Majors.

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Beam Splitters

(Step of potential)

Beam splitters is an optical device that splits a beam of incident light into two or many o/ps. This is accomplished by using planar waveguide technology to split optical signal into several o/p.

There are two basic forms of beam splitters according to construction:

1) Plate beam splitter.
2) Cube beam splitter.

The cube beam splitter is of two types:

(i) Polarising cube B.S
(ii) Non polarising cube B.S.

(I) Plate Beam Splitters

→ It consists of thin flat glass plate quoted with a thin film layer that is metallic layer or dielectric coating. It introduces a shift deviation into light beam

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due to the thickness of plate to get normal deviation the incident light works on 45° angle of incidence

↳ It divides the optical beam based on power / wavelength.

↳ Reflected and transmitted optical ~~parts~~ path lengths are different. Paths depends on angle of incidence and thickness of plate.

↳ It is designed for the highest power handling and coating types determines the strength.

Advantages

- Relatively inexpensive
- Light weight.
- Easy to manufacture in larger sizes.

Disadvantages

- Beam shift of transmitted light
- Reflected & transmitted optical paths are different.

(II)

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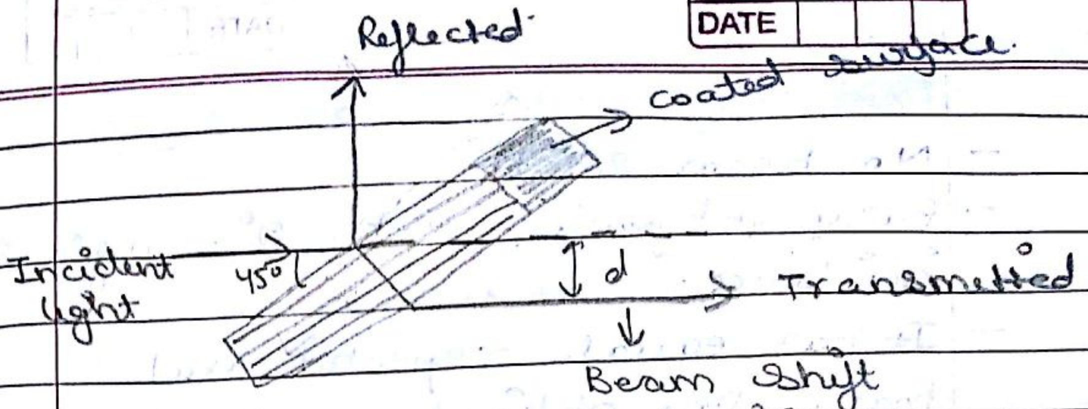

(Plate Beam Splitter).

(II) Cube Beam Splitter

It is composed of two ~~tri~~ triangular glass prism which are joined together at their base using polyester epoxy. It is used to split the incident light into separate polarised components.

There would be two polarised components:

- S - polarised
- ~~P~~ P - ''

It divides an optical beam based on power or polarisation.

S - polarised light is $\perp$ to incident light and P - polarised light is $\parallel$ to incident light.

2

Advantages

- No beam shift
- Easy integration with 0° angle of incidence.
- It has equal reflected and transmitted optical path length.
- Stable & compact.
- Durable
- Easy to mount.

Disadvantages

- Heavy solid glass constant
- It is difficult and more expensive to manufacture in larger sizes.

(i) Polarising Beam splitters (i) (ii) (iii) (iv)

There would be two polarised beams:

- P- polarised beam (transmitted beam)
- S - polarised beam (Reflected ").

It is normally incident upon entrance phase. Each i/p signal will transmit along a different o/p polarisation axis. It is used in photonic instrumentation.

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② Non polarising Beam splitter

Used to split incident light into specific reflected & transmitted or. R/T ratio while maintaining incident light to original polarisation state. So in this case it is 50% reflected & 50% of transmitted beam are there. So there would be same design ratio & is used in ideal laser application.

Application of Beam Splitters:

(i) laser System
(ii) Optical fiber sensor.
(iii) Amplifier combiner
(iv) Biomedical instrumentation.

Optical Amplifiers

Amplifiers

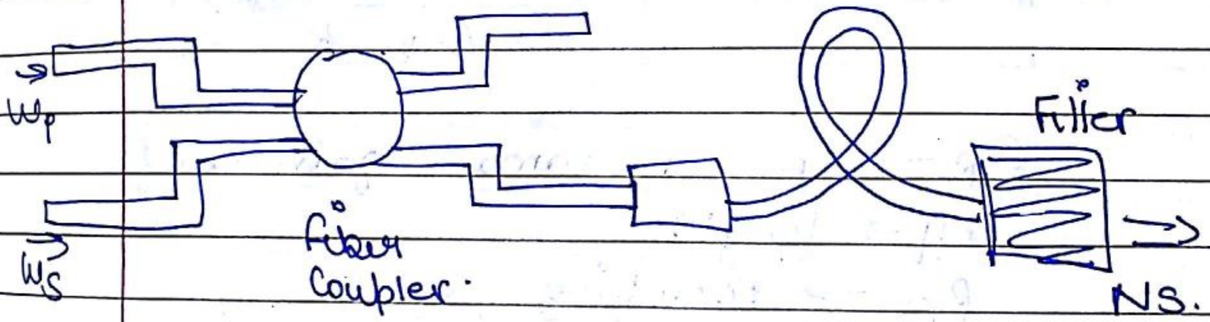
- Raman
- Brillouin
- EDFA (Erbium Doped fiber Amplifier).

