is not constant. So



0.026

- multimode fiber required more size of cladding

Ex8– Design consideration for step index fiber

$$\boxed{n_2 = n_1(1-\Delta)}$$

Δ = core cladding index diff^r = 0.01

multimode fibers : Δ = 1% to 3%

singlemode fibers : Δ = 0.2% to 1%

What does happen when Δ kept large ?

– for multimode we required core size is more to cladding bcoz in multimode more no. of waves will propagated.

$$\Delta = \frac{\text{change in refractive index}}{\text{refractive index of core}} = \frac{n_1 - n_2}{n_1}$$

(n_1) Core	(n_2) Cladding	Δ (in %)	Phase shift (N)	Parallel	Single mode	multi
Glass (1.5)	Air (1)	33.34%	1.992	4.46		
2.69	1.49	44.60%	1.23	3.894		
1.60	1.49	6.875%				
1.55	1.48					
1.4776	1.461					

$$\Delta = \frac{n_1 - n_2}{n_1}$$

48.18

56.36

$$\tan\frac{\delta_N}{2} = \frac{\sqrt{n^2\cos^2\theta_1 - 1}}{n\sin\theta_1}$$

$\theta_c = \sin^{-1}(n_2/n_1)$

$n = n_1/n_2$

$\theta_1 = \pi/2 - \theta_c$

- when θ_c is higher, than θ_1 (Phase shift is less)
- ~~when core - cladding distance is large reflection is less~~
- core - cladding difference is more, reflection is ~~more~~ ~~less~~ more and (critical angle is less → angle of incident is more)

$$\theta_c = \sin^{-1}(n_2/n_1) \qquad n_1 > n_2$$

when Δ is large,

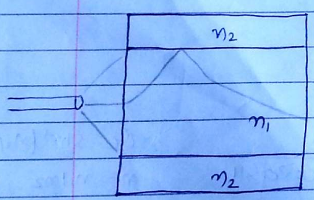
from slide:

Critical angle is less and reflection is more.

instrinsic absorption: absorption of photos inside fiber material

exterinsic absorption: caused by dissolved water in the glass as hydroxyl (OH ions)

launching light into fiber:

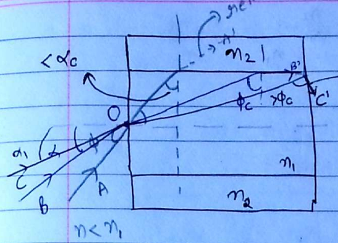


Ray A $\longrightarrow \phi$

Ray B $\longrightarrow \alpha > \phi$

Ray C $\longrightarrow \alpha_1 > \alpha$

Date: 16-jan



$n_1 \sin\phi_c = n_2$

$\sin\phi_c = n_2/n_1$

$\cos\phi_c = \sqrt{1 - \frac{n_2^2}{n_1^2}}$

- ray B represent the boundary
- ray A, refracted & ray C is reflected.

$\alpha \longrightarrow \alpha_{max}$.

$$\sin(\alpha_{max}) = f(n_1, n_2, n)$$

core, cladding, air (labels over n_1, n_2, n)

↑ max. acceptance angle

By applying Snell's law for ray B:

$$n \sin(\alpha_{max}) = n_1 \sin(90 - \phi_c)$$
$$= n_1 \cos\phi_c$$

$$n \sin(\alpha_{max}) = \frac{n_1 \sqrt{n_1^2 - n_2^2}}{n_1}$$

$$\boxed{n \sin(\alpha_{max}) = \sqrt{n_1^2 - n_2^2}}$$

$$NA = \sqrt{n_1^2 - n_2^2}$$

if light is ~~propagated~~ incident in the range of angle $2\alpha_{max}$, then ligh can propagated in fiber.

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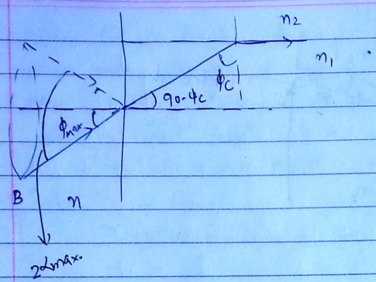

- if wave is not propagetad in fiber while incident angle is ≤ 2αmax
it is due to only phase shift.

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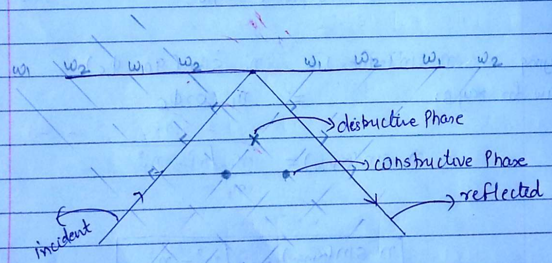

⇒ $NA = f(\Delta) = \sqrt{n_1^2 - n_2^2}$

$\because n_2 = n_1(1-\Delta)$

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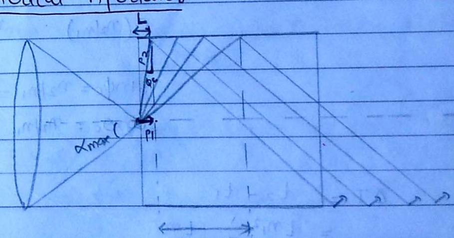
$$\frac{n_2}{n_1} = (1-\Delta)$$

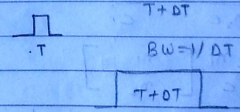
$$\therefore NA = \sqrt{n_1^2 - n_1^2(1-\Delta)^2}$$
$$= n_1\sqrt{1-(1+\Delta^2-2\Delta)}$$

$$\boxed{NA \approx n_1\sqrt{2\Delta}}$$

Significance of NA :- We can launched the light, at max. angle of acceptance.

Numerical Aperture:





if multiple rays is transmitted at 2αmax then multiple reflections is occur. pulse is spread due to reflection.

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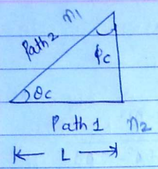


$$\cos\theta_c = \frac{L}{x}$$

Path 1: Time taken to travel Path 1

$$t_1 = \frac{L}{c/n_1} = \frac{Ln_1}{c}$$

Path 2: Time taken to travel Path 2

$$t_2 = \frac{L/\cos\theta_c}{c/n_1} = \frac{Ln_1}{c \cdot \cos\theta_c}$$

$$= \frac{Ln_1}{c \cdot (n_2/n_1)} = \frac{Ln_1^2}{n_2 c}$$

$\because \sin\phi_c = n_2/n_1 \Rightarrow \sin(90-\theta_c) = n_2/n_1$

$\cos\theta_c = n_2/n_1$

$$\Delta T = t_2 - t_1$$

$$= \frac{Ln_1^2}{n_2 c} - \frac{Ln_1}{c}$$

$$= \frac{Ln_1}{c}\left[\frac{n_1}{n_2} - 1\right]$$

$$\boxed{\Delta T = \frac{L}{c} n_1 \left(\frac{n_1 - n_2}{n_2}\right)}$$

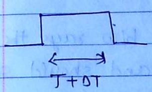
$$BW = \frac{1}{\Delta T}$$

– Single mode having the higher BW, as compare to

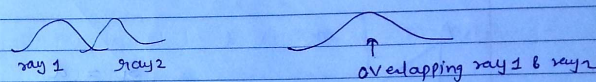
multimode. & Single mode $\longrightarrow$ NA is High

$\Delta T \rightarrow$ max. allowable spreading

$\Rightarrow$



$\longrightarrow$ if the spreading is more than this then overlapping b/w rays would occur.



– for max. spreading $\longrightarrow (n_1 - n_2)$ should be small.

$\Rightarrow$ Wave representation in a Dilectric slab waveguide:

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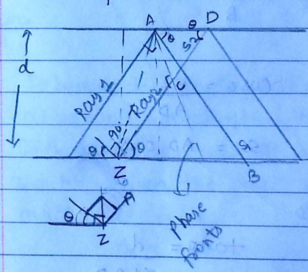
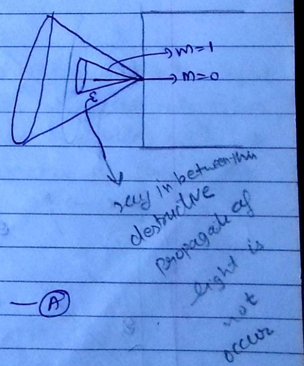


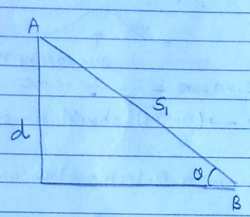


$$\frac{2\pi n_1}{\lambda}(S_1 S_2) + 2\delta = 2\pi m \quad — (A)$$

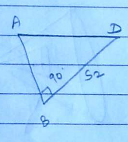
– as we know that if angle of incident between $2\alpha_{max}$. then ray must be propagated, but it is not always occur, due to destructive phase.

- The rays can collide constructive or destructive when sent at an angle < NA.

to get constructive collision b/w rays the angle should be multiple of 2π and should satisfy the condition given (eqn A)

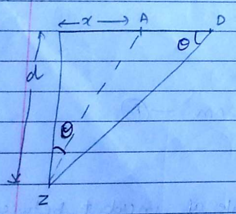


$$S_1 = \frac{d}{\sin\theta}$$



$$\cos\theta = \frac{S_2}{AD}$$

$$S_2 = AD\cos\theta$$



$$\tan\theta = \frac{d}{x + AD}$$

$$x + AD = d/\tan\theta$$

$$AD = \frac{d}{\tan\theta} - x$$

$$AD = \frac{d}{\tan\theta} - d\tan\theta$$

$$\frac{2\pi n_1}{\lambda}(S_1 - S_2) + 2\delta = 2\pi m$$

$$\frac{2\pi n_1}{\lambda}\left[\frac{d}{\sin\theta} - AD\cos\theta\right] + 2\delta = 2\pi m$$

$$\frac{2\pi n_1}{\lambda}\underbrace{\left[\frac{d}{\sin\theta} - \left\{\frac{d}{\tan\theta} - d\tan\theta\right\}\cos\theta\right]}_{2d\sin\theta} + 2\delta = 2\pi m$$

$$\boxed{\frac{2\pi n_1}{\lambda} d\sin\theta + \delta = \pi m} \quad m = 0, 1, 2, \ldots$$

its only valid for electric field, δ_N

this equation would satisfy when constructive collision is occur. and wave is propagated in the fiber optic cable.

20-Jan

Ex: Determine the set of angle (θ) for which the light at 1550nm wavelength will be propagated into fiber with refractive index of core and cladding with 1.5 and 1.4. Given the core diameter of 100 μm for multimode fiber?

Sol:

$$n_1 = 1.5$$

$$n_2 = 1.4$$

$$n = n_1/n_2 = 1.5/1.4 = 1.07$$

$$\theta_c = \sin^{-1}(n_2/n_1) = 68.96$$

$$\theta_1 = \pi/2 - \theta_c = 21.03$$

normal to the plane of incident

$$\tan\frac{\delta_N}{2} = \frac{\sqrt{n^2\cos^2\theta_1 - 1}}{n\sin\theta_1} =$$

rays is reflected back, so we have taken the same phase shift δ_N, at θ angle.

$$\delta_N = 2\tan^{-1}\left(\frac{\sqrt{n^2\cos^2\theta - 1}}{n\sin\theta}\right)$$

$$\Rightarrow \frac{2\pi n_1}{\lambda} d\sin\theta + \delta = \pi m$$

$$m = 0$$

$$\frac{2\pi n_1}{\lambda} d\sin\theta + 2\tan^{-1}\left(\frac{\sqrt{n^2\cos^2\theta - 1}}{n\sin\theta}\right) = 0$$

$$\frac{2\pi(1.5)}{1550\times10^{-9}} \times 100\times10^{-6} \sin\theta + 2\tan^{-1}\left(\frac{\sqrt{n^2\cos^2\theta - 1}}{n\sin\theta}\right) = 0$$

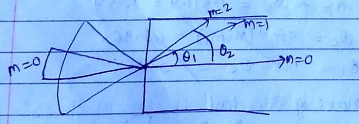
$$\frac{608.05}{2}\sin\theta = -\tan^{-1}\left(\frac{\sqrt{n^2\cos^2\theta - 1}}{n\sin\theta}\right)$$

$$\tan(304.02\sin\theta) = -\frac{\sqrt{n^2\cos^2\theta - 1}}{n\sin\theta}$$

$$n\sin\theta\tan(304.02\sin\theta) = -\sqrt{n^2\cos^2\theta - 1}$$

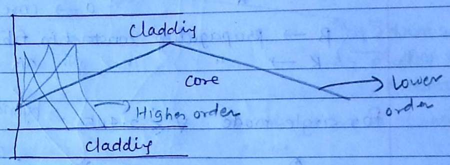
$$n^2\sin^2\theta\tan^2(304.02\sin\theta) = n^2\cos^2\theta - 1$$

$$\theta \cong 15^\circ$$

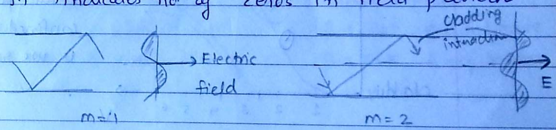


- $m = 0 \rightarrow$ single mode

- Higher order & lower order

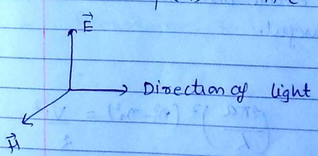


M → indicates no. of zeros in field pattern



Wave Model:

$$\psi(x,t) = A e^{j(\omega t - \beta x)}$$



V number (normalised frequency):

- How many no. of mode a fiber can supports.

