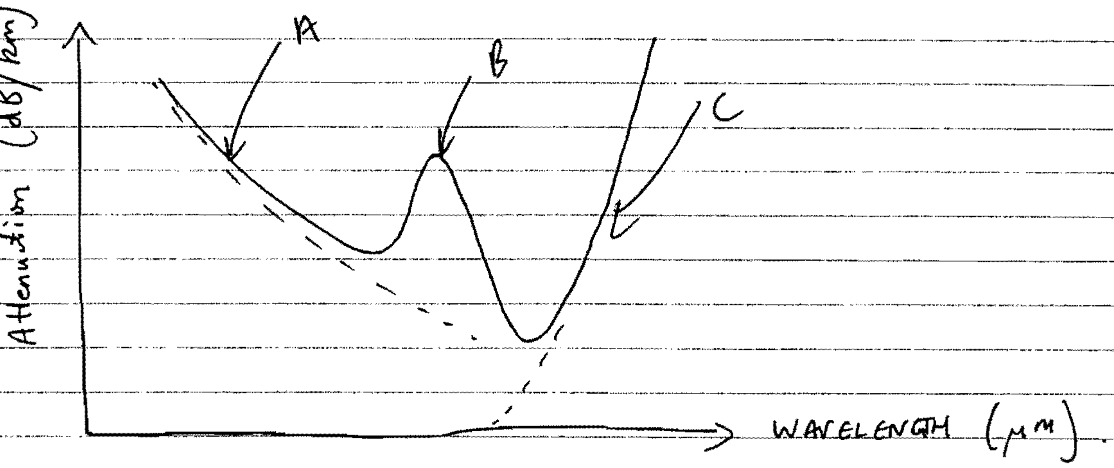
(a).



A – Rayleigh scattering. Scattering from variations in refractive index on $<\lambda$ scale. Rate $\propto \lambda^{-4}$

B – OH^- (water) impurity.

C – "Infra-red Absorption – excitation of Si–O, Ge–O vibrational resonances.

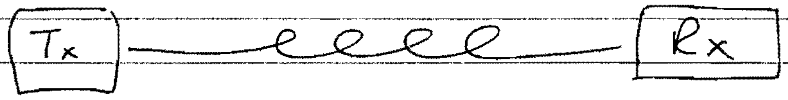
(4)

(b). Chromatic dispersion acts to temporaly broaden an optical pulse. If this is too large intersymbol interference takes place. (2)

Attenuation acts to reduce the intensity of the optical signal. If this is too large errors are caused in differentiating a '0' and '1'. (2)

These effects occur 'per unit length'. There is therefore a length at which either may prevent transmission.

c)



$B = 10$ GBit/s $\quad D = 0.8$ ps/(nm.km) $\quad P_{rec} = -15$ dBm

$\Delta\lambda = 2$ nm $\quad \alpha = 0.4$ dB/km

$P_{LAUNCH} = 5$ dBm

$\lambda = 1310$ nm $\quad$ n.b. margin $= 15$ dB

Loss Limit

$P_{LAUNCH} = 5$ dBm $\quad \therefore$ Budget $= 20$ dB $-$ Margin

$P_{REC} = -15$ dBm $\quad = 5$ dB

Total Distance $= \dfrac{\text{Budget}}{\text{Attenuation Coefficient}} = \dfrac{5}{0.4} = 12.5$ km.

Dispersion Limit

$B L \Delta\lambda D(\lambda) \leq \frac{1}{4}$!

$\Delta\lambda\, D(\lambda) = 2 \times 0.8$ ps/km $= 1.6$ ps/km $= 1.6 \times 10^{-15}$ s/m

$BL \leq \dfrac{1}{4 \times 1.6 \times 10^{-15}}$

$L \leq \dfrac{1}{4 \times 1.6 \times 10^{-15} \times 10 \times 10^{-9}}$

$L = 15.625$ km.

So system is loss limited @ 12.5 km.

Tx

Need to increase P_{LAUNCH}. Practical Limit is ~10dBm

If this is done → Loss Limit is 25 km so now Dispersion Limited. Could reduce linewidth to increase L in this case.

Rx

Need to reduce P_{REC} to increase available Power Budget.

Dispersion compensation fibre to be inserted?

