UNIT 04	ANALOG AND DIGITAL LINKS	11 October 2018 Wednesday

CO4:

Illustrate system design issues with the help of case studies and design problems related to optical links.

- There are two types of links supporting
  a. SCS : Single carrier systems
  b. MCS : Multi carrier systems

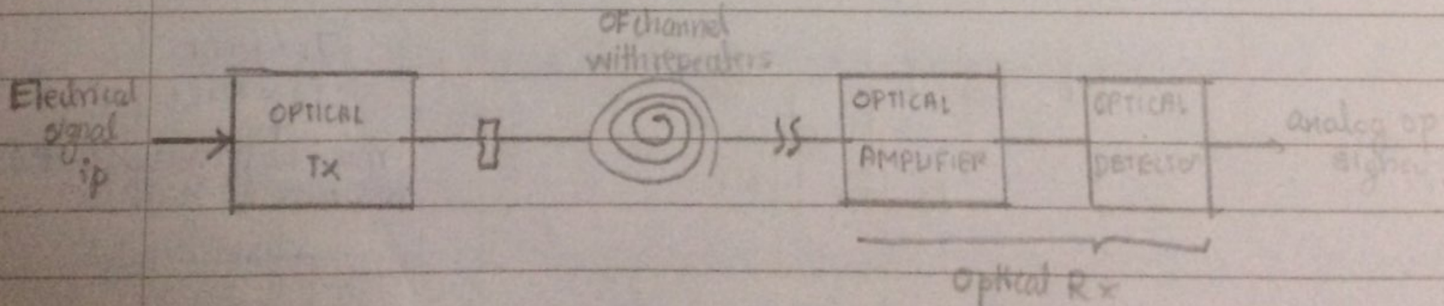
- Analog systems characterised by,
  - Bandwidth
  - CNR & SNR

- Digital systems are characterised by,
  - bit rate
  - Pe or BER

THURSDAY 12/10/2018

Analog optic fiber links

- Determining the correct value of CNR or SNR is an important task in link analysis.
- Signal power is easily estimated but noise estimation is complex.



Tx :

- Non linear distortion - based on the operating part of the active device
  ↓
  determined by driver circuit.
- Harmonic distortions : due to non linear operation there will be harmonic components.
- Clipping action of active device due to limited spectral width.
- RIN : Relative Intensity Noise

Channel :

→ This is the fiber link
- Attenuation loss or path loss
- Absorption loss
- Modal loss
  → intramodal
  → intermodal
- Bending loss
- Scattering loss
- GVD in MM
- MD and W.D in SM
- core-cladding losses

Rx : DETECTOR NOISES

→ Shot noise
→ Thermal noise
→ leakage noise
→ Dark current noise
→ Surface noise
→ Amplifier noise.
→ APD gain noise.

RIN :

Light intensity output of LD exhibits fluctuations in frequen
and phase even when operated above threshold region.

- Two fundamental reasons for this noise are.
  - (i) e-h recombination results in random shot noise.
  - (ii) Transition from spontaneous emmision to stimulated emmision near the threshold is not smooth.

- Among the two factors, second one is dominant.

- Mean Square Value of RIN current is

$$\langle i^2_{RIN} \rangle = \underbrace{\sigma^2_{RIN}}_{\text{Variance}} = RIN \left(R_o \overline{P} \right) B$$

where,

$$RIN = \frac{\langle (\Delta P_L)^2 \rangle}{P_L^2} = \frac{\text{MSV of fluctuations of intensity}}{\text{Average laser intensity}} \ dB/Hz$$

- CNR due to only RIN noise, $= \frac{C}{\sigma^2_{RIN}}$

- At 1550nm for DFD laser diode, $-152 < RIN < -156$ dB/Hz

- RIN also depends on the drive current at the input

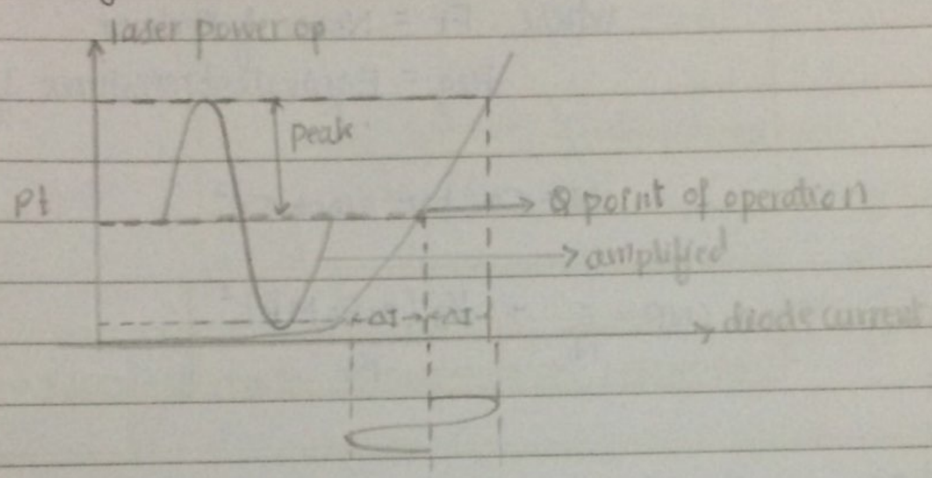
$$\boxed{RIN \propto \left(\frac{I_B}{I_{th}} - 1 \right)^{-3}}$$

RIN ↓ as injection current ↑

- CNR can be represented in two forms.
  - (i) in terms of 'm' → modulation index.
  - (ii) only in terms of C & N power

Friday. 13 Oct 2018

Analog link and CNR estimation



- Q point is selected in the middle of characteristic curve to avoid non linear distortion
- power output of LD corresponding to drive current is

$$P(t) = P_t\,[1 + m\ s(t)]$$

where,

m → modulation index. $= \dfrac{P_{peak}}{P_t}$ (< .5)

- Transmitted power from laser source is detected by a photodetector at the reciever.

$$C = \frac{1}{2}(m\,R_0\,M\bar{P})^2$$

R_0 → unit gain responsivity of photo detector

- Noise power = N = Noise contributed by detector + Noise of amplifier.

(i) PD noise = $N_P = \langle i_N^2 \rangle = \sigma^2_N$

(ii) RIN = NR = $\langle i_{RIN}^2 \rangle = \sigma^2_{RIN} = RIN(R_0\bar{P})B$

(iii) Thermal noise = $\langle i_p^2 \rangle = \sigma_T^2 = \frac{4K_BT}{R_{eq}} B F_t$

where, F_t = Noise of Reciever

R_{eq} = Equivalent resistance of amplifier

$$N = \sigma_N^2 + \sigma^2_{RIN} + \sigma_T^2$$

$$\therefore CNR = \frac{C}{N} = \frac{\frac{1}{2}(mR_0M\bar{P})^2}{N}$$

⇒ Performance of analog fiber link, is based on CNR

- There are 3 limits, defined for this CNR based on signal strength is recieved by photodetector.

a) limit-1 : when input signal is very weak then thermal noise of amplifier is predominant compared to other noises.

