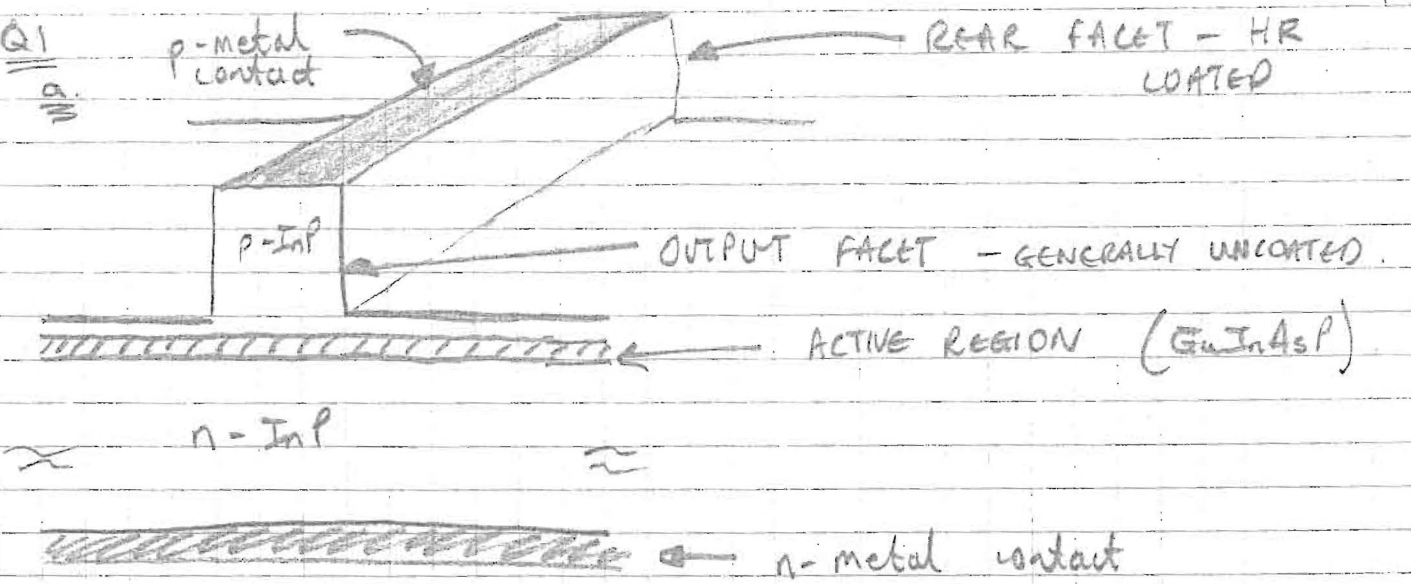
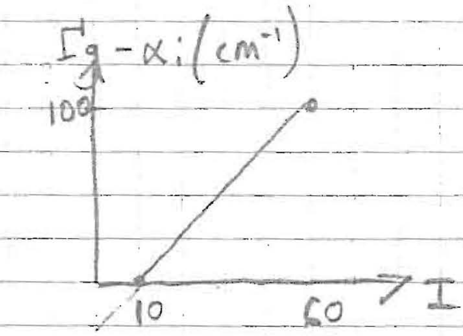
Q1

a.



1 MARK FOR SCHEMATIC, 1 MARK FOR EACH LABEL. [6]

b.



NET MODAL GAIN $= 2(I-10)$.