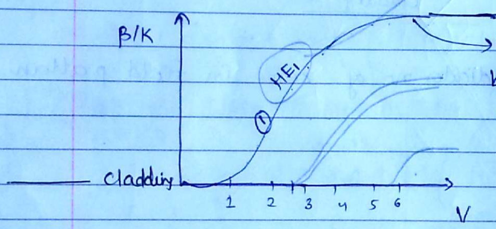
$$V = \frac{2\pi a}{\lambda}(n_1^2 - n_2^2)^{1/2} \rightarrow NA$$

$a \rightarrow$ core ~~diameter~~ radius

How much $\vec{E}$ power link with the cladding — $\beta \rightarrow$ propagation constant in fiber

$K \rightarrow$ " " " air

For single mode $V \leq 2.405 \rightarrow$ hybrid ~~transistion mode~~



→ its more preferable because power is more confined in core, which is ~~more~~ required.

- Less amount no. of eletric field we required link with cladding.
- Higher amount of electric field link with core → its requirement is useful.

no. of modes (M):

$$M \approx \frac{1}{2}\left(\frac{2\pi a}{\lambda}\right)^2 (n_1^2 - n_2^2) = \frac{V_1^2}{2}$$

power coupled in cladding (Pclad):

$$\frac{P_{clad}}{P} = \frac{4}{3\sqrt{M}}$$ $P \rightarrow$ total optical power

for a particular mode $\boxed{P_{clad} \propto \frac{P}{\sqrt{V}}}$ (from ①)

- Higher mode power confined in cladding is more which is normally not preferable.

Modes in fiber:

Radiation modes	leaky modes
- modes which are not trapped in core	- power leaks into cladding due to tunneling effect.
- radiation trapped in cladding	- condition for leaky/guided mode
- modes in cladding	$\beta > n_2 K$ guided mode
- power launched ouside α_{max} refracted outfrom core	$\beta < n_2 K$ leaky mode

cut off wavelength:

- minimum wavelength for single mode fiber
- Rearranging the eqn of V no. we can get

$$\boxed{\lambda_c = \frac{2\pi a n_1}{V_c}(2\Delta)^{1/2}}$$

Example $n_1 =$ $a = 25\mu m \times 2 = 50\mu m$

$n_2 =$ $V_c = 26.6$

$\lambda = 1300 nm$ $NA = ?$

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$$NA = \frac{V\lambda}{2\pi a}$$

$$= \frac{26.6 \times 1300 \times 10^{-9}}{2 \times 3.14 \times 25 \times 10^{-6} \times 2}$$

$$= \frac{0.220}{2} \quad \text{Ans.}$$

$$= 0.110 \quad \text{Ans}$$

$$NA = \frac{V\lambda}{2\pi \times a}$$

$$= \frac{26.6 \times 1300 \times 10^{-9}}{2 \times 3.14 \times 25 \times 10^{-6} \times L}$$

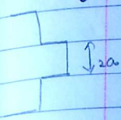
$$\simeq 0.11$$

Example: find cut off wavelength, $n_1 = 1.46$

Date: 23-jan

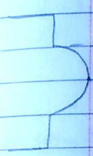
Step index & graded index fiber structure:

- Step index
  - refractive index of core is constant.



  - $n_2 = n_1(1-\Delta)$

- Graded index
  - refractive index of core is not constant.



$r=a$

$r=0$

$$n(r) = \begin{cases} n_1\left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2}, & 0 \le r \le a \\ n_1(1-2\Delta)^{1/2}, & r \ge a \end{cases}$$

where $\Delta = \frac{n_1 - n_2}{n_1}$

- multimode fibers are designed with the graded index fiber structure because in graded index dispersion is less compared to single mode.

Manufacturing of fiber optic cable:

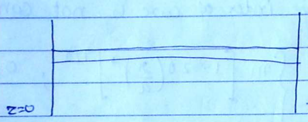
(Self study)

Signal degradation in optical fiber:

1

Attenuation & degradation:

power loss across a fiber



$P(0)$ mW $\qquad P(0)e^{-\alpha_p z}$ mW

$\alpha_p \rightarrow$ attenuation cofficient in km^{-1}

(dB/km) $\boxed{\alpha_p = \frac{10}{z}\log\left[\frac{P(0)}{P(z)}\right]} = 4.343\ \alpha_p\ (km^{-1})$ → in dB

* $dBm = 10\log\left(\frac{P}{1\,mW}\right)$

if $P = 10\,mW$
in dBm $= 10$
in dB $= -20 \quad (-20+30)$

for ex: emitter power $= -4$ dBm
Rx sensitity $= -27$ dBm

0 dBm
-4 dBm
$\updownarrow$ 23 dBm
-29 dBm

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19 dBm

Case I: Tx $\quad 7.3 \quad 4.8 \quad 6.9 \quad$ Rx = ✓
$-4 - 19\,dBm = -23\,dBm$

Case II: Tx $\quad 8.5 + 7.2 + 8.6 \quad$ Rx = ✗
24.3 dBm $\qquad -4 - 24.3 = -28.3$ dBm

in Case I, at Rx side power is detected.
in Case II, at Rx side signal is not detected because power > -27 dB

in dBm:

- $P(z)\,[dBm] = P(0)\,[dBm] - \alpha\,(dB/km)\,z\,(km)$
$\downarrow$
power at a distance

Ex:- Consider a 30 km long optical fiber that has an attenuation of 0.8 dB/km. find the optical o/p power Pout (in absolute and dBm) if 200 μW of optical power launched into the fiber.

Sol: $P_{(0)} = 200\ \mu W$
dBm $\longrightarrow -6.98$ dBm
dB $\longrightarrow -36.98$ dB
$\alpha = 0.8$ dB/km
$z = 30$ km
$P(z) = -6.98 - 0.8 \times 30 = -30.98$ dBm — (1)

$\alpha = \frac{10}{z}\log\left(\frac{P(0)}{P(z)}\right) \Rightarrow P(z) = 0.796\ \mu W$
$= -30.99$ dBm (2)

Ex: It is observed that for establishing a particular fiber link of 2 Km, the optical signal power would decreases by 75% of launched optical fiber. Determine the attenuation coefficient for given data. Comment how can we establish the fiber link of 20Km by maintaining the same i/p & o/p power relationship as mentioned.

Sol: $z = 2Km$ $\frac{P(0)_{in}}{P(z)_{out}} = \frac{100}{100-75}$

$\alpha = \frac{10}{2} \log\left(\frac{P(0)}{P(z)}\right)$

$= \frac{10}{2} \log\left(\frac{100}{25}\right) = \frac{6}{z}$

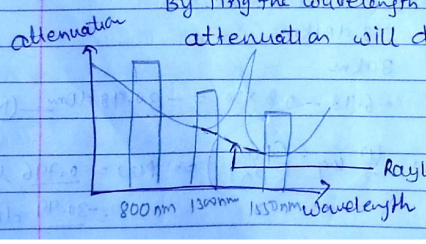
$= 3.01$ (dB/Km)

for, when $z = 20$ km, then $\alpha = \cdot 301$ dB/Km

from the graph of wavelength v/s attenuation

at wavelength = 800nm $\longrightarrow$ $\alpha = 3.0$ dB/Km

By Ting the wavelength = 1550nm $\rightarrow \alpha = 0.3$ dB/Km
attenuation will decreases



* 1st window : 850nm, attenuation 2 dB/Km
2nd window ; 1300 nm ; attenuation 0.5 dB/Km
3rd window ; 1550 nm ; attenuation 0.3 dB/Km

Example :

When the optical Power launched into an 8 Km length of fiber is 120 mw. the optical Power at the o/p is 3 mw. Determine:

i) overall signal attenuation in decibles through the ~~po~~ fiber assuming there are no connectors.

(ii) $\alpha = \frac{10}{2} \log\left[\frac{P(0)}{P(z)}\right]$

$= \frac{10}{8} \log\left[\frac{120}{3}\right]$

$= 2$ dB/Km

Overall attenuation per km.

(iii) attenuation = ~~20.68 dB~~
(10 log 120) in dB − (10 log 3) in dB
= 16.02 dB

(iii) the overall signal attenuation for a 10Km optical link using the same fiber with splices at 1 Km Intervals, each giving an attenuation of 1 dB.

2dB/Km means. for 1 Km $\longrightarrow$ 2 dB attenuation
10 Km $\longrightarrow$ 20 dB attenuation

bcoz of splicers ~~added~~ 9dB attenuation is there which we have to added

overall attenuation for link = 20 + 9 = 29 dB

with the total 9 splicers (fiber conn) along the link each with an attenuation of 1 dB.

splicers

iv) the O/P & I/P Power ratio in (c).

$$\alpha)_{dB} = 10 \log \left[\frac{P(0)}{P(z)}\right]$$

$$10^{\alpha/10} = P_{in}/P_{out}$$

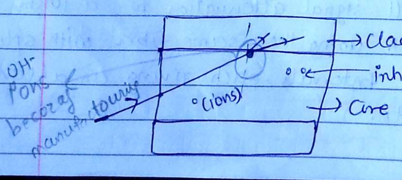
$$P_{out}/P_{in} = 1.25 \times 10^{-3}$$

attenuation depends on : λ wavelength, surface discont, absorption

2 **Scattering loss :**

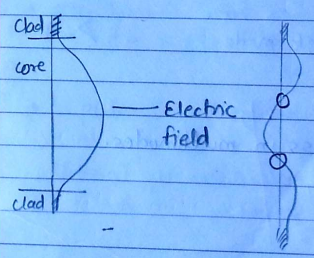
rayleigh scattering $R.S. \propto \frac{1}{\lambda^4}$

radiation in cladding bcoz of scattering is Known as R.S.



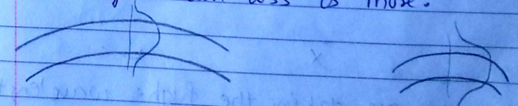
Bending :

Macro	Micro
radius of core < radius of bend curveture (bending radius)	radius of core > bending radius
power coupling to Higher order modes that are more lossy.	power coupling to lower order modes that are more lossy.

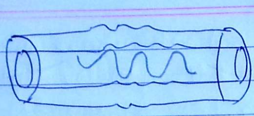


- in this when bending radius is less, then power radiated to Cladding is more, power loss is more in single mode ~~as compare to Macro~~. in macro

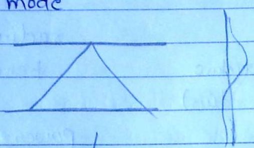
- In macro bending by reducing the bending radius, power associated with clad is more so information loss is more.

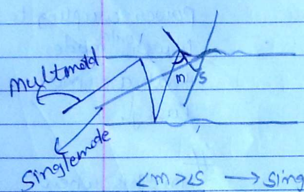


Micro bending:



in lower mode





does not get critical angle which we required → so losses is occur.

$\angle m > \angle s$ → single mode
↑
multimode

$\angle s \not> \angle \theta_c$ → condition of TIR is not meet

So losses is less in multimodes.

⇒	Attenuation Scattering (80% loss)	Bending loss (20% loss)
$\lambda \uparrow$	✓	X
$\lambda \downarrow$	X	✓

we are taking the higher wavelength to reduce the losses in fiber.