ie

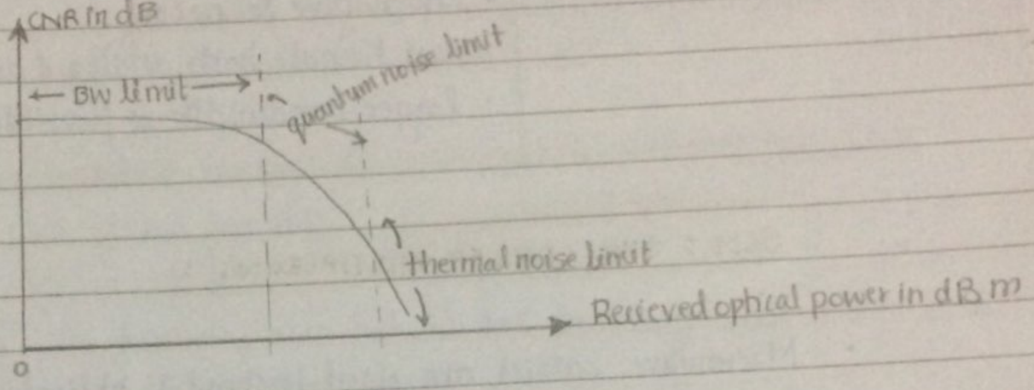
$$N \simeq \sigma^2_T \Rightarrow (CNR)_{lim 1} = \frac{C}{\sigma_T^2}$$

(b) limit 2 : For well designed photodetectors, bulk and surface dark currents are negligible at a verge of signal strength

$$(CNR)_{limit 2} = \frac{\frac{1}{2}(m^2R_0\bar{P})}{2q\,F(M) \cdot B}$$

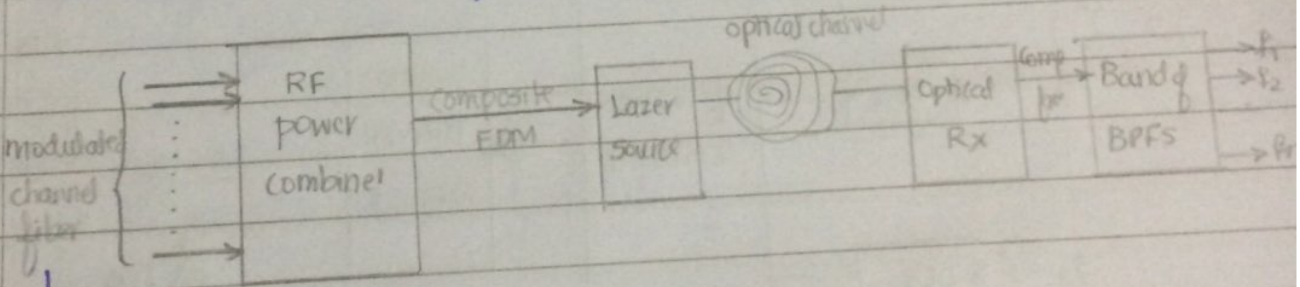
(c) limit 3 : For strong input signals, RIN is predominant

$$\boxed{(CNR)\ limit\ 3 = \frac{1}{2}\frac{(MM)^2}{RIN \cdot B}}$$



⇒ MULTI-CHANNEL TRANSMISSION METHODS :

- To better use the available bandwidth of fiber, Multiplexing technique is used to transmit information .



modulation schemes can be
VSB - AM, FM, SCM

	MODULATION FORMAT	CHARACTERISTICS
1.	VSB - AM	· cost effective · compatible with OFC systems · very sensitive to noise and NL distortions.
2	FM	· requires larger bandwidth than AM · provides highest CNR

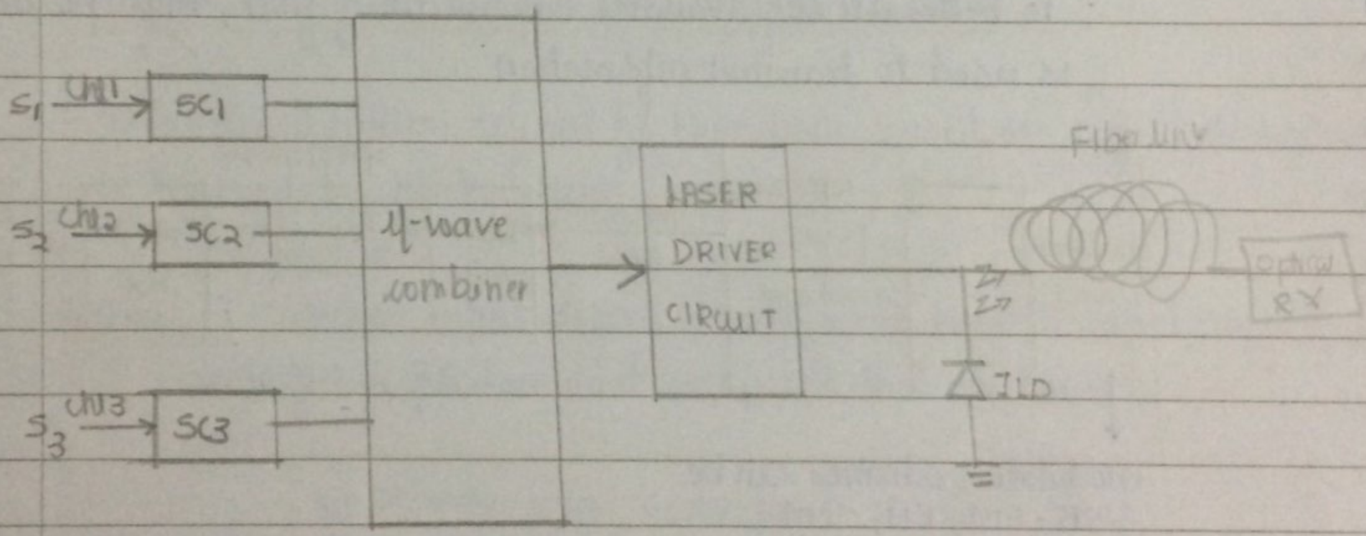
	· Better noise suppresion · minimum non linear distortion.
SCM	· operates at higher frequency than AM & FM · insensitive to noise · can handle both analog & digital signals. · larger bandwidth is possible

SCM : SUB CARRIER MULTIPLEXING :

13/10/2018

- Microwave carrier are used instead of optical carrier for modulating the different channel.

- If signals are transmitted over an optical fiber than bw > 10GHz.



ADVANTAGES :

- wide bandwidth available
- flexibility for upgradation of components/equipments
- useful in multimedia communication for number of users
- used in network monitoring management systems.

ROF or RF OF :

- ROF : Radio over optical fibers
- Principle : "light ~~super~~ signal is modulated by a microwave carrier and transmitted over fiber".

- provides wireless coverage in area where wireless backhaul or reverse link is not possible.

- Example : In tunnels, area behind tall buildings, mounting and secluded array like jungles, desert, sea etc

ADVANTAGES :

- low path loss : Since fiber is used as the medium.
- no EMI and RFI on the links.
- Fadings eliminated - both short term and long term
- noise effects reduced.

APPLICATIONS

- 3G, 4G, 5G and LTE of mobile systems
- Wi-Fi
- CATV
- RF - L band communication between base station or ground s and polar ~~bit~~ orbit sattelites.
- FTTA : Fiber To The Antennas

  ie fiber is used as the interconnecting link between Tx / antenna.

ADVANTAGES OF FTTA :

- Better coupling - Avoid standing waves
- Protection of system against lightning
- in mobile systems, simple base station design is possible.

DIGITAL LINKS :

Important considerations in link design.

→ We use line coupling methods to power the randomness, redundancy and signal security.