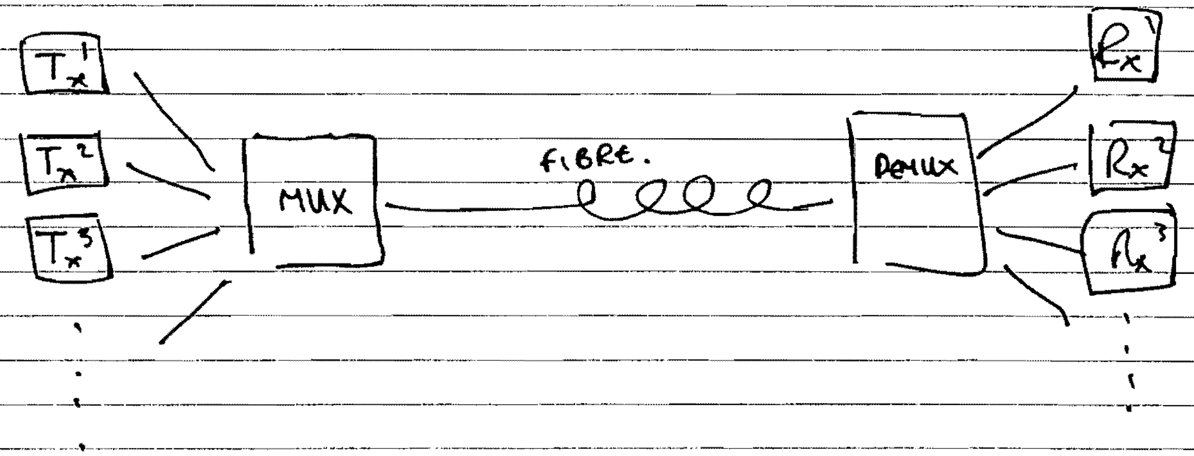
(4)

(a). WDM LINK.

RELIES UPON SPLITTING UP WAVELENGTH SPECTRUM INTO A NUMBER OF CHANNELS.

THE CHANNEL SPACING MUST BE SIGNIFICANTLY LARGER THAN THE TRANSMITTER LINEWIDTH. IN ORDER TO MAXIMISE # OF CHANNELS THE TRANSMITTER LINEWIDTH SHOULD BE AS SMALL AS POSSIBLE.

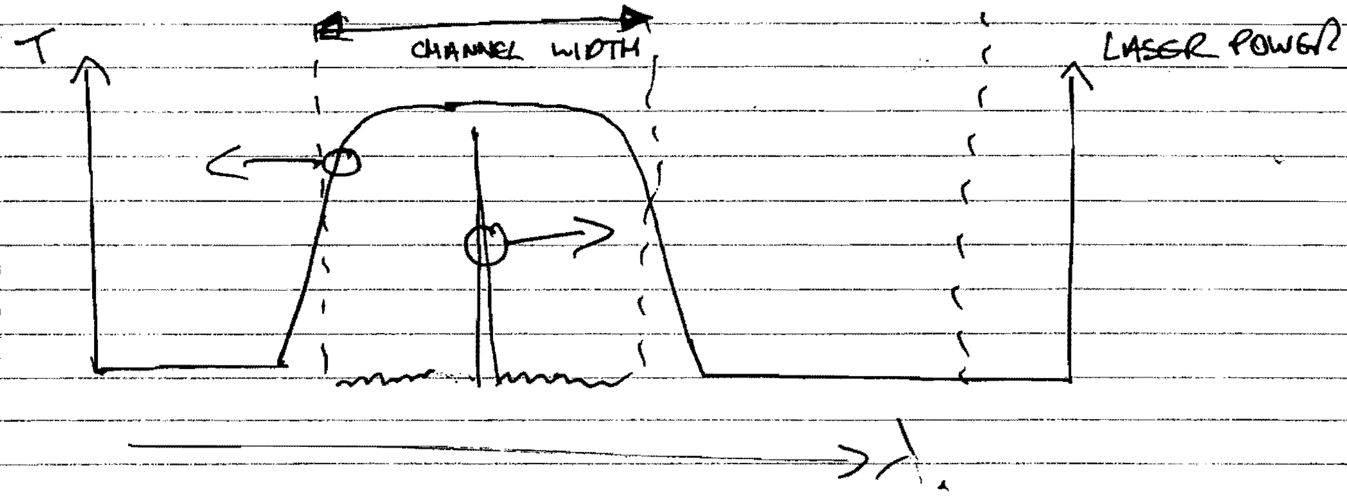
THE LINK MAY BE DRAWN SCHEMATICALLY BELOW.