$\frac{P_{clad}}{P} \propto \frac{\lambda}{R}$ → bending loss

and λ is $\uparrow$ses, Power associated with clad is more. So power loss is more.

Dispersion:

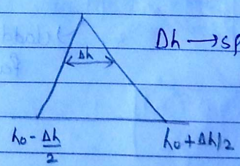
— intramodal dispersion (chromatic Dispersion)
 • single mode fiber
— intermodal dispersion (Modal Dispersion)
 • multimode fiber

$$\Delta T = \frac{L}{c} n_1 \frac{(n_1 - n_2)}{n_2}$$

• pulse is spreaded in dispersion

$v \propto \frac{1}{\lambda}$ (wavelength & velocity are inversly proportional)

chromatic Dispersion In single mode: as the source like LED not only transmit the single wave length it will transmit multiple wavelengths of signals so spreading will occurs.



$\Delta\lambda$ → spectral line width of source bcoz of this we get group velocity dispersion at the Rx or spreading at Rx side

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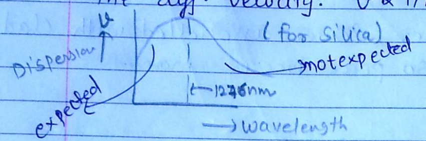
- groupdelay is occur due to all diff^r wavelengths having the diff^r velocity. $\vartheta \propto 1/\lambda$



In a particular material as silica, till wavelength = 1276nm, as ↑ses the λ then ϑ ↑ses as ϑ↑ses frequency is ↓ses * lower freq. travel faster through Dispersive medium.

Core-Cladding loss:

attenuation coefficient

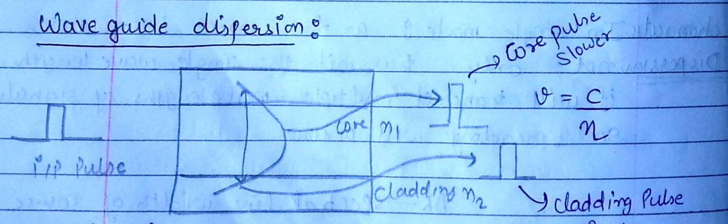
$\alpha_{clad} = \frac{P_{clad}}{P} \longrightarrow 20\%$

$+$

$\alpha_{core} = \frac{P_{core}}{P} \longrightarrow 80\%$

$\alpha_{av} \longrightarrow$ total attenuation coff. in fiber.

Wave guide dispersion:

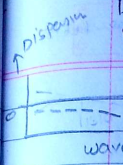


$\vartheta = \frac{C}{n}$

in single mode fiber we seen the wave guide dispersion.

$\boxed{\begin{matrix} n_1 > n_2 \\ \vartheta_1 < \vartheta_2 \end{matrix}}$

Due to pulse travelling in core & cladding are diff^r so pulse spreading will occur → Due to that ~~dispersion~~ wave guide Dispersion is there.

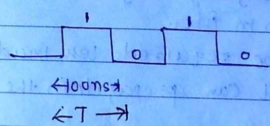


wavelength dispersion depends on the mode field distribution in the core & Cladding.

pulse spreading limitation towards bit rate:

In multimode, intersymbol of information signal will occur. Due to that information may loss. In this now we are seen that how much wavelength or spreading will allowed into fiber so that loss not occurs. or signal detect easily.

$$\Delta T = \frac{L}{c} \cdot \frac{n_1(n_1-n_2)}{n_2}$$



10 MbPs = 1/100ns

$$\Delta T < T$$

$$\Delta T < \frac{1}{\text{bit rate } B}$$

$\boxed{B \cdot \Delta T < 1}$ → for not getting the intersymbol interference

$$\text{Bit rate } (B) = BW \log_2(1+SNR) \approx BW$$

$$B \cdot \Delta T = BW \cdot \frac{L}{c} \frac{n_1(n_1-n_2)}{n_2} < 1$$

Unit of channel cap. is bit/sec & Bit rate is also bit/s

$$\boxed{BW \cdot L < \frac{c\, n_2}{n_1(n_1 - n_2)}} \longrightarrow (A)$$

Bandwidth distance product is defined in eqn (A)

- → 100 MHz for 100 m
  → 10 MHz · Km
  → 10 Mbps & length is 1 Km
  → 1 KHz for 10 m

} A single s/s can be expressed in any form given here.

if BW is ↑ses by 10 then Length will be ↓ses by 10.

- In single mode fiber, BW is high because $n_1 - n_2$ change in refractive index is very less. bcoz NA is the range of angle, in which we can launched the ligth in fiber.
  for single mode, we required less incident angle ~~bco~~ By which light can propagate in the axis of core (10g)

Example: L = 1 Km
NA = 0.275
n_{core} = 1.487

Calculate how much will a light pulse spread after travelling along 1 km.

Sol:

$$(NA)^2 = n_1^2 - n_2^2$$

$$n_2^2 = (1.487)^2 - (0.275)^2$$

$$n_2 = 1.46$$

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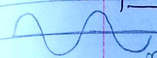
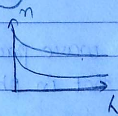
Important keywords:

① plane wave:



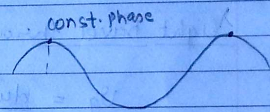
$$\psi(x,t) = A\, e^{j(kx - \omega t)}$$

K → propagation constant $= n(\lambda) \cdot \frac{2\pi}{\lambda}$ → β



$$\omega = 2\pi c/\lambda$$

② phase velocity:



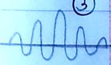
$$kx - \omega t = 0$$

$$v_p = \frac{dx}{dt} = \frac{\omega}{k}$$

↳ phase velocity

phase wave & phase velocity are associated

③ wave packets:



$$\psi(x,t) = \sum_{n=1}^{N} A_n\, e^{j(k_n x - \omega_n t)}$$

④ Group velocity:

$$v_g = \frac{d\omega}{dx}$$

- v_p & v_g

$v_p = c/n$ → single λ

$v_g = c/n_g$ → due to this dispersion will occur at Rx

diff. value of λ

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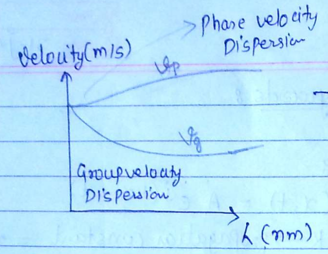

$\longrightarrow$ for fused Silica

any information signal is a wave packet, then its travels in group velocity, not in phase velocity.

light travel through dispersive medium:

$$v_g = \frac{d\omega}{dk}$$

$$k = n(\lambda) \cdot \frac{2\pi}{\lambda} \quad \& \quad \omega = \frac{2\pi c}{\lambda}$$

$$\frac{dk}{d\lambda} = \frac{-2\pi}{\lambda^2} n(\lambda) + \frac{2\pi}{\lambda}\frac{dn}{d\lambda} \qquad \frac{d\omega}{d\lambda} = \frac{-2\pi c}{\lambda^2}$$

$$\frac{d\omega}{dk} = \frac{c}{\frac{dn(\lambda)}{d\lambda} - \frac{n(\lambda)}{\lambda}} \cdot {}^{1}/_{\lambda}$$

$$\boxed{v_g = \frac{c}{n(\lambda) - \lambda \frac{dn(\lambda)}{d\lambda}}}$$

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

so; $v_g = c/n_g$

$v_p = c/n(\lambda)$

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for wave packet, refractive index is $\downarrow$ses due to group velocity.

GVD (Group velocity dispersion): (for single mode)

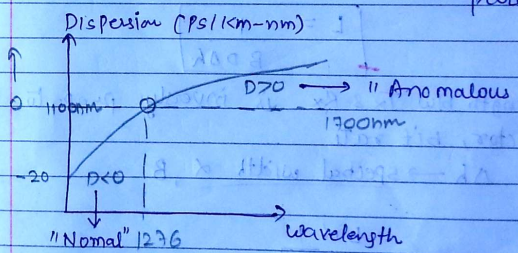
$$T = L/v_g$$

if $\Delta\lambda \longrightarrow$ spectral width of an optical fiber

pulse broading due to a differential time delay

$$\Delta T = L D \Delta\lambda$$

$$D = \frac{d}{d\lambda}(1/v_g) \longrightarrow \text{is dispersion parameter}$$

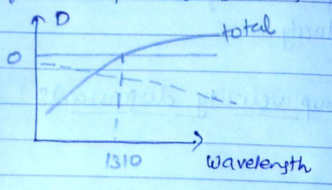


{ for silica $\longrightarrow$ at wavelength = 1276 $\longrightarrow D=0$

$D<0 \longrightarrow$ Pulse compressed

$D>0 \longrightarrow$ pulse broading

- Upper dispersion is material dispersion, bcoz dispesion is varies as wavelength is varies for wave guide dispersion: $D = 0$; $\lambda = 1310\ nm$ → total



total chromatic Dispersion = $\underbrace{D_{mat}}_{\text{material}} + \underbrace{D_{wg}}_{\text{wave}}$

$$\Delta T = L D \Delta\lambda$$

$$\frac{1}{(\text{Bit rate})B} = L D \Delta\lambda$$

$$\boxed{L = \frac{1}{B D \Delta\lambda}}$$

length b/w Tx & Rx is inversely prop. to Dispe[rsion] factor, bit rate

↳ $\Delta\lambda$ → spectral width $\propto B$

$$L \propto \frac{1}{B^2}$$

We can say that By ↑ing the bit rate By 4, the effect of chromatic disp. factor is decreases by 16.

$$\Delta T = \frac{L}{C}\frac{n_1(n_1-n_2)}{n_2} = \frac{9.16\times10^{-3}\times10^{3}}{10^{8}} = 91.6\ ns$$

for a link 10 MbPS ⇒ $T = 100\ ns$

$$\Delta T < T$$

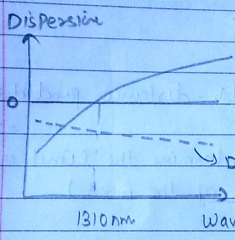
* for step index Bandwidth-distance product = 20 MHz·Km
  for graded " " " " = 2.5 GHz km
  (dispersive properties determine the limit of the information capacity of the fiber.)

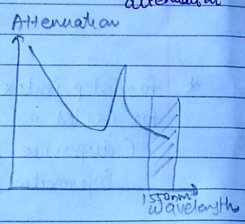
- measure of information capacity of an optical wave guide is usually specified by the BW-Distance product in MHz km.

What is our expectation:

as we know that $\lambda = 1310nm \rightarrow D = 0$ (Dispersion)

@ $\lambda = 1550nm \rightarrow \alpha = 0.3dB/km$ (attenuation)

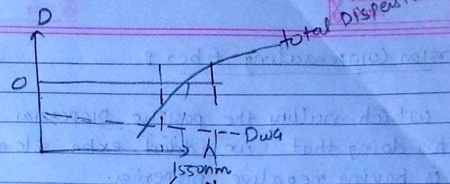




So we have to minimize the Dispersion & attenuation @ 1550nm, so we have to shift the graph of dispersion at 1550nm wavelength.

- material dispersion (refractive index & wavelength)
- waveguide dispersion (change is refractive index and radius of core)

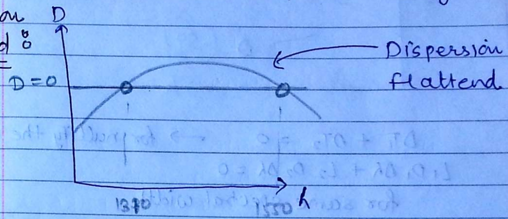
By changing the wave guide dispersion, we can shift the $D = 0$, @ $\lambda = 1550nm$.
and this will done by the change the ~~pattern~~ size of core ~~refractive index~~.



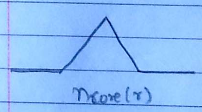
$\Delta\lambda \rightarrow$ "dispersion tailoriong"

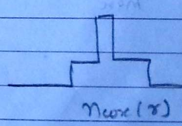
in this range of wavelength, Dispersion is (minimum) constant. For that Dispersion flatting is there.

Dispersion flattend :



for dispersion flattending, we changing the pattern of core refractive index.

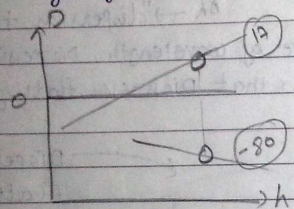




- Dispersion flattend in which n of core is changing this process in known as Dispersion Tailoring.