→ FEC can be used (FORWARD ERROR CORRECTION) codes are used to get better end to end fidelity

→ Pe and BER are limited by noise and dispersion effects

→ Use of SM fibers for long distance communication.

→ In high speed applications (rate > 400Mbps) consider the effects of
- modal noise
- spectral noise
- mode partition noise
- laser chirping
- reflection noise.

→ Selecting proper wavelength for transmission - fixing λ from 3 windows

This has bearing on the fo
- link length
- σ_λ
- scattering of losses

→ Optimising the performances of Tx, link and Rx

Generally optimise at last 2 unit

→ Selection of photodetector for QL of detection of detector with good sensitivity – PDS [PIN / APDS

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Example for Analog link power budget

Compute the maximum link length and various power margins.

DATA AVAILABLE:

→ BER $= 10^{-9}$ (ie. one bit will be in error for 10^9 bits Ix)

→ Data Max = $B_{T}max$ = 200Mbps

→ Operating wavelength $\lambda = 850nm$

→ Soure → GaAlAs LED = power output of $P_S = -13dBm$ (average power level)

→ Fiber core diameter = $50\mu m$

→ Detector in PIN PD, sensitivity = −42dBm (Pmin)

→ 1dB coupling loss between source and fiber.

→ 1dB coupling loss between fiber and photodiode.

→ System loss margin = 6dB

→ Attenuation of fiber is = 3.5dB/km (composite plastic fiber)

SOLUTION:

→ Total power loss that occurs between source and destination

$$P_L = P_S - P_R$$

$$= -13dBm - (-42dBm)$$

$$= 29dBm.$$

→ Neglecting the splicing, coupler and connector losses (not given)

P_L = Loss of coupling at soure + Loss of coupling at detector + power margin + attenuation loss of fiber

$$29dB = 1dB + 1dB + 6dB + \underbrace{(3.5)L}_{\alpha_F . L}$$

$\therefore$ Maximum link length possible = $L = 6km$.

There are two methods by which power budget of an analog link can be represented.

(i) conventional method

(ii) spread sheet method.

COMPONENT / LOSS PARAMETER	OUTPUT / SENSITIVITY / LOSS	POWER MARGIN IN dB
LED power output (P_s)	$-13dBm$	
PIN PD Sensitivity (P_n)	$-42dBm$	
Allowable loss ($P_s - P_a$)		$29dBm$
Connectivity loss at ip and output	1dB each	$29dB - 2dB = 27dBm$
Loss Margin tolerable	6dB	$27 - 6dB = 21dB$
loss due to fiber attenuation and others will be		21dB.

Scanned by CamScanner

RISE TIME BUDGET :

→ This gives dispersion limitations of optic fiber used in digital links

→ Total rise time for the digital link is

$$t_{sys} = \left(\sum_{i=1}^{N} t_i^2 \right)^{1/2} \quad \rightarrow (1)$$

where t_i → rise time contributed by each of the components of link.
N = Number of components in the link

→ In digital links we consider four basic parameters for determining rise time budget.

(i) t_{tx} → transmitter rise time
(ii) t_{GVD} → Group velocity dispersion rise time
(iii) t_{mod} → modal dispersion rise time
(iv) t_{rx} → Reciever rise time

MM fibers of SIF or GRIN

For single mode fibers, GVD is the only dispersion and no other dispersion.

→ Rise time specifications for a digital link is based on data format like NRZ or RZ, considering various factors.

- For NRZ, Total transitional time degradation < 70% of T (bit time)
- For RZ, Total transition time degradation < 35% of T (bit value time)

$$\boxed{T = \frac{1}{\text{Bit rate}}}$$

(i) t_{tx} :- (TRANSMITTER RISE TIME)

This is associated with driver circuits of the source and source equalisation circuit.

- Generally, this is specified based on
  - → window region of operation
  - → types of source
  - → $\sigma\lambda$

trx (RECIEVER RISE TIME)

Several considerations are

- * types of PD → PIN
  - → APD
- * Responsivity and wavelength
- * Modulation Bandwidth
  - Electrical } 3dB
  - optical
- * Modulation format
- * Front end passive and active circuits
- * Response of Reciever front end is modeled as a Low Pass filter with step input.

$$g(t) = [1 - \exp(-2\pi B_{rx} t)]\, u(t)$$

$u(t)$ → step input

B_{rx} → 3 dB bandwidth of Rx

→ $u(t) = 1$ for $t \geq 0$
$= 0$ for $t < 0$

* Generally rise time of reciever is defined as the transition time of response to change from 10% to 90% of amplitude levels.

Approximately $\boxed{t_{rx} \simeq \dfrac{350}{B_{rx}}}$

if B_{rx} is in MHz, then t_{rx} will be in nsec ii (t_{GVD} : (GROUP VELOCITY DISPERSION RISE TIME))

This is very diffiuult to ~~accurately~~ be computed accurately for a link because

- number of splices or joints
- even if we use same fiber there will be microvariations in R.I profile, modal characterisation, dispersion characteristics etc which cummulatively gets added.
- mode mixing and spreading characteristics of fiber further complicate the calculations.
- fiber misallignment losses further adds to this complication.

- Finally GVD rise time is a function of despersion factor, which depends on whether fiber is dispersion compensated / flattened or shifted type.

26-10-18

$$t_{GVD} \cong |\Delta| L \sigma_\lambda$$

where,

Δ : Average dissipiation factor

L : link length

σ_λ : spectral width.

Considering two types of fibers,

(i) Non dispersion shifted fibers

~~(ii)~~

$$D(\lambda) = \frac{\lambda S_0}{4}\left[1 - \left(\frac{\lambda_0}{\lambda}\right)^4\right]$$

where,

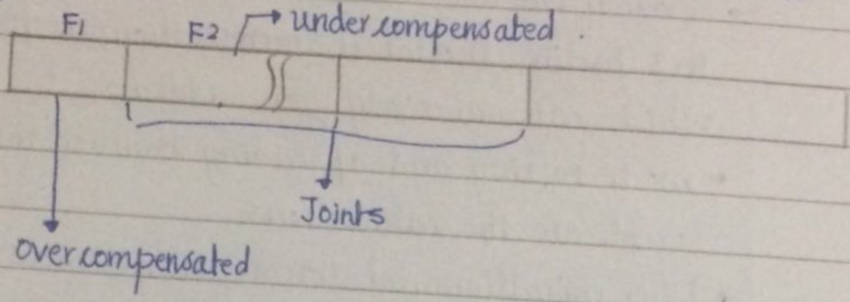
S_0 : Slope of the dispersion curve

λ_0 : zero ~~dir~~ dispersion wavelength

(ii) For dispersion shifted fibers

$$\boxed{D(\lambda) = (\lambda - \lambda_0) S_0}$$

To make D even over the given link length, splice different dispersion fibers together



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* Bm : Modal dispersion bandwidth :

It is the wavelength region over which D is uniform for a given length.