MULTIPLEXER & DE-MUX COMPONENTS ARE REQUIRED

THE MULTIPLEXER MAY BE SIMPLER THAN THE DEMULTIPLEXER IT MAY BE A NUMBER OF FUSED FIBRES → PASSIVE COUPLER.

THE DEMUX COMPONENT IS A FILTER WITH SUITABLY NARROW BAND-WIDTH (i.e. VERY HIGH FINESSE FILTER).

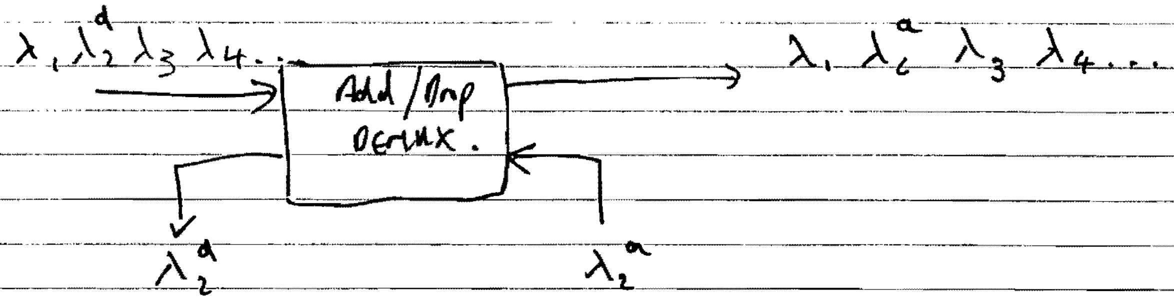


(8).

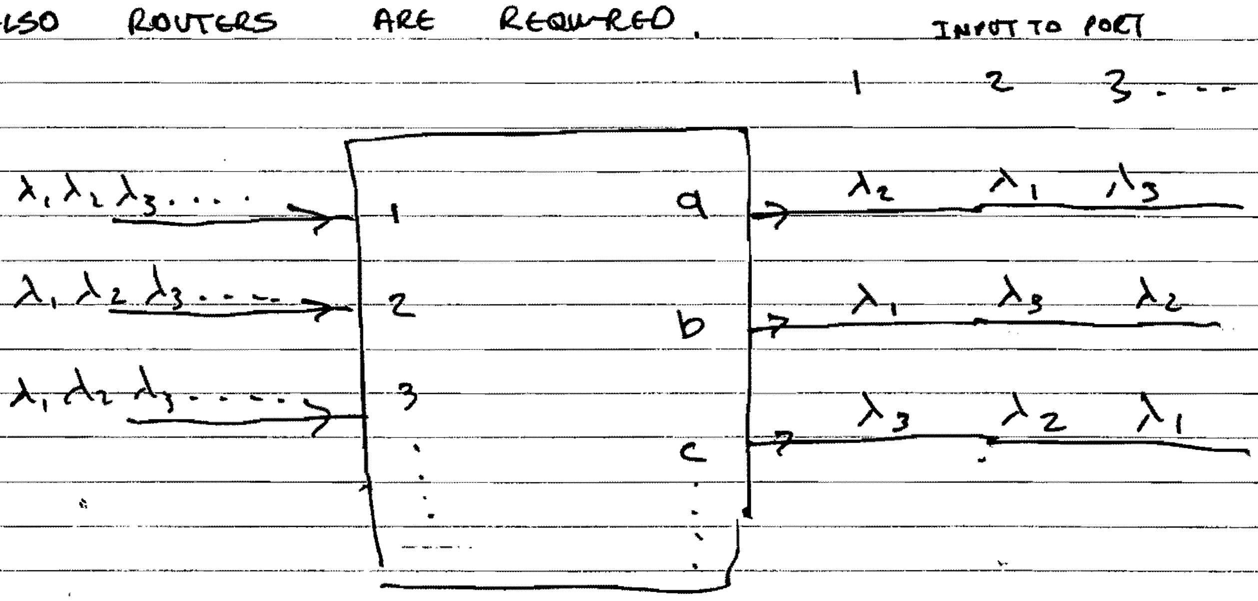
(b) WDM NETWORK.