(I) Raman Amplifiers

Raman amplifier is an optical amplifier which uses stimulated raman scattering occuring in silica fiber when an intense pump beam propogate through it. SRS differ from stimulated emission as in stimulated emission an incident photon stimulate emission of another identical photon, without losing its energy. In the case of SRS the incident pump photon gives up its energy to create another photon of reduced energy at a lower freq. (inelastic scattering). The remaining energy is absorbed by medium in the form of molecular vibs (optical phonon). thus non linear effects within the optical fiber may also be employed to provide optical amplification.

The basic components of Raman amplifier are:

- Pump laser.
- Wavelength selective coupler.
- Fiber.



$\vec{w_p}$ → pump freq.
$\vec{w_s}$ → signal "

Both are injected into fiber using the fiber coupler. The energy is transfered from pump beam to signal beam through SRS since pump photon must have ~~f~~ higher.

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freq than signal photon & also the pump wavelength is shorter than signal wavelength

Pump signal optical wavelength in Raman amplifier are typically $500 \, cm^{-1}$, higher in freq than the signal to be amplified. The pumping signal can propogate in both direction forward / backward.

Expression of Raman gain:

$$G_R = \exp\left[\frac{g_R \cdot P_p \cdot L_{eff}}{A_{eff} \; K}\right]$$

$G_R \rightarrow$ power raman gain coef.
$L_{eff} \rightarrow$ length
$P_p \rightarrow$ Pumping power.
$A_{eff} \rightarrow$ fiber area core.
$K \rightarrow$ Numerical factor which account for polarisation scrambling b/w opt pump & signal.

Raman gain ↑ if fiber length ↑
" " ↓ " core diameter ↓.

Higher
the

Advan

- High
- Sel
sig
gain
- Hig
se
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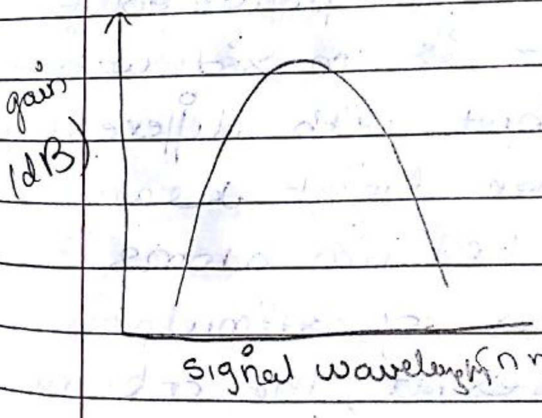
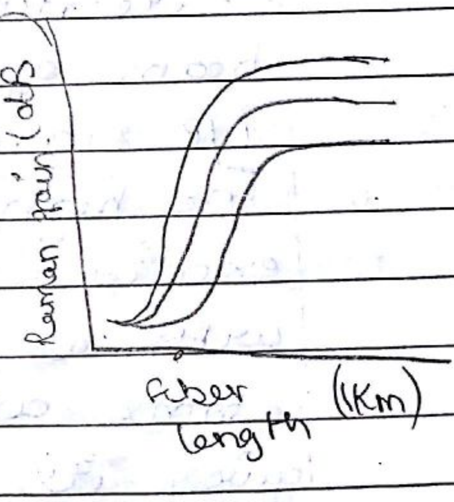
gain (dB)

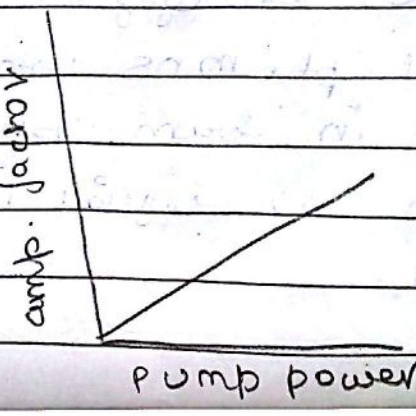
Higher the Raman gain & lower the loss in fiber.

Advantages

- High speed response.
- Self phase matching b/w pump & signal together with a broad gain b.w.
- High gain as compared to semicond laser amp (SLA)
- Offers more stability & insensitivity to reflection.
- Raman amp may be realised as continuous amplification along fiber. Thus signal strength would be normal.







(II) EDFA

(Erbium Doped fiber Amplifier)

Consists of a short portion of fiber where the core of a silica fiber is doped with trivalent erbium ions (Er^{3+}). Like a laser the working principle of EDFA is stimulated emission of erbium ions from higher energy states after absorbing photons of i/p light, the key operation of EDFA is to find a way of getting erbium atoms upto exciting state in order to pump Er^{3+} ions into higher energy level.