Dispersion compensating fiber:

which nullify the positive Dispersion effect. for doing that we added extra element, which is having negative Dispersion.



$\Delta T_1 + \Delta T_2 = 0$ → for nullify the dispersion

$L_1 D_1 \Delta\lambda + L_2 D_2 \Delta\lambda = 0$

for same spectral width

$L_1 D_1 = -L_2 D_2$

↑ Distance more | ↓ Distance less | ↳ more

polarization:

- Polarization varies along the fiber length.
- pulse broadening due to the orthogonal polarization modes

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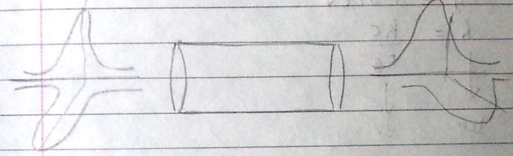
$$n = \frac{c}{v}$$

$$B = |n_x - n_y|$$

↓ refractive index in x-dir^c

B → ~~birefranges~~ birefringence index



With respect to central axis of fiber, var^n/dev^n in refractive index → causes velocity diff → causes polarization despersion.

η in x & y dir^c should small value as ≈ 10^{-6} to 10^{-5}

LED:

- photons → recombination of e⊖ & holes

$$E_g = h\nu = \frac{hc}{\lambda}$$

↳ $E_g = 1.421 + 1.266x + 0.266x^2$

($Ga_{1-x}Al_xAs$)

when $x = 0.07$

$E_g = 1.51\ eV$

$$\lambda = \frac{hc}{E_g}$$

λ ↓ μm, E_g ↓ eV

$$\lambda(\mu m) = \frac{1.240}{E_g(eV)} = 0.82\ \mu m$$

↳ transmitting wave length

- if we need low loss window then $\lambda = 1550\ nm$
  ↓
  E_g (will find)
  ↓
  $x \rightarrow (Ga_{1-x}Al_xAs)$

Desirable char^r of optical sources:

- response time min (when we apply electric field, then O/P will comes as soon as possible)
- quantum efficiency
- minimum spectral width

min. time for convert the electric field to optical

Radiative & non-radiative:

PN Diode ⟶ 1 junction

LED ⟶ multiple junctions (Hetrojunction)

↓

Active region ⟶ recombination of e⊖ & holes
↓
Photons

Recombination

Radiative	Non radiative
e⊖ & holes are recombine and photons will emitted. (Light)	e⊖ & holes are recombine but light don't emit but in the form of heat. (Heat)

$$\text{Quantum efficiency} = \frac{\text{radiation recomb.}}{\text{total recombination}}$$

↓

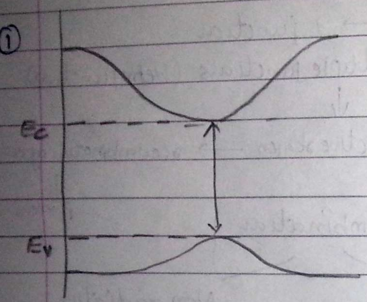
internal → light is within the material / not yet emitted.

external → $= \frac{\text{light emitted out}}{\text{total light generated}}$

- Diff^r b/w LED & Pn junction
  - Based on material
  - junctions

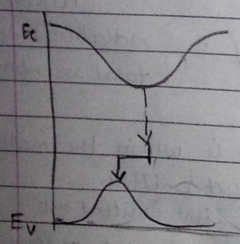
Direct Band gap & indirect Band gaps:

①



moment of $e^{\ominus}$ & holes are same, and lowest of conduction band, max. of valance
⟶ Direct Band gap
which is used in light source.

②



moment of $e^{\ominus}$ & holes are not same ⟶ indirect band gap.

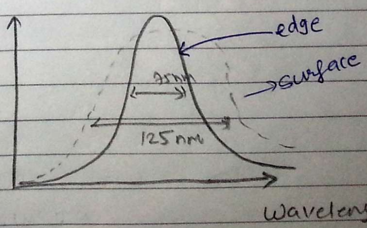
Charge confinement:
is dealing with the energy gap b/w charges. we arrange the energy gap b/w junctions in a such a way that the max. recombination occurs in Active region

optical confinement:
in the form of refractive index.
we kept the center at the highest refractive index due to that in that region max. recombination of $e^{\ominus}$ & holes will occur ⟶ due to that light (photons) emitted in that region is high.

- We realised that because we only realised the minimum spectral width, and concentrating light in a particular dir^c ⟶ so that we are using multiple junctions ⟶ and by which providing diff^r band gap & diff^r n, we get the max. light in Active Region.

LED spectral patterns:

- Surface emitting LED (125nm)
- Edge-emitting LED (75nm)



- spectral width is less in edge-emitting LED so we are using this.

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Internal Quantum efficiency :

fraction of e⊖ & holes recombine radiatively :

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}}$$

$R_r \rightarrow$ radiative recomb. $= \frac{n}{\tau_r}$ $n \rightarrow$ e⊖ density (cm^{-3})

$R_{nr} \rightarrow \frac{n}{\tau_{nr}}$

$$\eta_{int} = \frac{1}{1 + \tau_r / \tau_{nr}}$$

$\tau_{nr} \rightarrow$ non radiative recomb. life time

$\tau_r \rightarrow$ radiative recomb. life time

- in order to generate recomb. , we have supplied some reversed bias current.

$R \rightarrow$ rate at which total recomb. take place

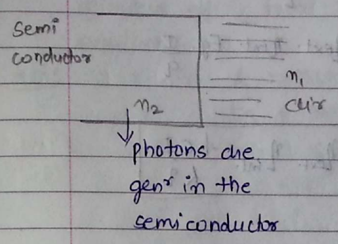
$$R_r + R_{nr} = \frac{I}{q} \qquad \begin{cases} I = q/t \\ I/q = 1/t = \text{rate} \end{cases}$$

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}} = R_r \cdot \frac{q}{I}$$

$$\boxed{R_r = \frac{I}{q} \eta_{int}}$$

if $\eta_{int} \rightarrow 0.6$ means 60% recombination is done which are radiative and 40% $\rightarrow$ non radiative

External quantum efficiency :



- all photons which are gen^r in the semiconductor material, are not completly emitted outside (or in the air). its based on the refractive index , which amount of photons are emitted.

$$\eta_{ext} = \frac{\text{no. of Photons Emitted}}{\text{no. of photons generated}}$$

let RI of semiconductor material $= n$

$$\boxed{\eta_{ext.} = \frac{1}{n(n+1)^2}}$$

then and then only when emitted in the air $n_1 = 1$.

power emitted by the LED $P_{optical} = \eta_{ext} \cdot P_{int}$

Scanned by CamScanner

$$P_{int} = \frac{E_g}{time}$$

Power confined with the semiconductor

$$= E_g \cdot R_r$$

$$= E_g \cdot \frac{I}{q} \cdot \eta_{int}$$

$$P_{optical} = \eta_{ext} \cdot \eta_{int} \cdot E_g \cdot \frac{I}{q}$$

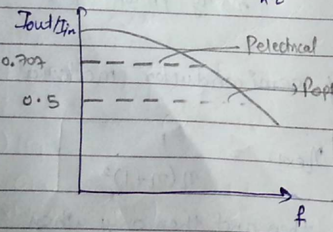
$$\boxed{P_{optical} = \eta_{ext} \cdot \eta_{int} \cdot \frac{hcI}{\lambda q}}$$

Power o/p in the air

Optical BW / Electrical BW :

Electric Power : $P_{elec} = I^2/R \longrightarrow P \propto I^2$

optical power : $P_{optical} = \eta_{ex} \cdot \eta_{int} \cdot \frac{hcI}{\lambda q} \rightarrow P \propto I$



when power is half

Electrical $\rightarrow I_{out}^2 / I_{in}^2 = 1/2 \Rightarrow I_{out}/I_{in} = 1/\sqrt{2}$

$I_{out}/I_{in} = 1/2 \longrightarrow$ optical

Date: 13-feb

Ex: A Double hetrojunction InGaAsP LED emit at peak wavelength 1310nm has radiance and non-radiance time of 30ns & 100ns. respectively. The drive current is 40mA & RI is 3.5. find int. quantum eff., total optical Power gen and power emitted?

Sol:

$\lambda = 1310nm$

$t_R = 30ns$

$t_{nr} = 100ns$

$I = 40mA$

$$\eta_{int} = \frac{1}{1 + t_R/t_{nr}} = \frac{1}{1 + 0.3/1.0} = \frac{1}{1.3} = 0.76$$

$$\eta_{ext} = \frac{1}{n(1+n)^2} = \frac{1}{3.5(1+3.5)^2} = 0.014$$

$$P_{int} = \eta_{int} \cdot \frac{hcI}{q\lambda}$$

$$= \frac{0.76 \times 1.24 \times 40 \times 10^{-3}}{1.6 \times 10^{-19} \times 1310 \times 10^{-6}}$$

$$= \frac{0.76 \times 6.67 \times 10^{-34} \times 3 \times 10^8 \times 40 \times 10^{-3}}{1.6 \times 10^{-19} \times 1310 \times 10^{-9}}$$

$= 9.29 \times 10^{-1}$

$= 292$ mW

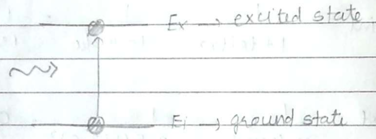
$P_{ext} = P_{int} \cdot \eta_{ext}$

$= 4.088$ mW

LASER: light amplification through stimulated emission of radiation

- spectral line width
  - BW
- response time < 1ns
- operating principal – Stimulated emission
  – spontaneous emission } → Plank's law
  – Absorption emmision

Absorption



By absorption of energy e⊖ travel from E_i to E_x → Absorption

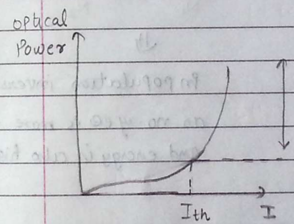
	Before	After
Absorption (By absorbing the light e⊖ travel E_i to E_x)	E_x, $h\nu$, E_i	E_x, E_i
Spontaneous (Random Place) (By emitted the light e⊖ E_x to E_i) (without external stimulation)	E_x, E_i	E_x, $h\nu$, E_i
Stimulated (By an external stimulator)	E_x, $h\nu$, E_i	E_x, $h\nu$, $h\nu$ (in phase), E_i

Condition for stimulated emission:

Population of excited e⊖ > population of groundstate e⊖

To acheive this, popularity inversion is done when e⊖ at ground state are provided energy so that they move to E_2 ⇒ stimulated emission takes place.
(By injecting the e⊖ in mat. at the device contact to fill the lower energy states of the conduction band)

- necessary amount of e⁻ present at E_2 with sufficient amount of energy so that they are stable at E_2
- more amount of e⊖ in excited state ⇒ more no. of photons emitted. Population → e⊖ present at E_2



I_{th} depends on the material for stimulated emission fabrication of LASER.

↕ spontaneous emission } → Laser will work as LED in this region

$I < I_{th}$ → LED

$I > I_{th}$ → LASER

Types of Laser diode:

(I) febry parot cavity

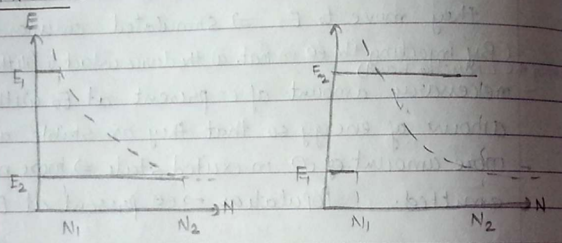
$\Delta\lambda = \sigma_\lambda = 2nm$
↳ spectral width

In stimulated emission:

- identical energy → identical wavelength → narrow line width

- identical direction → narrow beam width
- identical phase → coherence & identical polarization

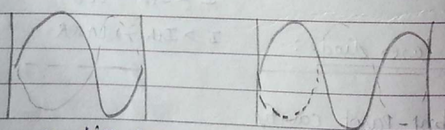
<u>population inversion:</u>



⇓

In population inversion as no. of e^- is more and energy is also high

<u>Laser Diode</u>



standing wave

Resonator wave length

non-resonator wave length

febry perot cavity resonator only passes the standing wave.

↳ Distributed feeback laser

Gratings → present so that we can have very less linewidth ⇒ only required wavelength is transmitted.