REQUIRES ADDITIONAL COMPONENTS COMPARED TO A LINK.

ADD / DROP DEMUX FUNCTION IS ATTRACTIVE.



ALSO ROUTERS ARE REQUIRED.



N.B. * WILL ACCEPT DISCUSSION ON CIRCULATORS .... NOT PRESENTED BUT IN BOOKS (!?).
* ALSO SOAs → IMPORTANT BUT NOT NECESSARY.

NOISE.

INTER-CHANNEL ("OUT OF BAND") CROSSTALK. ⇒ DUE TO FINITE EXTINCTION OF NEIGHBOURING OPTICAL CHANNELS.
e.g. λ_1 "leaking" thru to R_x^2 DUE TO DEMUX.

+ IN-BAND CROSSTALK.

DUE TO ADD/DROP DEMUX / ROUTERS ALLOWING SIGNAL OF SAME λ FROM OTHER PHYSICAL CHANNELS.

+ SOA NOISE (NOT OBVIOUS).

ALL DEMUX, ROUTERS NEED HIGH FINESSE & HIGH EXTINCTION, NARROW LINEWIDTH...

(c). CHROMATIC DISPERSION

→ BROADENING OF OPTICAL PULSE AS DISTANCE PROPAGATED INCREASES.

→ INCREASE IN INTER-CHANNEL CROSS-TALK

→ INCREASED BER

→ PAY POWER PENALTY TO RECOVER REQUIRED BER a). A = p -doped InP

B = intrinsic InGaAs (Quaternary alloys accepted).

C = n doped InP. (3).

b). High Responsivity.

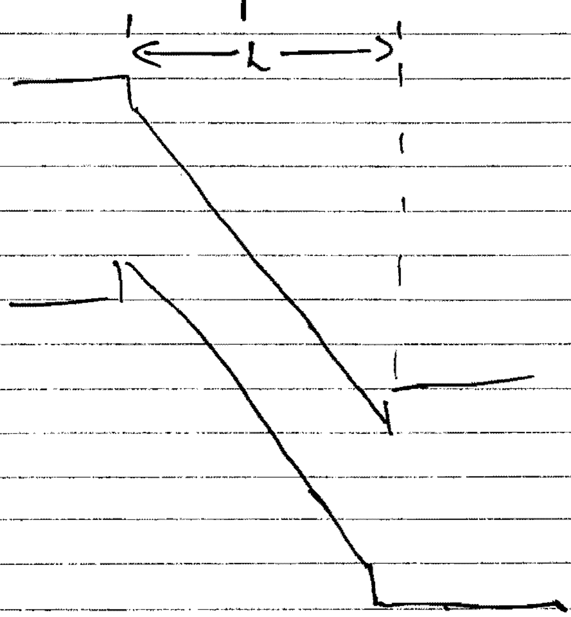
Internal Quantum Efficiency $\eta_{int} = 1 - e^{-\alpha L}$

so for high efficiency / responsivity need $\alpha L > 1$

as responsivity $= \dfrac{\eta_{int}\, q}{h\nu}$ (2)

High Speed - Limits.

1). Carrier sweep out time.



Carrier collection time (t_{col})

$t_{col} = \dfrac{L}{V_{sat}}$

where V_{sat} = Saturation velocity of carriers

so want L small. (2)

2) RC time constant.

p-i-n diode is a capacitor. $C = \frac{\varepsilon\varepsilon_0 A}{L}$.

to minimese RC need L big. (2).

$$t_{col} = \frac{L}{V_{sat}}$$

$$t_{RC} = \frac{R\varepsilon\varepsilon_0 A}{L}$$ equating t_{col} & t_{RC}.

$$\frac{L}{V_{sat}} = \frac{R\varepsilon\varepsilon_0 A}{L}$$

(2).

$$L = \sqrt{R\varepsilon\varepsilon_0 A V_{SAT}}$$

C. EFFECT OF TEMPERATURE ON PHOTODIODE.

1) INCREASE THERMAL NOISE – WHICH IS MAIN SOURCE OF NOISE. EFFECT ON SYSTEM IS TO INCREASE BIT-ERROR-RATE. IF BER IS TO BE MAINTAINED A POWER PENALTY MUST BE PAID.