∴ relatively high powered beam of light is mixed with i/p signal but with different λ. The high power light beam excited the erbium atoms with a process of stimulated atoms as a result, the Erbium gives its energy in form of additional photons which are exactly in same phase & direction as signal i.e to be amplified

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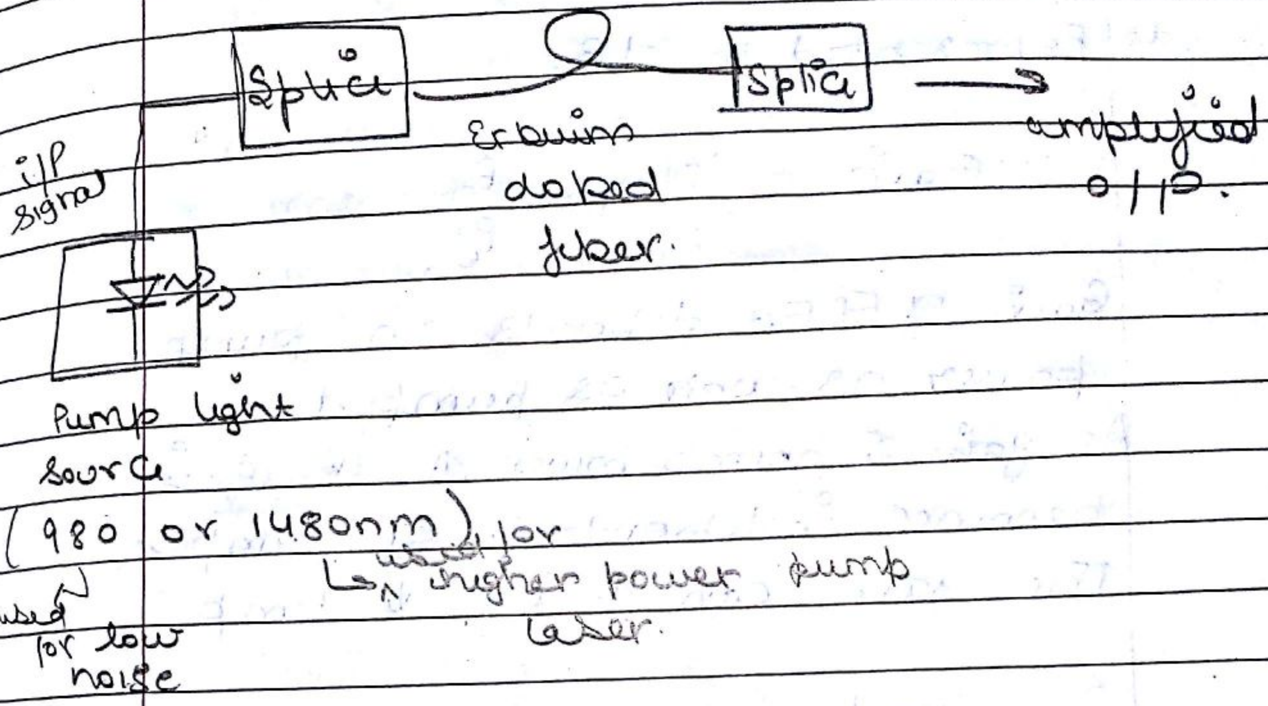
Working Principle



Features

- Wide b-w around 20-70nm.
- High gain
- Insensitive to bit rate
- These are all opt fiber compatible with minimal interchannel crosstalk.
- Low distortion, insertion loss, noise etc.

Gain

↳ Ratio of o/p signal to i/p signal power.

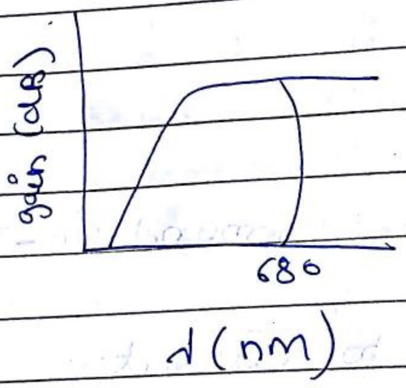
↳ Represented in dB.

$$\text{Gain} = 10\log_{10}\frac{P_o}{P_i}$$

Gain of EDFA depends on pump power as well as pump λ.

As ~~gain~~ pump power ↑ ∴ the gain becomes independent of pump λ.

The gain can ↑ by ↓ temp.



* Gain flatening :

relative flat gain > 20dB is

used for WDM app.

* Gain Saturation

After ↑ pumping power ~~above~~ to a particular level all the dopened are excited will

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not ↑ pop^n of excited level any further and gain saturation will take place. further as i/p signal ↑ inversion level reduces & there will be no further amplification. The max o/p power beyond which no amplification occurs is known as gain saturation.

Noise figure

(quality of amplification).

$$NF = \frac{SNR\,(i/p)}{SNR\,(o/p)}$$

Advantages

- Gain is flat so they can be cascaded for long distance.
- High power transfer efficiency.
- It provides inline amplification of signal without requiring the electronics i.e no need to convert signal to electrical, the amplification is entirely optical.