Bragg reflector

Chp-5

Date: 17-feb

power launching and coupling:

→ (depends on NA, size of core, η, change in η of core-clad, Radiance)

launching of power → source to fiber

coupling of power → (source to fiber / fiber to fiber)

* coupling efficiency = $\frac{\text{Power coupled into fiber}}{\text{power emitted from fiber}}$

↳ int. quantum efficiency → radiative recombination int. (source)

↳ ext. quantum efficiency → radiative emmision (source to medium)

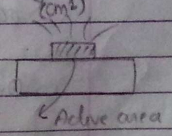
↳ coupling efficiency → source → med → fiber

* Radiance → brightness

$$\text{Radiance} = \frac{\text{Optical Power}}{\text{solid angle} \times \text{surface area emitted}} \quad (W/sr \cdot cm^2)$$

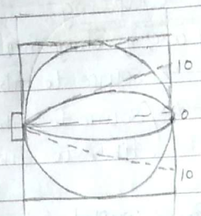
solid angle (sr), surface area (cm²)

optical power radiated into a unit solid angle per unit area emitting surface

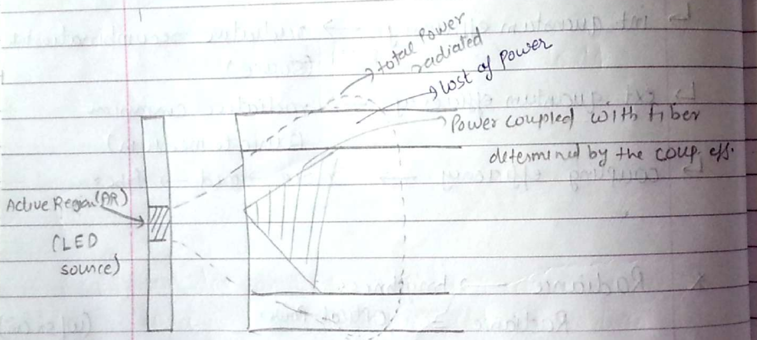


Surface emitting LED radiation pattern: (lambertian)

surface emitting LED are charcterized by their lambertian o/p pattern, which means the source is equally bright when viewed from any direction.



$B(\theta, \phi) = B_0 \cos\theta$ (LED)



$$\text{radiance} = \frac{\text{Optical Power}}{\text{solid angle} \times \text{area}}$$

$$\text{O.P.} = \text{Rad} \times \text{solid} \times \text{area}$$

$$= \text{Rad.} \times \Omega_F \times A_I$$

Ω_F → numerical apperature

A_I → core diameter of fiber

$$P_f = \int_{A_F} \left[\int_{\Omega_F} B(A_s, \Omega_s)\, d\Omega_s \right] dA_s$$

↓

Power coupled with fiber

$$= \int_0^{r_m} \int_0^{2\pi} \underbrace{\left[\int_0^{2\pi} \int_0^{\theta_{0,max}} B(\theta, \phi) \sin\theta\, d\theta\, d\phi \right] d\theta_s \cdot r\, dr}_{\text{Power coupled from point source}}$$

$$r_m = a \quad r_s > a$$
$$= r_s \quad r_s < a$$

↑ source emitted surface radius

$$= \frac{1}{2} \int_0^{r_s} \int_0^{2\pi} \left[\int_0^{2\pi} \int_0^{\theta_{max}} 2 B_0 \cos\theta \sin\theta\, d\theta\, d\phi \right] d\theta_s\, dr \cdot r$$

$$= \frac{B_0}{2} \int_0^{r_s} \int_0^{2\pi} \int_0^{2\pi} \left[-\frac{\cos 2\theta}{2} \right]_0^{\theta_{max}} d\phi\, d\theta_s\, r \cdot dr$$

$$= \frac{B_0}{2} \cdot \frac{2\pi}{2} \int_0^{r_s} \int_0^{2\pi} r\, dr\, d\theta_s\, (1 - \cos 2\theta_{max})$$

$$= \frac{B_0}{\cancel{2}} \cdot \frac{\cancel{2}\pi}{\cancel{2}} \cdot \frac{r_s^2}{2} \cdot 2\pi \cdot (1 - \cos 2\theta_{max})$$

$$= \frac{B_0}{2} \pi^2 r_s^2 (1 - \cos 2\theta_{max}) = \frac{B_0 \pi^2 r_s^2}{2} \cdot 2\sin^2\theta_{max}$$

Date: 20-feb.

$$\boxed{P_F = \pi^2 B_0 r_s^2 (NA)^2} \quad r_s \leq a$$

$$P_F = \pi^2 a^2 (NA)^2 B_0 \quad ; \; r_s > a$$

power emitted from source (P_s):

$$P_s = \text{radiance} \times \text{solid angle} \times \text{Area}$$

$$= \left[\int_0^{2\pi} \int_0^{\pi/2} B_0 \cos\theta \sin\theta \, d\theta \, d\phi \right] A_s$$

$$P_s = \pi^2 r_s^2 B_0$$

Ex: Consider an LED that has circular emitting area with radius 35 μm and lembardian pattern 150 W/cm² sr at ~~given~~ driven ~~calculate~~ current. compare OP coupled into a step index fiber. One has co-radius of 25 μm & other has co-radius of 50 μm. NA = 0.2 ;

Sol:

i)

$$r_s = 35 > a = 25 \, \mu m$$

$$P_F = \pi^2 B_0 r_s^2 (NA)^2$$

$$= \pi^2 \frac{(150)}{10^{-4}} \times (35)^2 \times (0.2)^2 \times 10^{-12}$$

$$= 36.27 \times 10^{-5}$$

ii)

$$r_s = 35 < a = 50$$

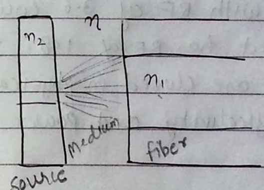
$$P_F = \pi^2 a^2 (NA)^2 B_0$$

$$= \pi^2 (150)(50)^2 (0.2)^2$$

$$= 74.02 \times 10^{-5}$$

Reflectivity:

⇒



$$R = \left(\frac{n_1 - n}{n_1 + n}\right)^2 = \text{freshnel reflection (Reflectivity)}$$

$$r = \left(\frac{n_1 - n}{n_1 + n}\right) = \text{reflection cofficient}$$

rate at which power coupled into fiber reduces w.r.t. emitted power from source

$$R = f(P_s, P_t)$$

$$\boxed{R = \frac{P_s - P_F}{P_s}}$$

— When there is no space b/w fiber & source then

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Date: 21-feb

Coupling effi $\longrightarrow$ how much power is transmit in fiber

Reflectivity $\rightarrow$ its provide the cause of power loss in fiber

Ex:- GaAs optical source with RF of 3.6 coupled with silica fiber that has RF of 1.48. If the fiber and the source are closed in physical contact. Calculate Reflectivity and power loss ratio

Sol:
$$n_2 = 3.6$$
$$n_1 = 1.48$$
$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 = \text{reflectivity}$$
$$= 0.174$$

~~NA = 3.28~~

$$P_F = \pi^2 B_0 r_s^2 (NA)^2$$
$$= P_s (NA)^2$$
$$\cancel{\frac{P_F}{P_s} = (3.28)^2 = 10.76} \qquad R = \frac{P_s - P_F}{P_s}$$
$$\cancel{10 \log\left(\frac{P_F}{P_s}\right) = 10.32 \text{ dB}}$$

NA is not given ; for fiber
$$P_F = (1-R) P_s$$
$$10 \log \frac{P_F}{P_s} = -0.80 \text{ dB}$$

* Power loss L in decibles (from book)
$$L = -10 \log\left(\frac{P_F}{P_s}\right)$$

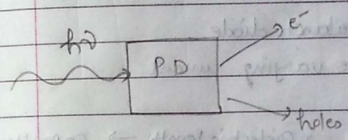
Chp-6

Photodetector :

To receive the optical signal at Rx side

principal :

- optical to electric signal converted by the photo-detector.
- Optical (power) $\longrightarrow$ Electrical (time varying current)



- photons striking on the photo-detector and produces the $e^\ominus$ & holes pairs.
- quantum efficiency of PD = $\dfrac{\text{No. of } e^\ominus \text{ \& holes pair}}{\text{No. of incident photons}}$

in Pin diode $\longrightarrow$ 30 - 45% quantum efficiency which means that 100 photons strikes on the PD and effectivity photons 30 to 45 are makes the hole-e^- pair.

- We required Quantum efficiency as High as possible for that some factors are there:
  - E_g (energy band gap)
    $h\nu \geq E_g$ (for changing the QE)
  - Dimension of material (thickness of region)
  - λ (wavelength)

By changing the E_g & h, Quant. eff. may be varies as per the requirement.

Types of Photodiodes:

① Semiconductor

Pin photodetector Avalanch diode

- they gives the time varying current.

② polyelectric

photons → heat → Dielectric length → Capacitor

- they gives the time varying capacitors.

③ Photo multipliers

their large size and High volt. req. make them unsuitable for optical fiber s/s.

PIN Diode:

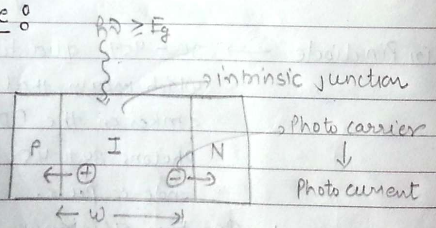
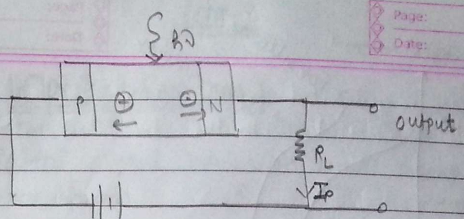
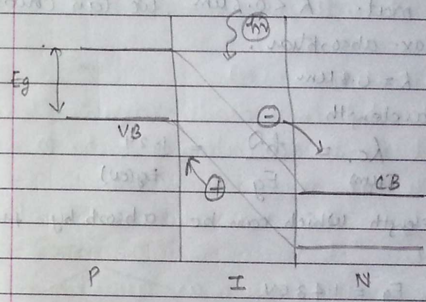


Photo carrier → are free charges (as e⁻ & holes) which are due to photons.



- it gives the time varying current



power in intrinsic mat.

$$\boxed{P(x) = P_0 \left(1 - e^{-\alpha_s(\lambda) x}\right)}$$

$x \rightarrow$ depth of intrinsic material

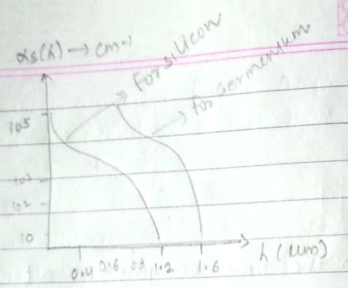
depth is as high as possible so that our intrinsic material can absorb the max. optical power

if $x \rightarrow \infty$; $P(x) = P_0$ which is not practically fisible.

$P_0 \rightarrow h\nu$ power, which we strike on the mat.

$\alpha_s(\lambda) \rightarrow$ ~~attenuation~~ absorbtion cofficient

- we required the largest value of $\alpha_s(\lambda)$, so for that



- for silicon mat. $\lambda < 0.6\,\mu m$, we can choose for the max. absorbtion.
- for Ge $\to \lambda = 0.8\,\mu m$
- cut off wavelength

$$\underset{(\mu m)}{\lambda_c} = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)}$$

max wavelength which can be absorb by the mat.

for ex: if $E_g = 1.43\,eV$
then $\lambda_c \cong 800\,nm$

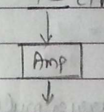
chp-7

Date: 10-March

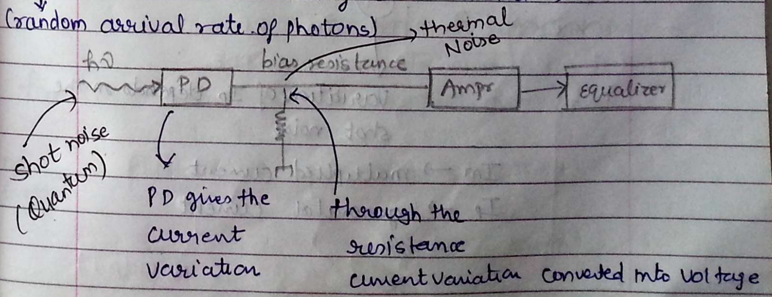
Optical Receivers

- Digital signal emission and reception
- Error sources
- prob. of error
- Quantum limit

① PD (Photo detector)



② Error
- int.
  - Short noise → (random arrival rate of photons)
  - thermal noise → (random motion of e⊖ in conductor)
- Ext



- noise is generated by the amp^r
thermal noise associated with the biased resistance

Shot noise :

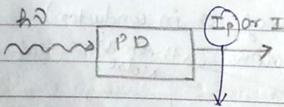
→ random arrival rate of photons
- random arrival rate of photons at the PD side, due to that random variation of photo current will occurs

→ Carrier multiplication (M)

In avalanched photo diode, carrier multiplication factor is M, is not const. Variation of factor M will there due to that noise will occurs.