- $$Bm(L) = \frac{B_0}{L^q}$$

  where,

  Bm → Bandwidth over 1 km of fiber

  $0.5 < q < 1$ → loading factor

  typically $q \simeq 0.7$

- Bandwidth of fiber connector expressed in terms of optical or electrical bandwidth

  optical → (3dB)

→ $$f_{3dB} = B_{3dB} = \frac{0.44}{t_{FWHM}} = B_m$$

→ t_{FWHM} → Rise time resulting from modal dispersion or (full width half max rise time)

$$f_{3dB} = B_{3dB} = \frac{0.44}{t_{FWHM}} = \frac{0.44}{t_{mod}} = B_m$$

$$\therefore t_{mod} = \frac{0.44}{B_m} = \frac{0.44 L^q}{B_0}$$

If B_m is in MHz, t_{mod} is in nsec,

then,

$$\boxed{t_{mod} = \frac{440 L^q}{B_0}}$$

- Total rise time budget for the given digital link is

$$\rightarrow t_{sys} = \left[\sum_{i=1}^{4} (t_i^2)\right]^{1/2}$$

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

$$= \left[t_{tx}^2 + \left(\frac{440 L^q}{B_0}\right)^2 + (D L \sigma_\lambda)^2 + \left(\frac{350}{B_{rx}}\right)^2\right]^{1/2}$$

NOTE:

- For SM fibers in window 1, $D = D_{mat}$
- In windows 2 and 3, D further gets reduced.

NUMERICAL:

Consider a digital link, which uses LED source with spectral width of 40n having NRZ input data, approximate rise time of transmitter is 15nsec material dispersion related rise time degradation is 6 nsec above the transmitter rise time. Approximate link length is 6km, with a bandwidth of 25MHz. Rise time degradation corresponding to reciever system is 14nsec Assume $q = 0.7$ and average modal dispersion rise time is around 3.9nsec. What is the rise time budget for this digital link and what is the inference?

$$t_{sys} = [(15\,nsec)^2 + (21\,nsec)^2 + (3.9\,nsec)^2 + (14\,nsec)^2]^{1/2}$$
$$\simeq 30\,nsec$$

Inference

Starting with rise time budget, WKT for window 1 digital links maximum limit on rise time degradation must be < 35nsec (ie 35% of T). Hence given digital link degradation is well within prescribed limits.

HOMEWORK

$D = 0.07$ nsec/ ~~km~~ nm-km

$L = 8$ km

Window 3 region

$\sigma_\lambda = 2nm$ } for ILD

$B_0 \simeq 50MHz$

Saturday — 27 OCT 2018

TRANSMISSION DISTANCE IN SINGLE MODE FIBERS

Link length depends on

(a) λ of operation
(b) Attenuation of fiber
(c) Type of source at its σ_λ
(d) Detector Sensitivity
(e) Type of Data
   - NRZ
   - RZ
(f) power output source
(g) GVD
(h) Datarate

For SM fibers, GVD is predominant and hence no other dispersion

$$t_{GVD} = |D| L \sigma_\lambda$$

Example: SM fiber at 1550nm

$D_{average}$ = 2.5 psec/ nm-km = 2.5×10^{-3} sec/m-km

Compute link length for

(a) RZ data, $\sigma_\lambda = 3.5nm$ LD source, $B_{Tmax} = 200Mbps$.

t_{GVD} is limited to 35% of bit time.

Solution I.

$t_{GVD} = 35\% \cdot \frac{1}{B_{Tmax}}$

$= (35\%)\left(\frac{1}{200\times10^{6}}\right) = 1.75nsec$

Bit time = $T = \frac{1}{B_{Tmax}} = \frac{1}{200\times10^{6}} = 5nsec$

$1.75nsec = (2.5\times10^{-3})L(3.5\times10^{-9})$

$\therefore L = 200m$

II Instead of multimode LD source, if we use SM LD source $\sigma_\lambda = 1m$

(a) $t_{GVD} = 35\%\left(\frac{1}{200\times10^{6}}\right) = 1.75nsec$

$L_{RZ} = 700m$

(b) $t_{GVD} = 1.4nsec$

$L_{NRZ} = 560m$

CONCLUSIONS :-

(i) As $\sigma_\lambda \downarrow$, $L \uparrow$ for both RZ and NRZ data

(ii) For RZ and NRZ having smaller link lengths larger data rate is possible because of reduced GVD.

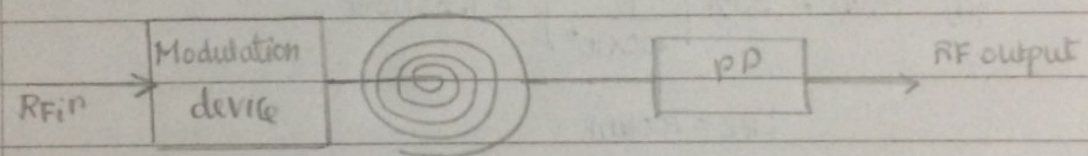
: If D is reduced by 10 fold, find the improvement in 'L'

MWP : MICROWAVE PHOTONICS :- (MICRO PHOTONS)

- This is inter disciplinary which integrates microwaves and photonics.
- Using photonic crystals, we can increase & enhance microwave systems based on SWAP system
  - ↳ Size, Weight And Power
- Improvements wrt
  - a. Bandwidth
  - b. Range (Dynamic Range)
  - c. Reducing power requirements
  - d. Reduction in IL (Insertion loss)
  - e. Reflection, impedance matching requirement can be eliminated.

FRIDAY 2/11/2018

HEART OF MICROWAVE PHOTONICS IN THE MICROWAVE LINK :



FUNCTIONALITIES :

i. TIME DELAY :

- * Rise time constraints
- * Time delay of active devices

ii. PHASE SHIFT :

- * Phase compensation for long distance communication to preserve mode patterns.

* micro active components in the circuit introduces unwanted phase change

iii. FILTERING OF UNWANTED FOR COMPONENTS

iv. FREQUENCY CONVERSIONS

Microwave range to optical range converssions and vice versa.

v. MODULATION FORMATS FOR TRANSMISSION

Most of the links use IMDD (Intensity Modulation Direct Detection)

⇒ Modulation is of two types

(a) DIRECT : Information signal is converted to optical signal and is modulated using an optical carrier (MM)

(b) INDIRECT : Modulation is done at microwave frequency and then translation is done.

CW → Continuous wave modulation

EOM → Electric optical modulators are used.

★ Other advantages :

- → Constant attenuation over a given window
- → Large dynamic range (increased tunability)
- → Immune to EMI/RFI

★ PARAMETERS

i) link gain

ii) Dynamic range (SFDR → Spurious Frequency Dynamic Range)

iii) NF

iv) Fidelity and Sensitivity

APPLICATIONS OF MICROWAVE PHOTONICS

- GHz - THz frequency generators / function generators
- HSWN : High Speed Wireless Networks
- WSN : Wireless Sensor Networks used in IoT
- Radar and Satellite Communication.
- Cellular mobile system
- CATV / HDTV
- Distributed and multiple antenna system etc. MIMD
- OSP : optical Signal processing
- Optical Computing
- Medical imaging and endoscopy applications.

MODAL NOISE

- Various discontinuities in the connecting medium alters the modal patterns
- This happens in
  - i) couplers / connectors / jumpers
  - ii) Splices

- Due to changes in the modal pattern, mean optical power level reduces which affects Quantum limit of detection.

- Variation in power levels create variations in CNR, Pe and BER performances and also increases power penalties

Main reason for increased power penalties are
(a) Modal noise
(b) Laser chirping
(c) Spectral broadening effects
(d) Mode partition noise effects.

- Modal noise generally occurs in coherent single mode lasers when signal is coupled to multimode fibers. (ie modal compatibility between two)

- Not important if Bit Rate B_T for 100Mbps upto 400Mbps
But critical if $B_T > 400$Mbps.

- Frequency and wavelength variations of the source.