Optical Amplifier

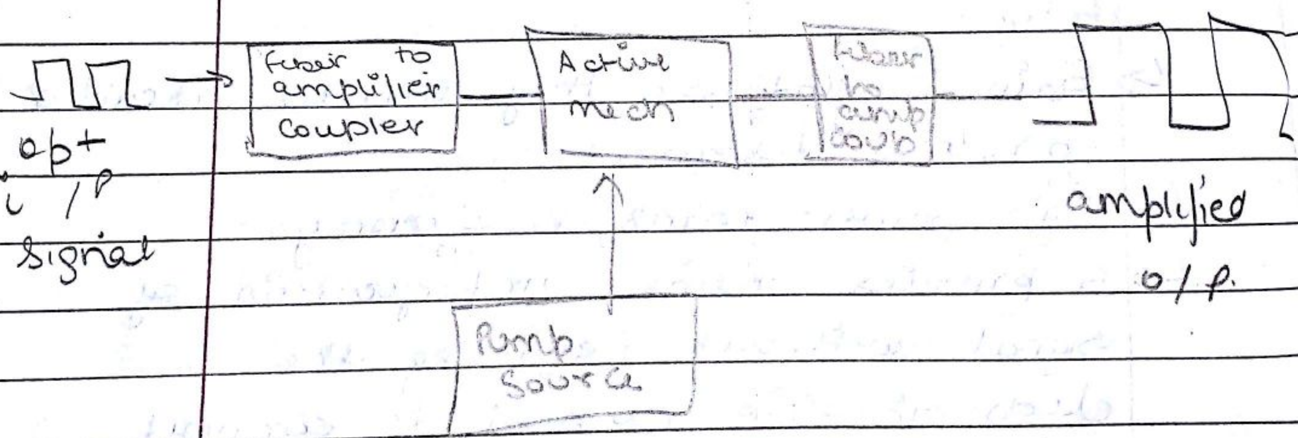
They provide inline amplification of optical signals by affecting.

stimulated emission of photons by rare earth ions.

Erbium, SiO_2, GeO_2 are implanted in core of optical fiber. Erbium is prefered.

EDFA's are used to provide amplification in long dist opt comm with fiber loss less than 2dB/Km by providing amp in long λ window

(III) Stimulated Brillouin Scattering



$$P_B = 4.4 \times 10^{-3}\, d^2 \lambda^2 (\alpha\ dB)\, B \text{ watts.}$$

d — core diameter (μm)

λ — (μm)

α — (dB/km)

B — Source b.w (GHz).

(pru theory).

Mechanism

opt amp increase the power level of incident light through a stimulated process. It also uses popⁿ inversion b/w ip is incoherent light.

Device absorbs energy supplied from ext source called pump. The pump supplies energy to e⁻ in active medium which raises them to higher energy level to produce popⁿ inversion. SBS can also transfer energy from high freq channel to low freq channel, when channel spacing equals brillouin shift. SBS occurs only in backward direction with freq shift given by:

$$\Omega_B = 2V_A |K_p|$$

$$K_p = \frac{2\pi \bar{n}}{\lambda_p}$$

↳ pump λ.

Brillouin shift is given by

$$\nu_B = \frac{\Omega_B}{2\pi} = \frac{2\bar{n}\, V_A}{\lambda_p}$$

$\bar{n} \rightarrow$ mode index.

- SBS is most efficient non linear amplifier.
- High gain
- It is a narrow band process
- It doesn't induce inter channel crosstalk.

Advantages

- used for channel selection within a WDM system by allowing amp of a channel without other nearby channel.

Limitations

→ Low spectral B.W hence can be employed for wide band application.

→ Bidirection WDM app results in crosstalk

→ Restricts range of application

Application

→ Long dist pt to pt opt fibre link.

→ Pre amp are used to improve the Rx sensitivity.

→ used to ↑ Transmitted power.

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Optical fiber Connections

Fiber Splices

A permanent joint formed b/w two individual optical fibers in field or factory is called fiber splice. It is used to establish long haul optical fiber links where smaller fiber lengths need to be joined., & there is no requirement for repeated connection & disconnection.

A requirement with fibers intended for splicing is that they have smooth and square end faces. (using scribe).

Types of fiber splices :

① Fusion Splices

The fusion splicing of single fibers involves the heating of two prepared fiber ends to their fusing pt with application of sufficient axial pressure b/w 2 optical fibers. It is ∴ essential that the stripped fiber ends are adequately positioned & aligned positioned & aligned in order to achieve good continuity of transmission medium at junction pt. Hence fibers are usually positioned & clamped with aid of inspection microscope.

Most widely used heating source is electric arc. Others are microplasma torches.

Prefusion: before fusion, the fiber ends ~~with~~ are rounded with low energy discharge before pressing the fibers together & fusing with stronger arc.

(2) Mechanical Splices

A common method involves the use of accurately produced rigid alignment tube into which prepared fiber ends are permanently bonded. Transparent adhesive is injected through a transverse bore in capillary.

to give mechanical sealing &
index matching of splice.

Other method is use of V groove into which two prepared fiber ends are pressed.

(3) multiple Splices

Multiple simultaneous fusion splicing of an array of fibers in a ribbon cable has been demonstrated for both multimode and single mode fibers. In both cases 12 - fiber ribbon was prepared by scoring & breaking prior to pressing fiber ends onto a contact plate. An electric arc fusing device was then employed to provide simultaneous fusion.