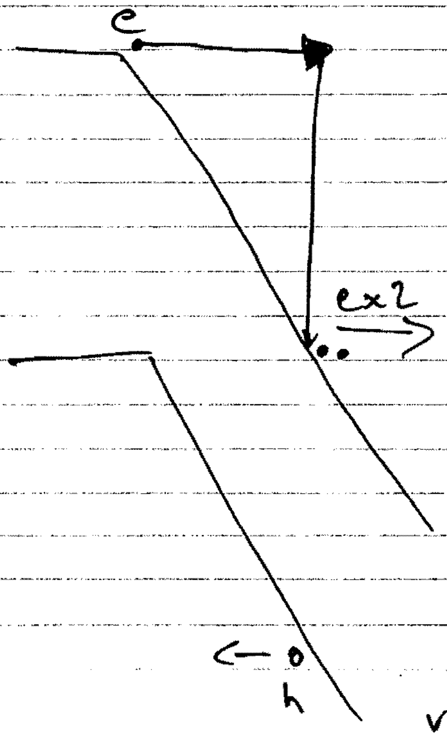
(2).

d) Electrical Gain is via Impact Ionization which results in current multiplication.

Impact Ionization occurs when under a high electric field carriers obtain high excess energies.

When this excess energy is large enough the energy is lost to the creation of an electron-hole pair, resulting in current multiplication.

This process can run-away resulting in avalanche breakdown and this is the breakdown mechanism for high purity p-i-n diodes in reverse bias.



Impact Ionization process for electrons

Device utilizing this mechanism is known as an Avalanche Photo Detector (APD).

(5).

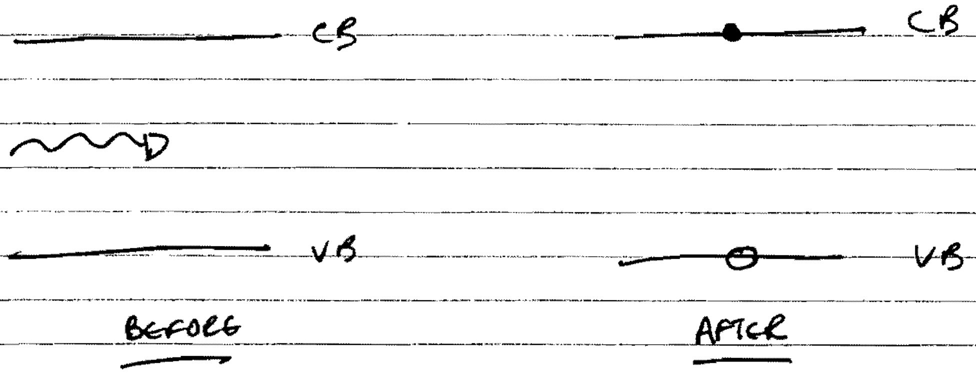
Effect of temperature on APD.

High Temperature provides higher phonon density which provide additional pathway for energy loss of carriers.

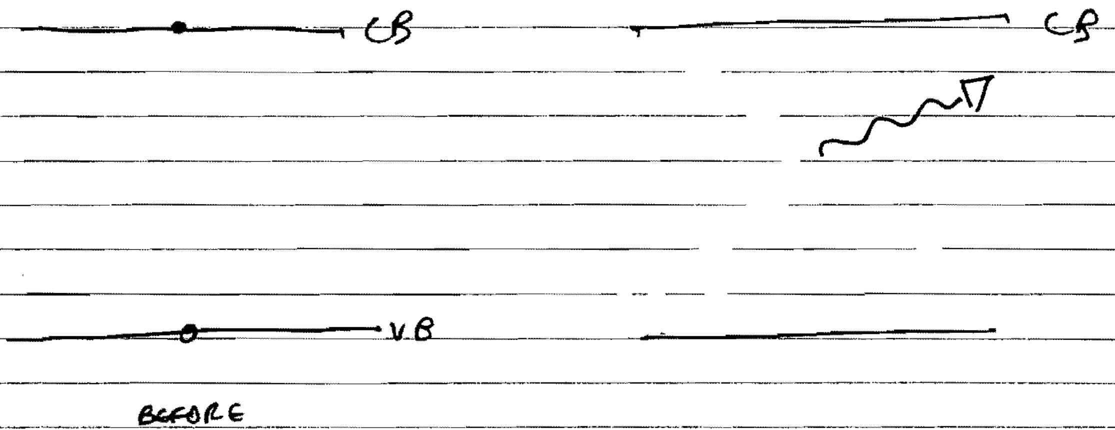
As temperature increases so II coefficients reduce, so gain reduces. APDs are usually cooled.