- Mechanical vibrations

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3 Nov 2018

Modal noise depends on BER performance
Example : APD is the detector $\lambda = 1200$nm
$B_T = 280$Mbps

If 'M' is the number of spectral components (speckles) incident on APD
Then if $M_1 = 2910$ (very large for dominant LD mode)
then BER $= 10^{-6}$ no power penalty required or no modal losses detected

$M = 50$ (Reduced speckles)
To achieve BER $= 10^{-6}$, we need 1dB additional power penalty

Similarly

$M = 20$

to achieve BER 10^{-6} we need 2dB additional power penalty.

REMEDIAL MEASURES :

1. Use non coherent source like LED where MN is completely avoided.
2. Use LD source with more number of ~~longitudin~~ longitudinal spectral components.
3. As far as possible avoid mechanical vibrations
4. Keep mode compatibility between source and fibre & use large numerical aperture fiber which generally supports MM operation where 'M' will be sufficiently large.
5. Use all SM source fiber etc such that IM dispersions can be avoided.

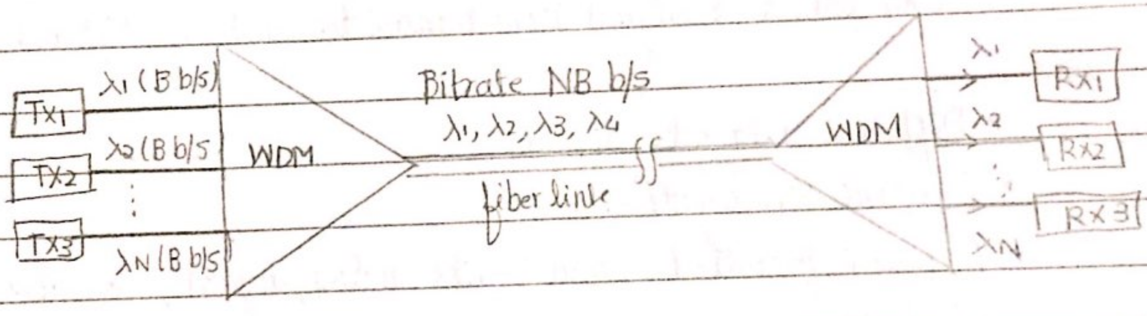
UNIT 5 — WAVELENGTH DIVISION MULTIPLEXING & NETWORKS

3 NOV 2018
SATURDAY

CO5 : Demonstrate awareness about emerging trends in the field of optical communication and networking.

WDM PRINCIPLES :

- It is basically a FDM system.
- Many different wavelength signals are simultaneously transmitted through channel or fiber.
- WDM is generally implemented in W2 and W3 regions because
  - i. Attennae is small
  - ii. Using dispersion shifted or flattened fiber, minimum dispersion can be obtained.
- Proper guard band spacing is required to overcome inter channel interference.



WDM FEATURES ARE :

(i) CAPACITY UPGRADE :

- point to point link capacity can increase many fields which increases spe efficiency (η)
- Number of wavelengths can be multiplexed depending on data rate of individual channel.

Example:

- If $B_T = 2.5$ Gbps
  $N = 32$

- * $B_T = 10$ Gbps
  $8 < N < 10$

- * According to ITU specifications
  B_T of fiber = 2 Tbps (theoritical)
  B_T of fibers available = 80 Gbps (practical)
  ↓
- Due to various constraints like E/O conversion at transmitter O/E conversion at reciever.

using number of electrical circuits.

(ii) IMPROVED TRANSPARENCY:

Any format of signal from transmitter can be multiplexed.

- Different data rate signals.
- Different wavelength signals
- Different formatted signals like analog, digital, SX, HDX, FDX, at fast etc.

(iii) FLEXIBILITY OF WAVELENGTH ROUTING.

Using optical routing devices like routers, network switching wavelength addressing is possible

WAVELENGTH SWITCHING :

- Reconfiguration of optical layer possible
- Unwanted delays in switching can be reduced.
- Switching speed can be increased
- Key components are
  - Add/drop MUX
  - Optical Cross Connect
  - Wavelength convertors

Some more devices required to implement WDM are

- Optical power splitters or combiners
- Tunable optical sources
- Tunable optical wavelength filters
- Optical amplifiers
- Directional couplers.

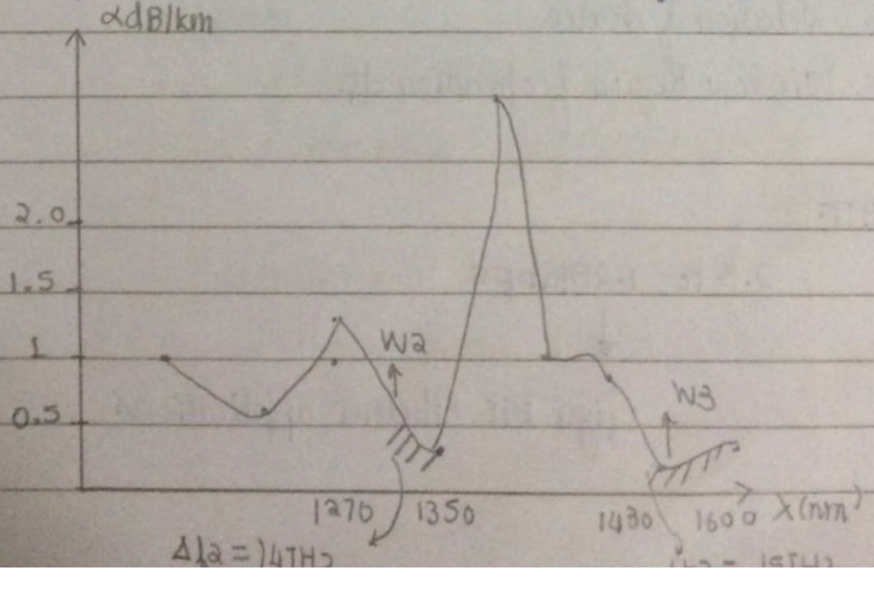
OPERATION PRINCIPLES OF WDM :

(i) OPTICAL ~~SOURCE~~ SENSORS

- DFB layer
- $\sigma\lambda = 10^{-3}$ nm
- Guard Band spacing 0.4 to 1.6nm

Considering ~~gifts~~ drifts in peak emmision wave

→ length, temparature/bias variations, aging etc



- While selecting the window region of operation consider minimum fiber attenuation and also use dispersion shifted / flattened fibers to keep both losses at minimum level.

- Total optical bandwidth available in W2 and W3 is 29 THz ($\simeq$ 30THz)

- $\Delta v = \left(\frac{c}{\lambda^2}\right)|\Delta\lambda|$

  $|\Delta\lambda|$ → RMS spread spectral width of source.

  Δv → optical Bandwidth

- Channel spacing depends on the operating window
  (x) 1552 nm : Spacing can be 100GHz (0.8nm)

  Both attenuation and spacing can be 50GHz (0.4nm)

  Dispersion loss are minimum spacing can be 200GHz (1.6nm)

- Normally if spacing is 100 to 200GHz it is normal WDM if spacing is < it is DWDM.

- WDM STANDARDS :

  ITU under its G.615 charter has given specifications for WD

  This includes

  a. Bit Rate (x) Channel spacing
  b. Selection of Source
  c. Window Region of operation etc

⇒ BIT RATE

2.5 to 1.259Gbps

↓

Giga bit Ethernet applications

Unidirectional and Bidirectional operation

Link length

40km and 80km

Number of WDM channels

1271-1611

Channel ~~Spreading~~ Spacing

20nm

- Guide Operation of WDM is possible (similar to frequency range system) to improve channel capacity and spectral intensity, spacing can be 100GHz, 50GHz, 20GHz
  ↳ overlay

12.5 and 6.25GHz
↳ underlay.