Fiber Connectors

It terminates the of an optical fiber, and enables quicker connection and disconnection than splicing. The connectors mechanically couple & align the cores of fibers so light can pass.

Better connectors lose very little light due to reflection of fibers.

(I) Cylindrical ferrule connectors

The two fibers to be connected are permanently bonded in metal plugs known as ferrules which have an accurately drilled central hole in their end faces where the stripped fiber is located within the connector the 2 ferrules are placed in an alignment sleeves which, using accurately machined components, allows fiber ends to be butt joined.

(II) SMA

- Insertion loss (dB) = 1.00 – 1.50.
- A slotted screw-on connector; preferred in multimode fiber; data comm; multimedia & instrumentation connections.

(III) FDDI

A push on, pull off type of dual connector primarily used with multimode fiber in LANs.

I.L : 0.20 – 0.70 dB.

Fiber Coupler

- An optical fiber coupler is a device that distributes light from a main fiber into one or more branch fibers.

- Optical fiber couplers are often passive devices in which power transfer takes place either:
  - through the fiber core cross section by butt joining the fibers.

Types.

3&4 port Three & 4 port couplers, which are used for signal splitting, dist^n & combining	Star couplers which are generally used for distributing a single i/p signal into multiple o/ps.	Wavelength Division multiplexing (WDM) devices, which are specialized form of coupler designed to permit a no. of different peak λ opt signal to be transmitted in ∥e on single fiber.

WDM couples combine different λ opt signal onto fiber.

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Direct Detection Rx Performance

* Noise

It is a term used to refer to any spurious that mask the received signal in comm system. It O.F.C system we are concerned with noise due to spontaneous fluctuations rather than erratic disturbances.

There are 3 main types of noise due to spontaneous fluctuations :

(I) Thermal Noise

It is spontaneous fluctuation due to thermal interaction b/w the free e^- & vibrating ions in a conducting medium, it is prevalent in resistors at room temp.

$$\bar{i}_2 = \frac{4KTB}{R}$$

K → Boltzmann const

T → absolute temp.

B → post detection b.w of system.

R → Resistance

$\bar{i}_2$ → thermal noise current

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(II) Dark current noise

When there is no opt power incident on photodetector a small leakage current still flows from device terminals. This dark current contributes to total system noise & gives random fluctuations about avg particle flow of photo current

$$\overline{i_d^2} = 2eBI_d \rightarrow \text{dark current}$$

charge on e⁻

(III) Quantum Noise

The quantum behavior of EM radiation must be taken into account at opt freq since $hf > KT$ & quantum fluctuations dominate over thermal fluctuations.

Rx Noise

I) P-n & P-i-n photodiode Rx

The two main sources of noise in photodiodes without internal gain are dark current & quantum noise.

When these two noises are combined the total noise ($\overline{i_{TS}^2}$) is given as

$$i_{TS}^2 = 2eB(I_p + I_d)$$

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(II) Rx capacitance & B.W

The total capacitance for the front end of an opt Rx C_T is given by:-

$$C_T = C_d + C_a.$$

$C_d \rightarrow$ detector capacitance.
$C_a \rightarrow$ amplifier i/P "

The post detection b.w, B:

$$B \leq \frac{1}{2\pi R_L C_T}.$$

$R_L \rightarrow$ load resistance.

(III) Avalanche Photodiode (APD) Rx:

The internal gain mechanism in an APD ↑ the signal current into amplifier & so improves the SNR because the load resistance & amp noise remain unaffected.

However, the dark current & quantum noise are ↑ by multiplication process & may become a limiting factor.

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SNR for APD

$$\frac{S}{N} = \frac{M^2 I_p^2}{2eB(I_p + I_d)M^{2+x} + \frac{4KTBF_n}{R_L}}$$

$M \rightarrow$ factor by which photocurrent is $\uparrow$.

$x \rightarrow 0.3 - 0.5$ for ~~b/w~~ Si
$0.7 - 1.0 \rightarrow$ Ge.

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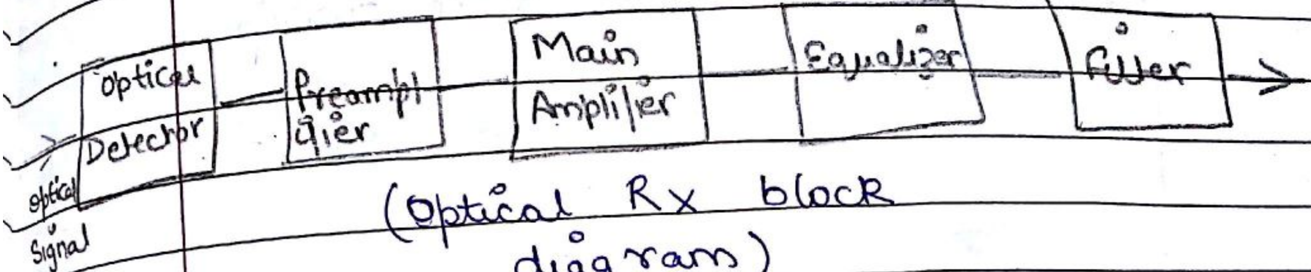
The Optical Receiver Circuit