- discontinuity in the variation in current is shot noise.
- Shot noise is also known as quantum noise.

Mathematical representation of shot noise :



Variation of I_p depends on the shot noise

$I_m \rightarrow$ multiplied current
$I_p \rightarrow$ generated current

avg. e^- - h pairs ($\bar{N}$) generated in given time τ for optical power $p(t)$

$$\bar{N} = \frac{\eta}{h\nu} \int_0^{\tau} p(t)\, dt$$

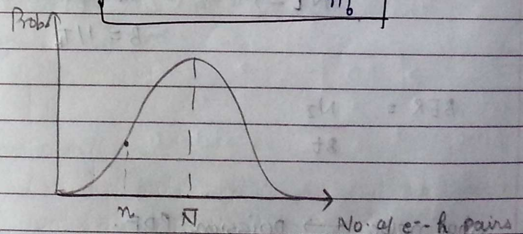
prob. of occuring K event

$$\boxed{P(K) = \frac{h^K e^{-h}}{K!}}$$

mean

actual n e^- - h pairs gen^r
prob. of that is

$$\boxed{P(n) = \frac{\bar{N}^n e^{-\bar{N}}}{n!}}$$

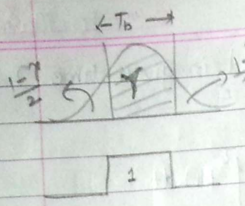


for RAPD (reach-through avalanched photo diode)

noise factor : $F(M) \approx M^x$ $\quad x \rightarrow 0 \le x \le 1$

depends on material

Page:
Date:



Receiver performance :

- prob of error (BER) $= 10^{-9} = \frac{1}{10^9}$

for optical fiber for transmitted the 10^9 bits only 1 bit error will there.

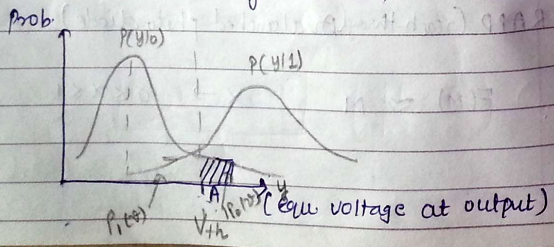
- $BER = \frac{N_I}{N_t}$ $N_I \rightarrow$ no of bits having error in time t; $N_t \rightarrow$ " " " transmitted in time t

$B = 1/T_b$

$BER = \frac{N_I}{Bt}$

- shot noise $\longrightarrow$ poission PDF.

thermal noise $\rightarrow$ gaussian PDF



Page:
Date: 14-march

A: $P_0(V_{th}) = \int_{V_{th}}^{\infty} P(y/0)\, dy$ — (A) $\longrightarrow$ error, when we transmit 0 , $Rx \rightarrow y$

$P_1(V_{th}) = \int_{-\infty}^{V_{th}} P(y|1)\, dy$ — (B) $\rightarrow$ error, when we transmit 1 & $Rx \rightarrow y$

$\hookrightarrow$ error prob. when $V_{th} \ngtr V$, while sending logic 1

$$\boxed{P_e = a P_1(V_{th}) + b P_0(V_{th})}$$

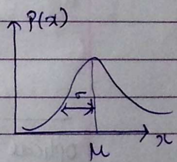
$a = b = 0.5$

Unbiased

14-March

$\ast$ $f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/2\sigma^2}$

gaussian



$\hookrightarrow$ for eqn (A)

$\left.\begin{aligned} \sigma_{OFF}^2 &= Var \\ b_{OFF} &= mean \end{aligned}\right\}$ – transmit logic = 0

for eqn (B)

σ^2_{ON} = Variance

b_{ON} = mean

so ; $P_0(V_{th}) = \int_{V_{th}}^{\infty} \frac{1}{\sqrt{2\pi\sigma_{OFF}^2}} e^{-(x-b_{OFF})^2/2\sigma_{OFF}^2}\, dV$

$$P_1(V_{th}) = \int_{-\infty}^{V_{th}} \frac{1}{\sqrt{2\pi\sigma_{ON}^2}}\, e^{-(x-b_{ON})^2/2\sigma_{ON}^2}\, dv$$

$$BER = \boxed{P_e(Q) = \frac{1}{\sqrt{2\pi}}\,\frac{e^{-Q^2/2}}{Q}}$$

where $Q = \frac{V_{th}-b_{OFF}}{\underbrace{\sigma_{OFF}}_{\text{std. dev}}} = \frac{b_{ON}-V_{th}}{\underbrace{\sigma_{ON}}_{\text{std. dev}}}$

Quantum limit :

- in Ideal condition

  $\eta = 1$

  that means, no dark current (means, current value when there is no incident photons, refered as dark current)

Optical pulse is not there $\longrightarrow$ $\boxed{PD}$ $\longrightarrow$ $I_D = 0$, e^{-}-holes $= 0$

- (avg. $\bar{N}$)

$$P_r(n) = \frac{\bar{N}^n e^{-\bar{N}}}{n!}$$

$$\boxed{P_r(0) = e^{-\bar{N}}} \qquad \left(\frac{\eta E}{h\nu} = \bar{N}\right)$$

$$\bar{N} = \frac{\eta P_0 \tau}{h\nu} = \frac{P_0 \tau}{h\nu}$$

$\tau \rightarrow$ time when photons strikes on Photo detector

Ex: if $BER = 10^{-9}$ & Op pulse is not present

(a) then find $\bar{N} = ?$

Sol:

$$P_r(0) = 10^{-9} = e^{-\bar{N}}$$

$$\bar{N} = 20.72 \simeq 21$$

(b) min. incident optical power, that must fall on Photo diode to acheive 10^{-9} BER. The given data rate is 10 MBPS, for simple binary level signalling

Sol: $\tau = \frac{2}{B}$, $B \rightarrow$ data rate $\qquad \lambda = 850\ nm$

$B = 2$ MbPs

$$\tau = \frac{2}{10M} = 0.2\ \mu s$$

as we know that $\bar{N} = \frac{P_0 \tau}{hc/\lambda}$

$$P_0 = \frac{\bar{N}\, hc}{\lambda \times \tau}$$

$$= \frac{21 \times 6.67\times10^{-34} \times 3\times10^{8}}{850\times10^{-9} \times 0.2\times10^{-6}}$$

$$= 2.4\times10^{-11}\ \text{Watt}$$

$$= 24.2\ pW$$

Date: 14-March

Chp-8

Digital links

- splicer → mountable joint (internally) (permanent)
- connector → dismountable joint (~~peramanent~~)(

- $P_S = -20\,dBm$
  $P_T = -10\,dBm$
  $P_R = -30\,dBm$
  $\boxed{P_T = P_S - P_R}$

P_T amount of loss, we can accept in fiber link and that losses due to various splicers, connector and due to fiber cable. And this known as "link Budget".

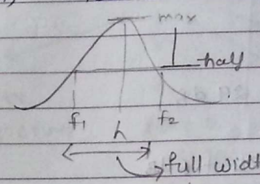
→ Source → Pin & LED
  → Laser

→ Detector → Pin diode
  → Avalanche

→ fiber cable

- Criteria for Selecting the fiber
  - BW
  - cost
  - single mode / multimode
  - step / graded

- Selecting the optical source
(FWHM) → full width half max



→ full width or spectral line width

- Selecting the detector.
Avalanche photodetector we may choose bcoz in this small amount of optical power can be detected and it ~~convete~~ can genⁿ the photo carriers

Optical power loss model:

l_{sp} → power loss occurs bcoz of splicer
α → attenuation coff.
L → loss occured by fiber
l_c → loss occured by connector
s/s margin → margin required for future expansion of fiber cable

$$\boxed{P_T = P_S - P_R} = m\,l_c + n\,l_{sp} + \alpha L + \text{s/s margin}$$

if splicer loss is included in cable loss, and no connector in b/w

$$\boxed{P_T = 2l_c + \alpha L + \text{system margin}}$$

Ex: if $P_R = -42\,dBm$; $P_S = -13\,dBm$

connector loss : 1 dB at both Rx & Tx

S/N margin : 6dB

find out αL

Sol:

$P_T = P_S - P_R = 29\ dB$

$= 2(1) + \alpha L + 6\ dB$

so, $\alpha L = 21\ dB$

↳ if $\alpha = 3.5\ dB/Km$, then 6 Km transmission path is possible.

↳ if $\alpha = 2\ dB/Km$, then $L = \frac{21}{2} = 10.5\ Km$

(By changing the wavelength, we can change the attenuation factor.)

17-March

Rise time Budget:

- Determine Dispersion (limitation of optical link)
- t_{sys}

  ↳ $< 0.7\ t_b$ (NRZ)

  $< 0.35\ t_b$ (RZ)

- rise time occurs at the Tx side.

t_{sys}

t_{tx} (rise time)

t_{GVD} (due to dispersion) due to group velocity

t_{RX}

t_{mod} (modal dispersion)

$$t_{sys} = [t_{tx}^2 + t_{GVD}^2 + t_{mod}^2 + t_{rx}^2]^{1/2}$$

↳ $t_{GVD} \approx L|D|\Delta\lambda$

$\Delta\lambda$ → spectral line width (nm)

L → Km

D → ns/nm.Km

↳ $t_{MOD} = \frac{440}{B_M}$ (ns)

B_M → BW for M, modes (MHz)

$$\boxed{t_{MOD} \cong \frac{0.44}{B_M}}$$

$B_M = \frac{B_0}{L^q}$

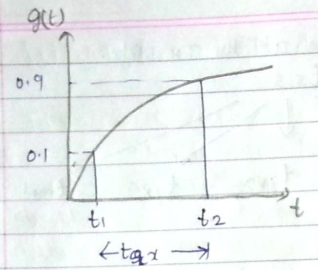
B_0 → BW for 1 Km

q → 0.5 to 1

L → length of fiber

q → amperical parameter (practical value = 0.7)

↳ t_{rx}



$$g(t) = (1 - e^{-2\pi B_{rx} \times t})\, U(t)$$

↓ 3dB ↳ $t \geq 0$

$g(t_1) = 1 - e^{-2\pi B_{rx} \times t_1}$

$0.1 = 1 - e^{-2\pi B_{rx} t_1}$

$e^{-2\pi B_{rx} t_1} = 0.9$ —(1)

$g(t_2) = 0.9$

$e^{-2\pi B_{rx} t_2} = 0.1$ —(2)

3dB ⟶ $t_{rx} = t_2 - t_1 = f(B_{rx})$

electrical BW

$$\boxed{t_{rx}^{(ns)} = \frac{350}{B_{rx}\,(MHz)}}$$

Example 8 Risetime Budget for multimode 6 Km fiber link with 20MbPs

t_{tx} → Tx Rise time 15ns

D – Dispersion of 0.08 ns/nm-km

$\Delta\lambda$ – Spectral line width of source 40nm

B_0 – B_{rx} = 400MHz Km

B_{rx} – Recieved BW = ~~400~~ 25MHz

$q = 0.7$, $t_{sys} = ?$

Sol: $t_{tx} = 15ns$

$t_{GVD} = L\, D\, \Delta\lambda$

$= 6\,km \times 0.08 \times 40nm = 21ns$

$t_{mod} = \frac{0.44}{B_m} = 3.9ns$

$B_m = \frac{B_0}{L^q} = \frac{400 \times 10^6}{(6K)^{0.7}}$

$t_{rx} = \frac{350}{25} = 14ns$

So, $t_{sys} = 30ns$

↳ 20MbPs (NRZ) ✓

$t_b = \frac{1}{20M} = 0.05 \times 10^{-6} = 50ns$

$t_{sys} < 0.7\, t_b$

$< 0.7 \times 50$

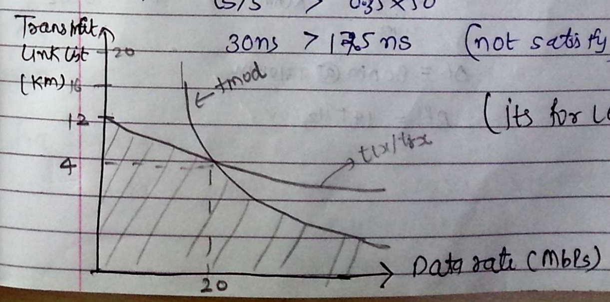
$< 35ns$

↳ (RZ) ✗

$t_{sys} > 0.35 \times 50$

$30ns > 17.5ns$ (not satisfy)

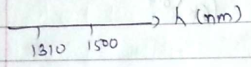
(its for LED)

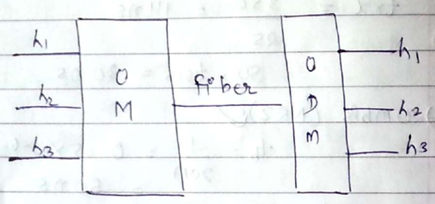


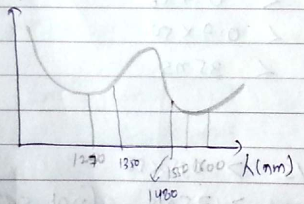
27-march

WDM: (wavelength division Multiplexing)

In TDM, its difficult to handle in the fiber because freq. is in THz.
But in WDM, for respective wavelength at that freq. is very less compare to TDM or FDM.