CLASSIFICATIONS

WDM
- Normal
  → W1 & W2 with Bandwidth ≃ 20THz
- Coarse
  → provides 16 channels ~~according~~ across multiple window additionally using silica fibers.
- Dense WDM
  - User C Band (1530-1565nm)

→ Conventionally we use EDFA for WDM with improved gain and narrow bandwidth, nowadays we use Raman amplifier.

↓

Operates in 'L' band region (1565 to 1625 nm)

↓

W3

Hence capacity of WDM system can be doubled.

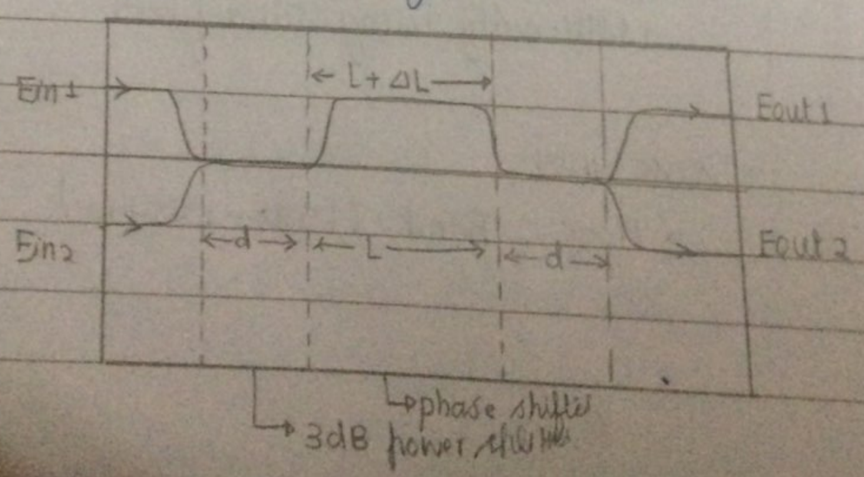
⇒ **APPLICATIONS OF WDM :**

- Ethernet LAN
- Storage area network
- CATV
- Enterprises network.

Saturday

MACH - ZENDER INTERFEROMETER MUX : 10/11/2018

Used to construct wavelength dependant MUX.



MZI consists of 3 stages

- two 3dB couplers for power splitting
- a phase shifter to introduce the phase shift between the curves.
- Extra length ΔL in one of the path in phase shifter, introduces a phase shift such that drive power combining at the output, the two powers can combine constructively or destructively.
- Fiber material and bending losses are neglected.

- Propogation of passive optical components are expressed in terms of propogation matrix 'M'.

- For coupler length 'd',

$$M_{coupler} = \begin{bmatrix} \cos kd & j\sin kd \\ j\sin kd & \cos kd \end{bmatrix}$$

k = coupling coefficient

- For a 3dB coupler (which splits the input power into two equal output powers)

$$2kd = \frac{\pi}{2}$$

$$kd = \frac{\pi}{4}$$

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

· Phase difference or shift introduced between 2 lines is

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

→ n_1, n_2 are R.Is of the two lines

If two lines / waveguides are ~~small~~ same $\eta_1 - \eta_2 = \eta_{eff}$

$$\Delta\phi = K\Delta L$$

where

$$K = \frac{2\pi\eta_{eff}}{\lambda}$$

- $\Delta\phi$ corresponding to 'M' matrix is

$$M_{\Delta\phi} = \begin{bmatrix} e^{j\frac{K\Delta L}{2}} & 0 \\ 0 & e^{-j\frac{K\Delta L}{2}} \end{bmatrix}$$

- Output and input of MZI are related by 'M' matrix

$$\begin{bmatrix} E_{out,1} \\ E_{out,2} \end{bmatrix} = M \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix}$$

where

$$M = M_{coupler} \, M_{\Delta\phi}$$

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

- If $E_{in,1}$ is at λ_1
  $E_{in,2}$ is at λ_2

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

Similarly

$$E_{out,2} = j\left[E_{in,1}(\lambda_1)\cos\left(\frac{K\Delta L}{2}\right) - E_{in,2}(\lambda_2)\sin\left(\frac{K\Delta L}{2}\right)\right]$$

Where $k_j = \dfrac{2\pi\eta_{eff}}{\lambda_j}$ $\quad j = 1 \;\&\; 2$

Optical power at outputs are given by

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

Similarly

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

normalized parameters.

- Cross products are neglected, since ~~these~~ these wavelengths will be outside the PB of individual fibers/waveguides.

$$z = \underbrace{|z|}_{\text{magnitude}} e^{j\phi} \quad \phi \to \text{phase.}$$

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

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- Power output from a given point is based on relative phase differences

ie

if $\frac{K_1 \Delta L}{2} = \pi$, $\frac{K_2 \Delta L}{2} = \frac{\pi}{2}$

then output from port 2 is obtained similarly.

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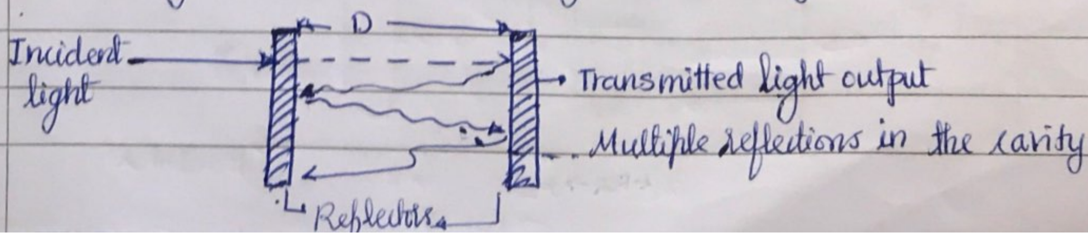
Wednesday. 14/11/2018

THIN FILM FILTER

- These are band pass filters used to select particular 'λ' from band of 'λs'
- They are based on "Fabry - Parot Cavity"



- This filter selects a particular
  - → λ based on cavity reasonance
  - → Round trip distance of reflected waves is generally integer multiple of λ (ie $n\lambda$) where $n = 1, 2, 3 \ldots$

- This is a bilateral device, light waves gets added if they are in phase.

FILTER PARAMETERS

(a) T(Transmission Parameters)

"Ability to select a particular wave length from a given set of wavelengths"

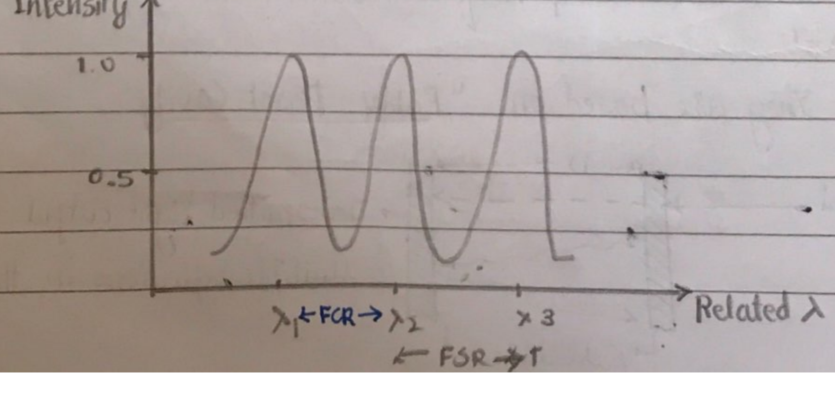
$$T = \left[1 + \frac{4R}{(1-R)^2} \sin^2\left(\frac{\phi}{2}\right) \right]^{-1}$$

where,

- → R → ~~Reflectaty~~ Reflectivity of the mirrors
- → ϕ → Round trip delay of the waves related to optical for $f = \frac{2\pi}{\lambda}$
- → $\phi = \left(\frac{2\pi}{\lambda}\right)(2\eta D \cos\theta)$
- → η = RI of the medium
- → θ = angle of normal to the incoming light beam

→ Filter exhibhits multiple reasonance and is hence called multi reasonance filter.