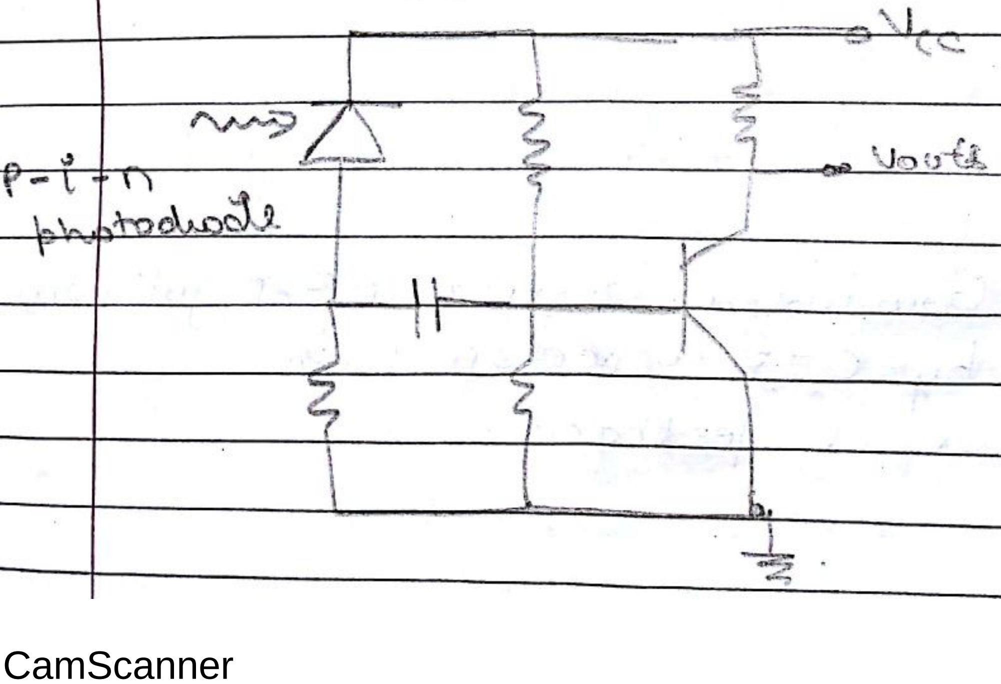


(Optical Rx block diagram)

Preamplifier

A preamplifier is an electronic amplifier that prepares a small electrical signal for further amplification

The simplest preamplifier structure is low - I/P - impedance voltage amplifier. This design is usually implemented using a bipolar config.



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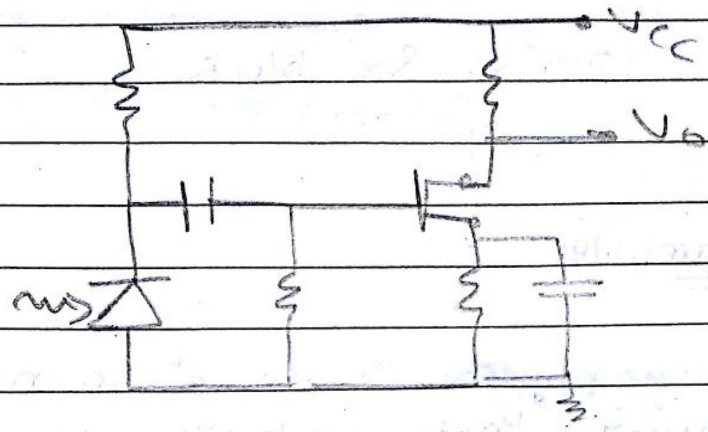
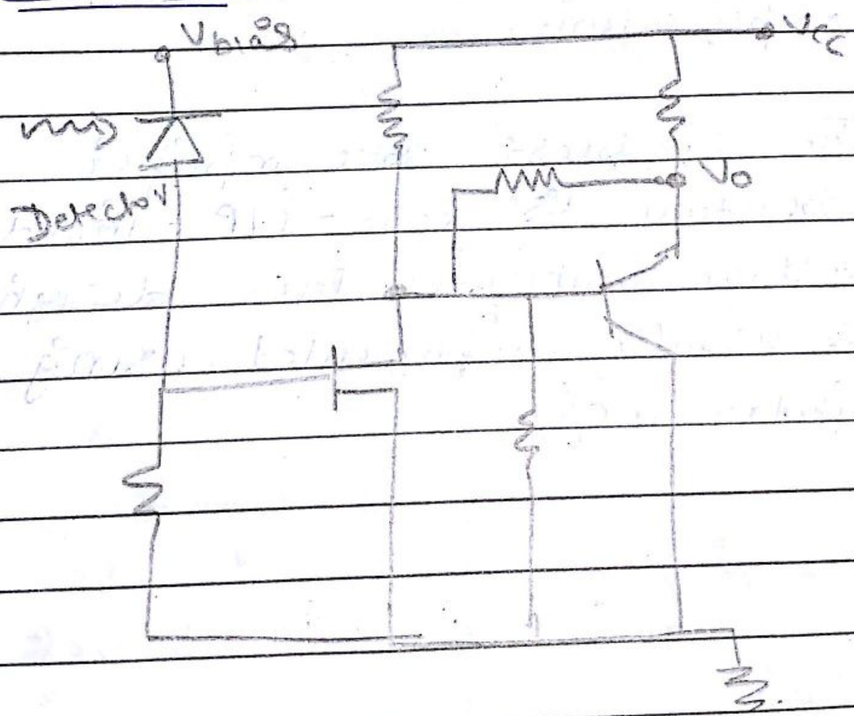
The prefered preamp config for low noise operation use either high integrating front-end or trans impedance amp