$\Delta\lambda = 120nm$ @ $1550nm$

$\Delta f = 15THz$

$\Delta\lambda = 80nm$ @ $1310nm$

$\Delta f = 14THz$

$$f = \frac{c}{\lambda}$$

$$\frac{df}{d\lambda} = \frac{-c}{\lambda^2}$$

$$df = \frac{-c}{\lambda^2} d\lambda$$

$$\boxed{|\Delta f| = \frac{c}{\lambda^2}(\Delta\lambda)}$$

available wavelength range

center wavelength

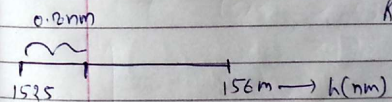
Ex: find out no of channels possible on 1525 nm to 1565 nm range. if req. freq. spacing is 100 GHz.

Sol:

$\lambda = \frac{1565+1525}{2} = 1545nm$

$\Delta f = 100GHz$

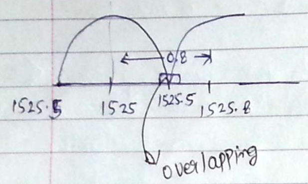
$100GHz = \frac{3\times10^8}{\lambda^2}(40nm)$



freq. spacing is $\Delta f = 100GHz$

$\Delta\lambda = \frac{3\times10^8}{100\times10} \quad \frac{100\times10^9 \times (1545)^2 (10^{-18})}{3\times10^8}$

$= 0.8nm$



(ii) Find out the max spectral line width available in the source, such that it accomadates 50 channels.

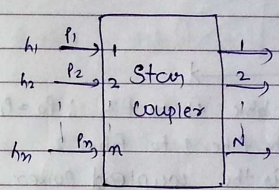
Sol:

Date: 31-March

passive components :

- Working in optical domain
- Varrient Star coupler

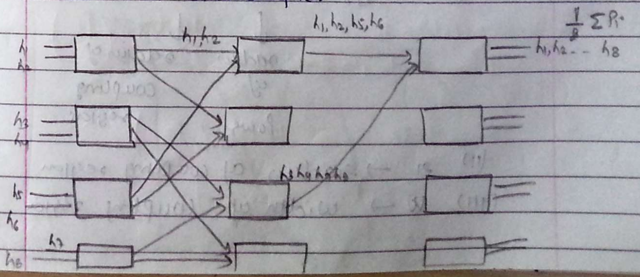
⇒ **Star coupler:**



$$\frac{1}{N}\sum_{i=1}^{N} P_i, (\lambda_1, \lambda_2 \ldots \lambda_n)$$

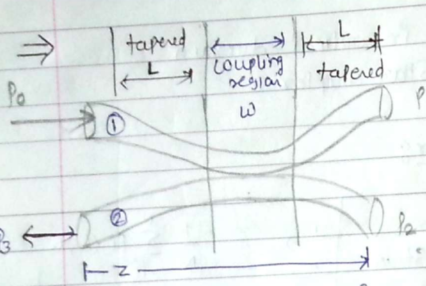
$$\sum_{j=1}^{n} P_i$$

- input power and output power is same.
- output power contains at a particular chann is the avg. of the input power at every wavelength.
- split and combine
- 8×8 star coupler —
  └ 2×2 starcoupler



$\Rightarrow N \times N \rightarrow \frac{N}{2}\log_2 N$ → needs the amount of coupler (2×2)

$\Rightarrow$



- if we don't combine f1 to f2 ; $P_0 = P_1$
- if we combine the fiber 1 to fiber 2 then P_2 is the coupled power

$P_3 \rightarrow$ cross talk, that means, some power is reflected from the P_2. So at terminal 3 we don't require any power is to given.

- coupling region

through that we can obtain the P_1 & P_2 that depends on

(I) $\Delta r = r_1 - r_2$

r_1 ↓ radius of fours; r_2 ↓ radius of coupling region

(II) r → radius of coupling region

(III) W → width of coupling region

Tapered region:

$V = r/h$

adurpt change in radius of fiber ⟶ as radius is changes → V is changes

due to that $\frac{P_{rad}}{P} \propto \frac{4}{3\sqrt{m}}$; $m < V$

Prad is there and loss is there at P_3

- so by smoothly change in radius of fiber we can change the power at P_3 which is loss.

Power coupled into node 2:

$$P_2 = P_0 \sin^2(Kz)$$

K → coupling cofficient

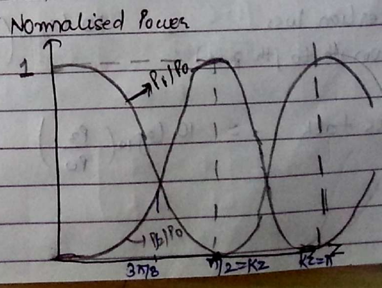
z → distance

$K = \frac{2\pi n}{\lambda}$

losseless condition:

$P_1 = P_0 - P_2$

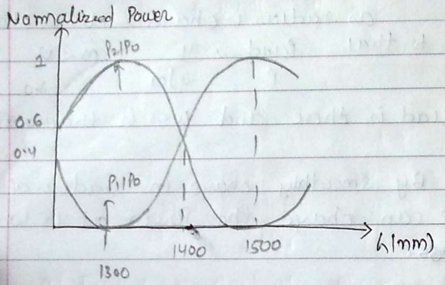
$P_1 = P_0 \cos^2(Kz)$



at $kz = \pi/4$; $P_1 = 1/2 P_0 = P_2$

at $kz = \frac{3\pi}{2}$; $P_1 = P_2$

at $kz = \pi/2$; $P_1 = 0$, $P_2 = max.$



⇒

- Splitting ratio (coupling ratio) $= \frac{P_2}{P_1 + P_2} \times 100$
- Excess loss $= 10 \log_{10}\left(\frac{P_0}{P_1+P_2}\right)$
- Insertion loss (from i^{th} to j^{th} port) $= 10 \log_{10}\left(\frac{P_i}{P_j}\right)$
- Cross talk $= 10 \log_{10}\left(\frac{P_3}{P_0}\right)$

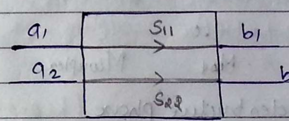
Date: 7 - April

1. 3dB coupler – for spliting the power $kz = \pi/4 \rightarrow$ 3dB coupler
2. – Cross bar (in that all power is $P_2 = P_0$, $P_1 = 0$) at $k = \pi/2$

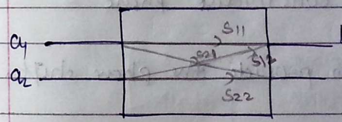
Scattering Matrix :

relation b/w i/p and o/p Power in terms of magnitude and phase.

1)



11)



(in context of coupling)

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

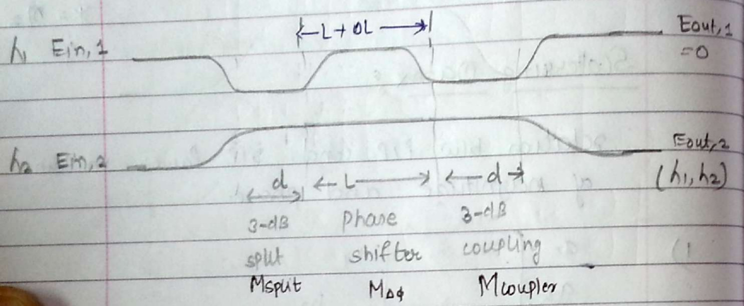
$$b_1 = a_1 S_{11} + a_2 S_{12}$$
$$b_2 = S_{21} a_1 + S_{22} a_2$$

Scattering matrix $S = \begin{bmatrix} \sqrt{1-\varepsilon} & j\sqrt{\varepsilon} \\ j\sqrt{\varepsilon} & \sqrt{1-\varepsilon} \end{bmatrix}$

$\varepsilon \rightarrow$ proportionate Power

MZI (Mach-Zehnder information) multiplexer :

- wavelength multiplexer



at Eout 1 → destructive phase (λ_1 and λ_2 added in such a way that $E_{out,1} = 0$)

at Eout, 2 → constructive phase

- ΔL is added to provide the phase shift.

↳ For 3 dB split (Msplit)
3dB means half

$$M_{split} = M_{coupler} = S = \begin{bmatrix} \sqrt{1-\epsilon} & j\sqrt{\epsilon} \\ j\sqrt{\epsilon} & \sqrt{1-\epsilon} \end{bmatrix}$$

$\epsilon = 0.5$

$$= \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

↳ Phase shifter:

$$\Delta\phi = \frac{2\pi n_1}{\lambda}(L + \Delta L) - \frac{2\pi n_2}{\lambda}(L)$$

Phase shift provided by the Path 1

Phase shift by the Path 2

assume: when both fiber are having the same RF. $n_1 = n_2 = n_{eff}$.

$$\Delta\phi = \frac{2\pi n_{eff}}{\lambda}(\Delta L)$$

$$= K \Delta L$$

Propostional constant

$$M_{\Delta\phi} = \begin{bmatrix} e^{jK\Delta L/2} & 0 \\ 0 & e^{-jK\Delta L/2} \end{bmatrix}$$

$$M = M_{split} M_{\Delta\phi} \cdot \cancel{M_{split}} \cdot M_{coupler}$$

$$= \frac{1}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \cdot \begin{bmatrix} e^{jK\Delta L/2} & 0 \\ 0 & e^{-jK\Delta L/2} \end{bmatrix}$$

$$= \frac{1}{2} \begin{bmatrix} 0 & 2j \\ 2j & 0 \end{bmatrix} \begin{bmatrix} e^{jK\Delta L/2} & 0 \\ 0 & e^{jK\Delta L/2} \end{bmatrix}$$

$$= \frac{1}{2} \begin{bmatrix} 0 & 2j\, e^{-jK\Delta L/2} \\ 2j\, e^{jK\Delta L/2} & 0 \end{bmatrix}$$