- Number of passbands produced depends on the condition $N\lambda = 2\eta D$



→ As R ↑ , the Band pass filter characteristics becomes more selective & sharper.

(b) FSR (FREE SPECTRAL RANGE)

This defines the spacing between the reasonant ~~carriers~~ curves or inter λ spacing. Very important in WDM application.

$$\boxed{FSR = \frac{\lambda^2}{2\eta D}}$$

(c) FWHM (Full Width Half Maximum)

This defines the passband width of the filter and also gives ~~information~~ information regarding number of λ's that can be accomodated in the P.B.

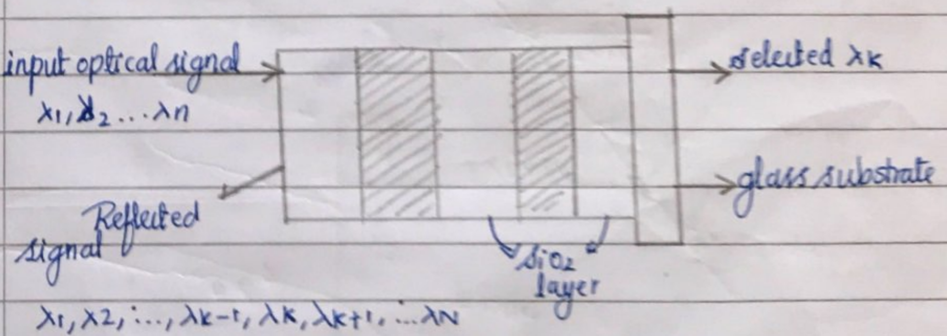
$$= \frac{FSR}{FWHM}$$

This is also called "Finesse" of the filter

$$\boxed{F = \frac{\pi\sqrt{R}}{rR}}$$

PRACTICAL CONSIDERATION :

Implemented by depositing multilayer thin coatings of alternatively low ~~voltage~~ & high RI regions on a glass substrate.



• Selectivity depends on number of layers. As number of layers ↑ it improves selectivity but PMD also increases.

Specifications :

- Two types of bandwidths are possible.
- Narrow Band

  Bandwidth = 50GHz

  → smaller λ spacing

- Wide Band

  Bandwidth = 80GHz

  → wider λ spacing.

Parameter :

(a) I.L < 3.5dB

(b) Chromatic design < 50 ps/nm

(c) PMD loss < 0.2 psec

(d) Isolation between successive wavelengths is > 25 dB

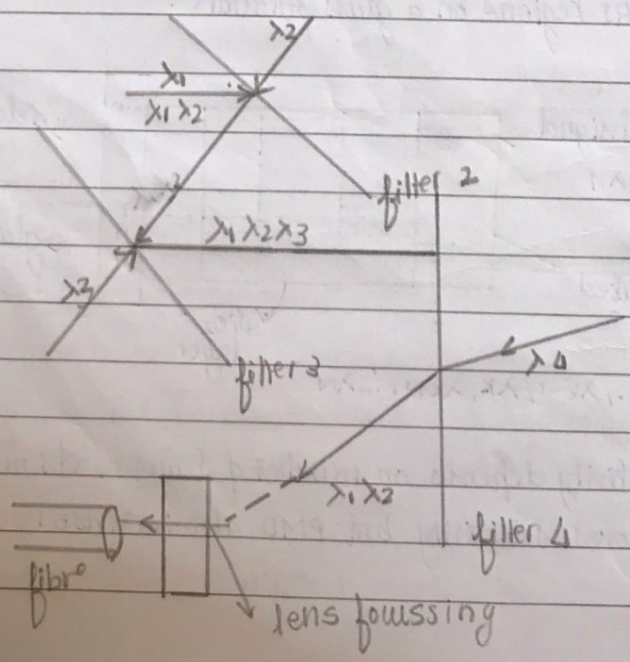
(e) Optical return loss > 45dB

(f) Polarization dependant loss < 0.2dB

⇒ APPLICATIONS OF TFF :

Wavelength of the MUX/ DE-MUX for separately of combining 'N', λs we require (N-1) filters.

Example :



NOTE : TO IMPLEMENT A DEMUX JUST REVERSE THE ARROWS .

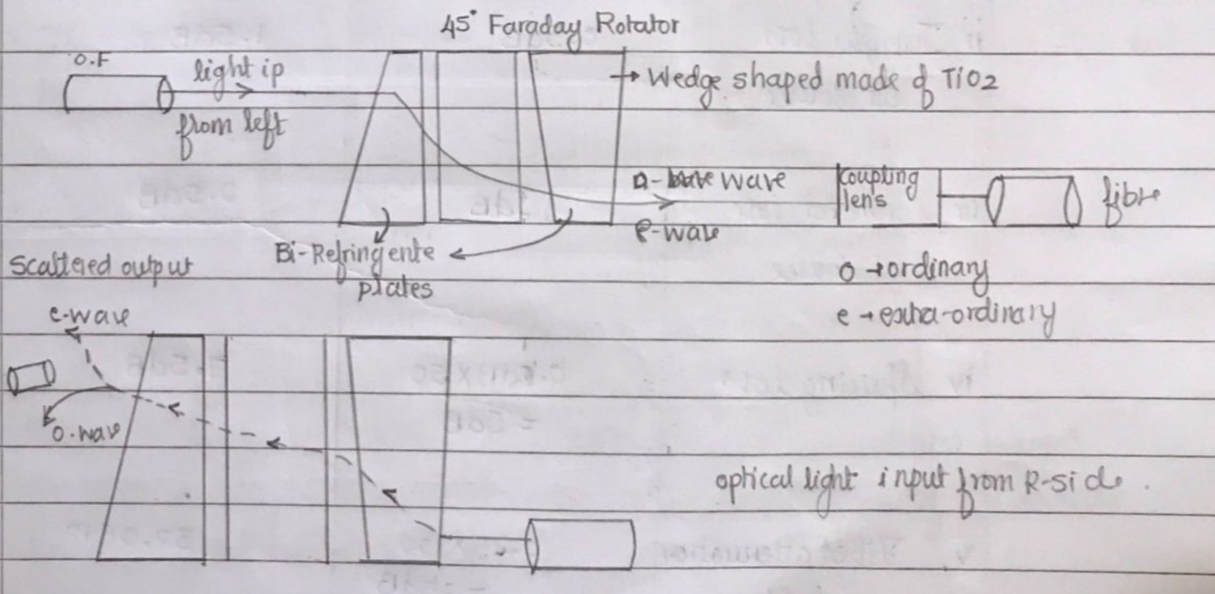
ISOLATORS AND CIRCULATORS :

Their working is based on polarization and are hence called "(POLARISATION SENSITIVE DEVICES)"

- A light wave is a combination of parallel and perpendicular vibrations of wave which forms two orthogonal plane of polarisation states.
- Faraday rotators is a device which rotates SOP (state of polarisation) by a specific angular waves.
- Walk off polarizer made of bi-refringent materials splits incident light to parallel and perpendicular waves.
- Half wave plate polarizer (HPP) rotates SOP clockwise by 45° when signal travels L to R & counter clockwise by 45° when signal travels from R to L.

i) ISOLATOR

- Allows signal only in one direction used to isolate and protect I/O sources.