At Rx end



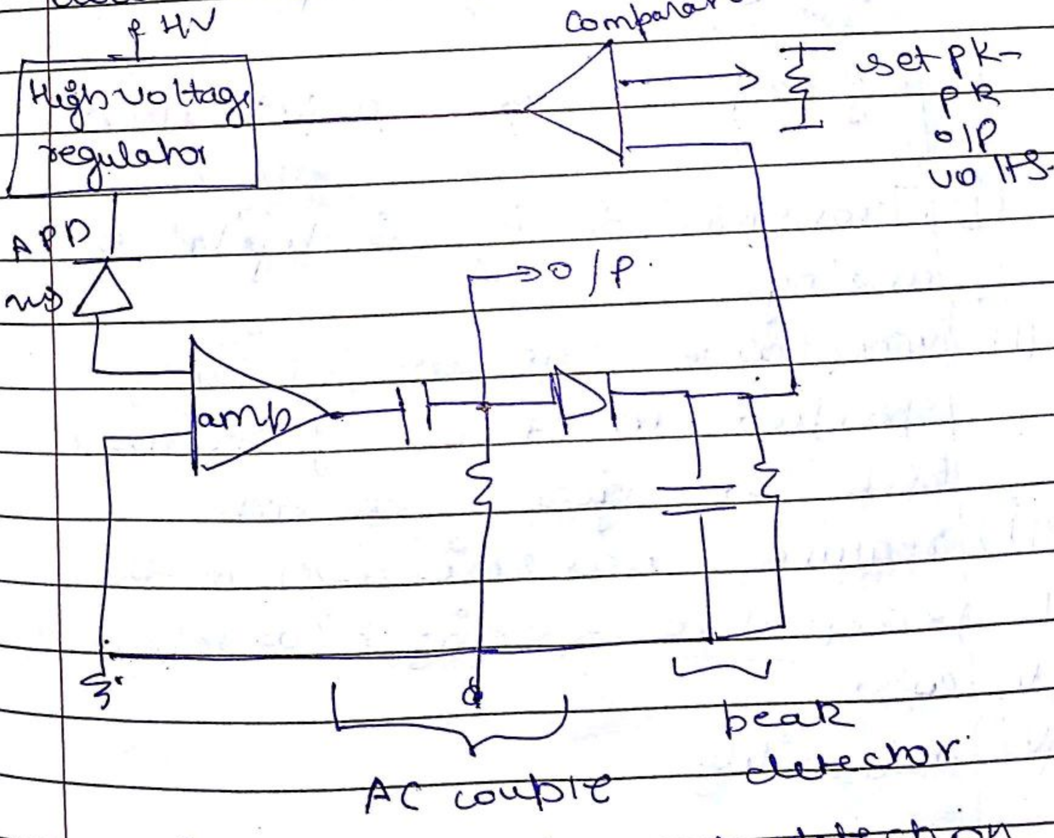
Grounded source FET followed by C-E connection with shunt feedback.

Automatic Gain Control

AGC reduces the dynamic range of signals applied to preamp giving increased optical dynamic range at Rx i/p.

one method of providing AGC is simply to bias APD with a const dc. current source I_{bias}.

A widely used method allows effect of variations in detector dark current while providing critical AGC is to peak detect the a.c coupled signal after suitable low noise amp.



(Bias of an APD by peak detection & feedback to provide AGC.

Equalization

The pulse overlapping causing ISI can be reduced through incorporation of suitable equalizer with freq response $H_{eq}(\omega)$ such that

$$H_{eq}(\omega) = \frac{F\{h_{out}(t)\}}{F\{h_A(t)\}} = \frac{H_{out}'(\omega)}{H_A(\omega)}$$

The equalizer will provide high freq enhancement in linear channel to compensate for high freq roll-off in recieved pulses, thus giving desired pulse shape

System design considerations

(i) Transmission type : digital or analog.

(ii) acceptable system fidelity, specified in terms of receiver BER for digital system.

(iii) required transmission b-ω

(iv) acceptable spacing b/w repeaters

(v) cost

(vi) reliability.

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Component choice

Major component choices available for system:

(i) O.F type and parameters:
multimode or single mode, size, ref index profile, attenuation, dispersion etc.

(ii) Source type & characterstics:
Laser or LED.

(iii) Tx config: design for digital or analog transmission.

(iv) Detector type: avalanche diode, p-n, p-i-n.