(2).

a). Absorption → Anihilation of a photon & creation of electron & hole.

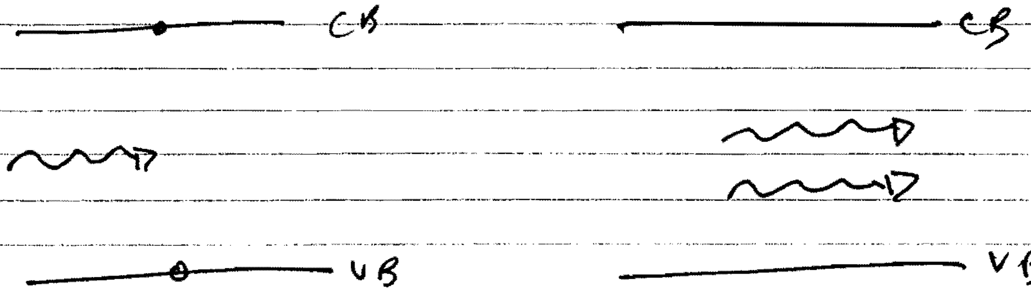


SPONTANEOUS EMISSION → Recombination of an electron & hole to produce a photon with random phase & energy.



STIMULATED EMISSION → Recombination of an electron & hole - stimulated by a photon.

The resultant photon has the same energy phase & direction as the stimulating photon



(3)

(b). From A to C

Rate for Absorption reduces.

Rate for spontaneous emission increases

Rate for stimulated emission increases.

At A : Absorption High
Spontaneous Low
Stimulated Low.

At B : Absorption and Stimulated Emission are equal.
Spontaneous medium.

At C : Absorption Low
Spontaneous High
Stimulated High.

(3).

(c). Straight line so $y = mx + c$

$$g\,(cm^{-1}) = n\,J\,(A\,cm^{-2}) - 40$$

where $n = \frac{4}{50}\ A^{-1}\,cm$.

$$g_{threshold} = \alpha_i + \alpha_m$$

α_i = internal loss
α_m = mirror loss

$$\alpha_m = \frac{1}{2L}\ln R_1R_2$$

$$g_{threshold} = \alpha_i + \frac{1}{2L}\ln R_1R_2 = nJ_{th} - 40$$

(3).

Mim. $J_{th} = \frac{1}{\eta}\left[\frac{1}{2L} \ln R_1 R_2 + \alpha_1 + 40\right]$

Minimising this. L = larger

R_1 = larger

R_2 = larger.

α_i = 0 (minimized). (1).

$I_{th} = W L J_{th}$.

$$I_{th} = \frac{WL}{\eta}\left[\frac{1}{2L} \ln R_1 R_2 + \alpha_i + 40\right]$$

$$I_{th} = \frac{W \ln R_1 R_2}{2\eta} + \frac{W L \alpha_i}{\eta} + \frac{40 WL}{\eta} \quad (2)$$

Minimising I_{th} Increasing L acts to increase I_{th}, but reduces J_{th}.

$R_1 R_2$ increase results in I_{th} reduction

$\alpha_i \rightarrow 0$.

(3).

700 $A\,cm^{-2}$ vs 800 $A\,cm^{-2}$ J_{th} Laser.

Assuming laser is RO - frequency limited.

$$\omega_{RO} = \left(\frac{V_g \cdot \frac{dg}{dn} \cdot P_{MODE}}{\tau_{photon}} \right)^{\frac{1}{2}}$$

v_g = group velocity → not applicable.

$\frac{dg}{dn}$ = constant as straight line.

P_{MODE} = Power in mode ①

τ_{photon} = Photon lifetime ②

① Not really enough information given to discuss this
Would expect same for each laser though.

② τ_{photon} is smaller for 800 $A\,cm^{-2}$ laser as threshold is higher. This laser will have higher modulation rate.

(6)