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Specifications :

- Central wavelength around which isolator operates : 1350 to 1550nm
- Peak isolation loss loss ≃ 40dB
- I.L < 0.5dB (loss informed direction or coupling loss)
- PD loss < 0.1dB
- PMD < 0.25 psec.

Friday 23 NOV 2018

Solution to test III pattern :-

Available power at the output of ILD = Po = $4mW \times \eta_q$

$= 4mW \times 0.8$

$= 3.2mW$

$= 5.05dB$

Spread sheet for power budget

COMPONENT	LOSSES	MARGIN
i Source-Fiber coupling loss	1dB	1dB
ii Jumper loss at source	0.5dB	1.5dB
iii Connector loss at source	1dB	2.5dB
iv Splicing loss	0.1dB x 50 = 5dB	7.5dB
v. Fiber attenuation loss	0.25 x 100 = 25dB	32.5dB

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Connector loss at reciever	1dB	33.5dB
Jumper loss at reciever	0.5dB	34dB
fiber to detector coupling loss	1dB	35dB
power available at input of detector	5.05dBm - 35dBm = -30dBm	~~~~ -
power margin available	-30dB -(-40dBm) = 10dB	

power available at the input detector is 10dB more than the required power, detection is possible

TOF : Tunable optic fibers

- They are the key components of WDM and DWDM networks used to select the channels at Rx

- Fabricated by (MEMS) or (Braggs grating) methods

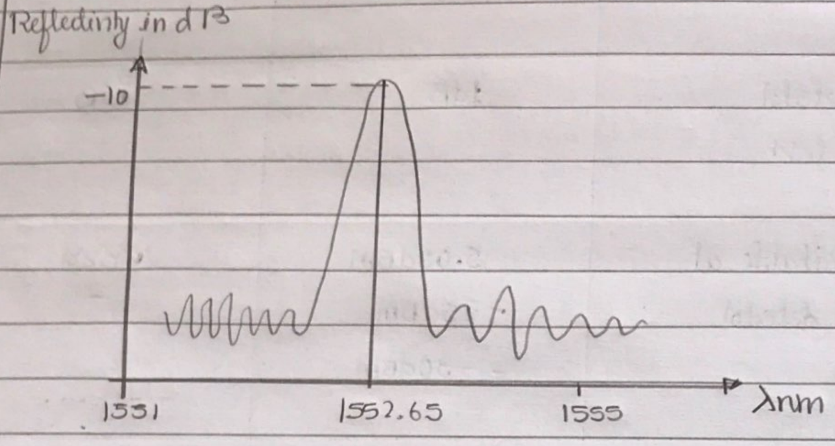
$\downarrow$ MEMS: Wideband BPF

$\downarrow$ Braggs grating: Narrowband BPF

- MEMS technology used ~~~~ epitaxially grown Semiconductor mirror facets on a single substrate, where using actuators one of the ~~mirrors~~ mirrors facet can be varied.

→ This varies B and hence λ can be varied.

→ Bragg's grating filters are reflective type using reflective materials, unwanted wavelengths are rejected and only desired λ can be selected.



→ BGF use streching and relaxing process of spaing between the periodic RI profiles, that varies RI and hence λ can be varied.

→ Alloy glass is used for fabrication.

If λc is centre wavelength of grating then,

$$\boxed{\lambda c = 2\eta_{eff} \, \Lambda}$$

↳ period of grating index variations.

If grating is streched

$$\boxed{\Delta\lambda = 2\eta_{eff} \, \Delta\Lambda}$$

→ Streching and contraction can be done by
- → Thermomechanical method
- → piezo electric method
- → stepper motor

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- TOF are used in II and III window regions
  (SC and L band)

SPECIFICATIONS

- Tunable range : 1nm – 100nm ($\Delta\lambda$)
- channel spacing (FSR) $\simeq$ 150nm • typical
- Selectivity of channel width = 0.2nm to 50nm
  - 0.2nm ↓ narrow band
  - 50nm ↓ wide band.
- I·L < 3dB in the tunable range
- Tuning speed (TS) = 10nm/μsec (typical)

DISADVANTAGE

- large bias voltage = 40V

APPLICATIONS

- Gain tilt monitoring of components in optical Amplifier (OA)
- Optical performance monitoring of survivable optical networks
- Reciever of DWDM and WDM networks
- Suppression of ASE (Amplifier Spontaneous noise in EDFA)

Saturday 24/11/2018

Optical networks:

These networks came into existence because of the requirement in

- commerce – Banks
- ~~banks~~ finance – Markets/Malls
- education
- ~~scientists~~ scientific
- Research
- Medical
- Healthcare
- national and international security
- entertainment

Infrastructure requirements :

- High end terminal equipments / computers / peripherals.
- large storage devices
- high speed channels
- large bandwidth
- BER performance
- low interference / Noise.

Two types of optical networks

i) SONETS
- Synchronous optical networks
- Standard by ANSI used in North America.

ii) SDH
- Synchronous Digital Hierarchy
- ITU
- Rest of the globe

SDH formats are based on

(a) Speed

SDH level	Actual line rate in Mbps	Common or commercial rate in Mbps
STM-1	155.52	155
STM-2	622.08	622
-16	2488.32	2.5Gbps
-64	9953.28	10Gbps
-256	39813.12	40Gbps

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based on link by that and wavelength of operation.

Transmission distance / λ	fiber type	SDH terminology
≤ 2km	G.652	Inter office (I.1)
upto 15km - 1310nm	G.653	Short haul (S.2)
upto 15km - 1550nm	G.653	Short haul (S.2)
upto 40km - 1310nm	G.655	long haul (L.3)
upto 80km - 1550nm	G.655	long haul (L.3)
upto 120km - 1550nm	G.655	very long haul (V.4)
upto 160km - 1550nm	G.655	ultra long haul (U.5)

→ G.652 to G.655 Optical fiber cables
  → GRIN - MM : non dispersion shifted
  → GRIN - SM : dispersion shifted
  → operated at 1310nm and 1550nm windows.

1310nm ↓ attenuation min
1550nm ↓ dispersion minimum.

→ Attenuation Criteria (dB/km)
  0.5 to 3.5 at 1310nm → Short Haul
  0.2 to 0.35 at 1510nm → long haul, very long haul, ultralong haul

→ BER performance.
  for
  $B_{T}max = 1Gbps$ BER ≃ 10^{-10}
  $B_T > 1Gbps$ BER ≃ 10^{-12}

→ Sources:
- monomode or singlemode ILD³ & DFBLD³
- σλ → rms 0.1 to 0.2nm in DWDM
  2nm to 20nm in WDM

- In SH communication
  multilayered LEDs ie DH structure are used.

Detectors:

- APDs with $M \simeq 10$ for long haul, very long haul and ultra long haul communication
- $M \simeq 100$ for short haul
- low noise devices
  - Bulk current noise
  - Surface leakage noise.