(v) Rx config: preamp design, BER or SNR.

(vi) Modulation & coding:
source intensity modulation.

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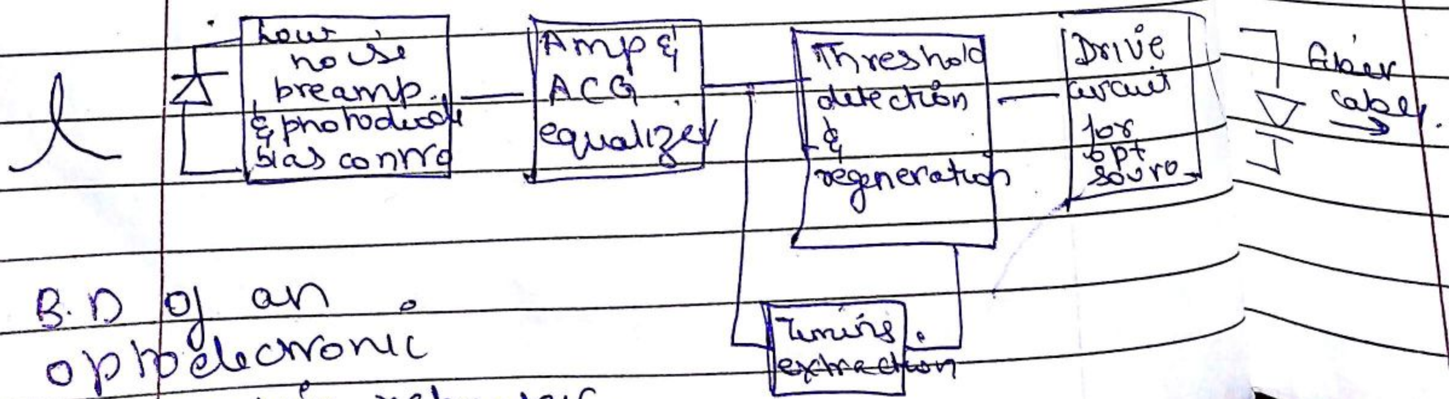
* Multiplexing

Used to maximise info transfer over an O.F.C link it usual to multiplex several signals onto a single fiber. It is possible to convey these multichannel signals by multiplexing in electrical ~~time~~ time or freq. Domain
(WDM; DWDM; TDM; FDM.

* Optoelectronic Regenerative Repeater

A regerative repeater consists of a photodiode followed by a low noise preamp. The electrical signal thus acquired is given a further ↑ in power level in main amp prior to reshaping to compensate for transfer characteristic of O.F using equalizer



B.D of an optoelectronic regenerative repeater.

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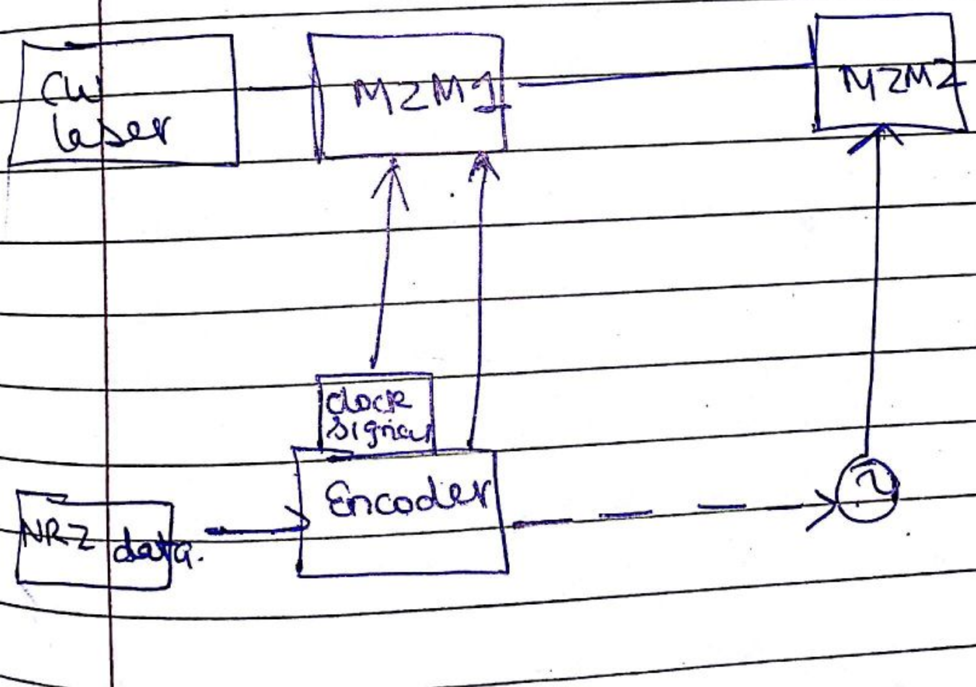
* Optical Tx

The avg power launched into fiber from Tx depends upon type of source used & required system bit rate.
The signal generated by opt. source is required to be modulated in Tx prior to transmission over O.F link. There are 2 major modulation formats — NRZ & RZ.
↑ prefered.



R-Z signal format Tx.