Scanned by CamScanner

$$= j\begin{bmatrix} 0 & \cancel{e^{-jK\Delta L/2}} \\ e^{jK\Delta L/2} & 0 \end{bmatrix}$$

$$= \frac{1}{2}\begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}\begin{bmatrix} e^{j\theta} & 0 \\ 0 & e^{-j\theta} \end{bmatrix}\begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

$$= \frac{1}{2}\begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}\begin{bmatrix} e^{j\theta} & je^{j\theta} \\ je^{-j\theta} & e^{-j\theta} \end{bmatrix}$$

$$= \frac{1}{2}\begin{bmatrix} e^{j\theta} - e^{-j\theta} & j(e^{j\theta} + e^{-j\theta}) \\ j(e^{j\theta} + e^{-j\theta}) & (e^{-j\theta} - e^{j\theta}) \end{bmatrix}$$

$$= \frac{1}{2}\begin{bmatrix} 2j\sin\theta & 2j\cos\theta \\ 2j\cos\theta & -2j\sin\theta \end{bmatrix}$$

$$= j\begin{bmatrix} \sin\theta & \cos\theta \\ \cos\theta & -\sin\theta \end{bmatrix}$$

$$M = j\begin{bmatrix} \sin(K\Delta L/2) & \cos(K\Delta L/2) \\ \cos(K\Delta L/2) & -\sin(K\Delta L/2) \end{bmatrix}$$

$$\begin{bmatrix} E_{out1} \\ E_{out2} \end{bmatrix} = j\begin{bmatrix} \sin(K\Delta L/2) & \cos(K\Delta L/2) \\ \cos(K\Delta L/2) & -\sin(K\Delta L/2) \end{bmatrix}\begin{bmatrix} E_{in,1} \\ E_{in,2} \end{bmatrix}$$

$$K_j = \frac{2\pi n_{eff}}{\lambda_j}$$

at λ_1 and λ_2 wavelength

$$\begin{bmatrix} E_{out,1} \\ E_{out,2} \end{bmatrix} = j\begin{bmatrix} \sin(K_1\Delta L/2) & \cos(K_2\Delta L/2) \\ \cos(K_1\Delta L/2) & -\sin(K_2\Delta L/2) \end{bmatrix}\begin{bmatrix} E_{in}(\lambda_1) \\ E_{in}(\lambda_2) \end{bmatrix}$$

$$E_{out,1} = j\left\{\sin\left(K_1\frac{\Delta L}{2}\right)E_{in,1}(\lambda_1) + \cos\left(K_2\frac{\Delta L}{2}\right)E_{in,2}(\lambda_2)\right\}$$

$$E_{out\,2} = j\left[\cos\left(K_1\frac{\Delta L}{2}\right)E_{in1}(\lambda_1) + \sin\left(K_2\frac{\Delta L}{2}\right)E_{in2}(\lambda_2)\right]$$

$E \rightarrow$ intensity

- if we want to find the Power $P = E * E^*$

$$P_{out,1} = E_{out1} \cdot E_{out,1}^*$$

$$P_{out,2} = E_{out,2} \cdot E_{out,2}^*$$

$$P_{out,1} = P_{in,1}\sin^2\left(K_1\frac{\Delta L}{2}\right) + \cos^2\left(K_2\frac{\Delta L}{2}\right)P_{in,2} \quad \text{— (1)}$$

$$P_{out,2} = P_{in,1}\cos^2\left(K_1\frac{\Delta L}{2}\right) + P_{in,2}\sin^2\left(K_2\frac{\Delta L}{2}\right) \quad \text{— (2)}$$

↳ for getting the $P_{out,1} = 0$
$P_{out,2} = P_{in,1} + P_{in,2}$

$\frac{P_{out,1}}{P_{out,2}}$: so; $\sin^2\left(K_1 \frac{\Delta L}{2}\right) = 0$ & $\cos^2\left(K_1 \frac{\Delta L}{2}\right) = 1$

$$\boxed{K_1 \frac{\Delta L}{2} = \pi}$$

$\cos^2\left(K_2 \frac{\Delta L}{2}\right) = 0$ & $\sin^2\left(K_2 \frac{\Delta L}{2}\right) = 1$

$$\boxed{K_2 \frac{\Delta L}{2} = \frac{\pi}{2}}$$

so; $K_1 \Delta L = 2\pi$
$K_2 \Delta L = \pi$

$(K_1 - K_2)\Delta L = +\pi$

$$\left(\frac{2\pi n_{eff}}{\lambda_1} - \frac{2\pi n_{eff}}{\lambda_2}\right)\Delta L = \pi$$

$$\boxed{\Delta L = \left\{2 n_{eff}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\right\}^{-1}}$$

this is extra path which is provided for getting the @ terminal 1 destructive phase Pout,1 = 0 and @ term 2 $P_{out,2} = P_{in,1} + P_{in,2}$ const phase

$$\Delta f = \frac{c}{\lambda_1} - \frac{c}{\lambda_2}$$

$$\boxed{\Delta L = \frac{c}{2 n_{eff} \Delta f}}$$

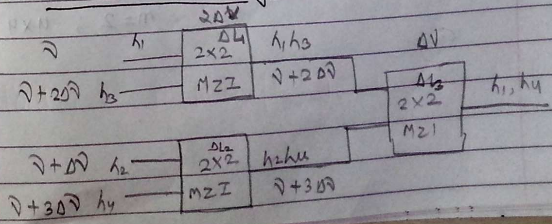
Example: Assume that input wavelengths for 2x2 Silicon MZI are separated by 10 GHz with $n = 1.5$. determine length diff b/w interferometer arm for given wave length.

Sol:
$$\Delta L = \frac{c}{2 n_{eff} \Delta f}$$
$$= \frac{3\times10^8}{2\times1.5\times10^{10}}$$
$$= \frac{0.1}{10}$$
$$= 10\ mm$$

$\Delta L = 10mm$ for $\Delta f = 10 GHz$
$\Delta L = 0.77 mm$ for $\Delta f = 130 GHz$

By ↑ing the freq. or BW, path diff will ↓ses.

⇒ 4x4 MZI using 2x2 MZI:



Date: 10-April

Stage : 0 $\quad 2\Delta\nu$

Stage : 1 $\quad \Delta\nu$

- Each of mux having the same freq. separation.
- Stage: 0

freq. separation $= 2\Delta\nu$

$$\Delta L_1 = \Delta L_2 = \frac{c}{n_{eff}.(2\Delta\nu)}$$

Stage : 1

$$\Delta L_3 = \frac{c}{n_{eff}(\Delta\nu)}$$

N×N Mux

↳ 2^n ; $n \geq 1$

$$\boxed{\Delta L_j = \frac{c}{2^{n-j}\, n_{eff}.\, \Delta\nu}}$$

Stage no.

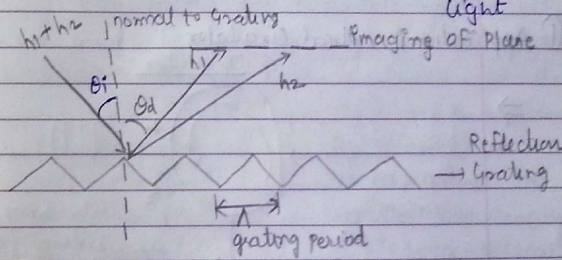
$0 \leq j \leq n$

$N = 2^n$

$n = 2$; 4×4 Mux

Grating

- Grating is a periodic structure or variation in a material.
- depend on the wavelength → operation
- for design the optical filter, we req. grating principal. for supressing and enhanced the wavelengths by fiters.
- working principal of grating: Diffraction of light



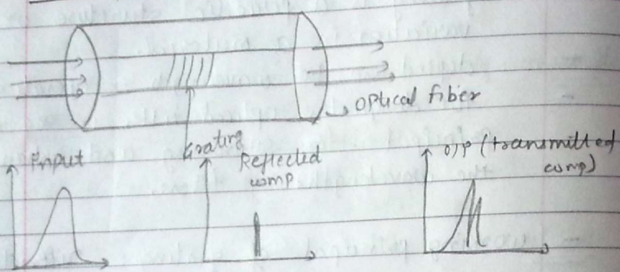
What is the slope of grating, which we required to split the wavelengths as $\lambda_1+\lambda_2$ into λ_1 & λ_2.

Constructive interference:

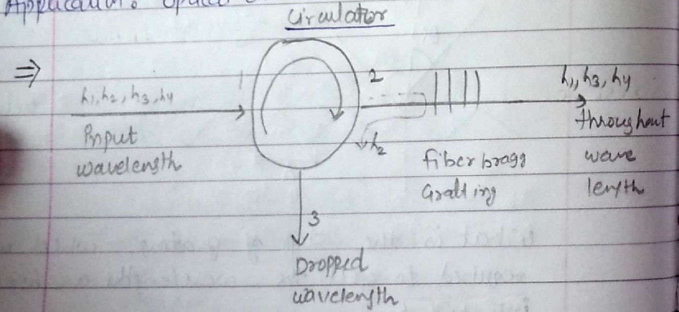
$$\Lambda(\sin\theta_i - \sin\theta_d) = m\lambda$$

Λ ↑ Grating space; $\sin\theta_i$ ↑ incident angle; $\sin\theta_d$ ↑ diffraction angle

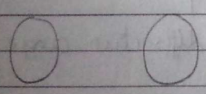
Development of fiber Bragg Gratings:



① Application: optical Circulator



② Application: Demux & mux



Date: 11-April

Advantages:
- tempr and stress sensitive
- can separate the wavelength

Tunable Laser sources:

Available choices for laser sources for WDM App:

① DFB laser (Distributed feedback

② (very costey for tunnable wavelengths)

② wavelength tunable laser

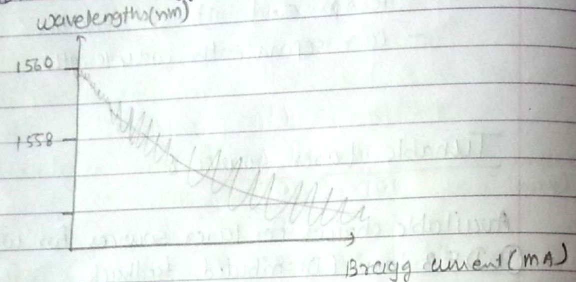
(0.1 nm/°C) By changing the tempr, we can change the optical Wavelength "Thermo-optical"

(0.008 – 004 nm/mA) By chaging the bias current, By changing the RI, we can change the optical wavelength. "Electric-optical"

Disad: time required for tune the wavelength is more.

③ Multi wavelength laser array
- We are making an array which are having the multiple wavelengths, By using the diff types of grating.

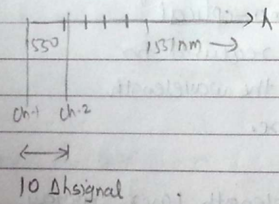
- Distributed bragg reflector (DBR) laser



By changing the Bragg current, we can change the operating wavelength.

- Channel spacing depends on the spectral line width

$\Delta\lambda_{signal} = 0.01$ nm



Channel spacing = 10 times of the $\Delta\lambda_{signal}$

If we don't take it, then interfacing b/w them is possible.

↳ How many channel can ~~accomodate~~ possible in the system

$$\underset{1500}{|}\!\!\text{———————}\!\!\underset{1600}{|} \rightarrow \lambda\,(nm)$$

$$\boxed{N = \frac{\Delta\lambda_{tunable}}{\Delta\lambda_{channel}}}$$

no of channels

↳ tunnability range is given by the (variation of RI)

Tuning range

$$\boxed{\frac{\Delta\lambda_{tune}}{\lambda} = \frac{\Delta n_{eff}}{n_{eff}}}$$

operating wavelength

<u>Example:</u> max. index change of particular DFB laser operating at 1550 nm is 0.65%. Then find out $\Delta\lambda_{tune}$. if source of 0.02 spectral line width is modulated with 2.5 Gbps signal then find out no of channel in tuning range.

<u>Sol:</u>

$$\Delta\lambda_{tune} = 0.65\% \times \lambda$$

$$= 0.65\% \times 1550 \text{ nm}$$

$$= 10.075 \text{ nm}$$

Scanned by CamScanner

$\Delta\lambda)_{signal} = 0.02\ nm$

$\Delta\lambda)_{channel} = 10 \times 0.02$

$= 0.2\ nm$

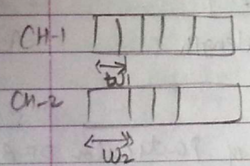
$$N = \frac{\Delta\lambda)_{tune}}{\Delta\lambda)_{channel}}$$

$$= \frac{10.075 \times \cancel{100}}{0.2}$$

$$= \cancel{5.0375}\ 50.37 \cong 50\ \text{channels}$$

Array of tunable laser :

$\lambda/4 \rightarrow$ shifted



$+w \rightarrow$ width of grating

$w_2 = w_1 + \lambda/4$

- Tuning range of such fibers is around 60 nm having channel BW 1 nm (125 GHz @ 1550 nm)

$$|\Delta\nu| = \frac{c}{\lambda^2}\Delta\lambda$$

$$= \frac{3 \times 10^8 \times 1\,nm}{1550 \times 1550 \times (nm)^2}$$

$$= 1.24 \times 10^{-6} \times 10^8 \times 10^9$$

$$= 124\ GHz$$