(α_m)

Threshold current given by mirror loss $\alpha_m = \frac{1}{2L}\ln\left(\frac{1}{R_1 \ldots}\right)$

For 200 µm $\quad \alpha_m = \frac{1}{2\times 2\times 10^{-2}} \cdot \ln\left(\frac{1}{0.3\times 0.3}\right)$

$$\alpha_m = 60 \text{ cm}^{-1}$$

$$2(I-1) = 60$$

[also by inspection of graph]

$$I_{th} = 40 \text{ mA}$$

For 300 µm $\quad \alpha_m = \frac{1}{2\times 3\times 10^{-2}} \cdot \ln\left(\frac{1}{0.3\times 0.3}\right)$

$$\alpha_m = 40 \text{ cm}^{-1}$$

$$2(I-1) = 40$$

$$I_{th} = 30 \text{ mA}$$

[8]

c. Before onset of stimulated emission

$$\frac{dn}{dt} = \frac{J}{qd} - \frac{n}{\tau}$$

n = carrier density
t = time
J = carrier density
q = electron charge
d = thickness
τ = carrier lifetime (probably dominated by spont. emiss & Auger).

For an abrupt change in J

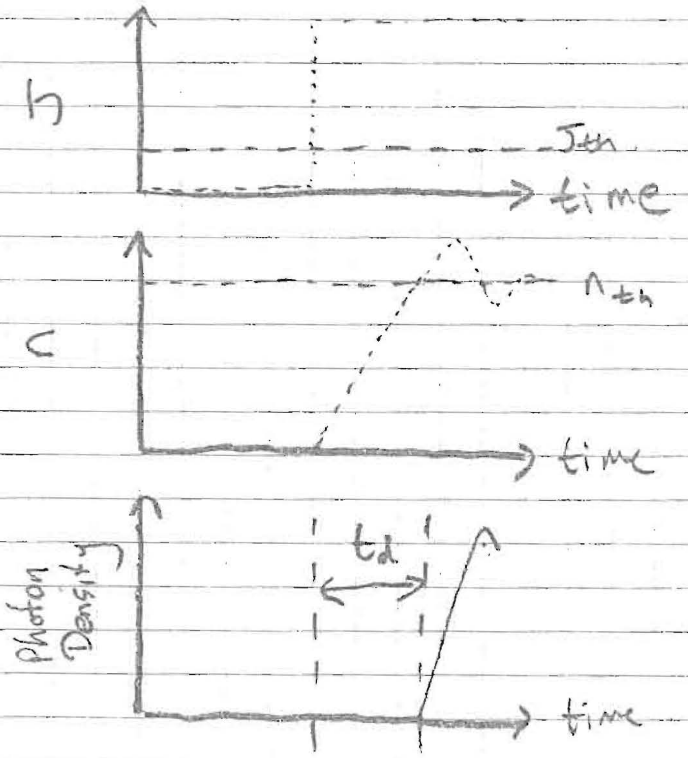
$$\frac{n(t)}{n_{th}} = \frac{J}{J_{th}}\left(1 - e^{-t/\tau}\right)$$

where n_{th} / J_{th} relate to laser threshold

$$t_d = \tau \ln\left(\frac{J}{J - J_{th}}\right)$$

[3]

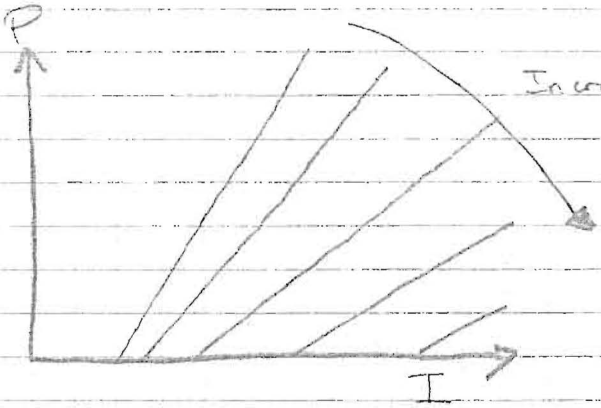
$\tau \sim$ ns so $\sim$ ns delay in laser turn on



[3].

2

a



[1]

2 clear changes with Increasing T:

i) I_{th} Increases. This is due to the reduction in number of carriers at the lasing wavelength due to fermi statistics, and increase in Auger recombination. [2]

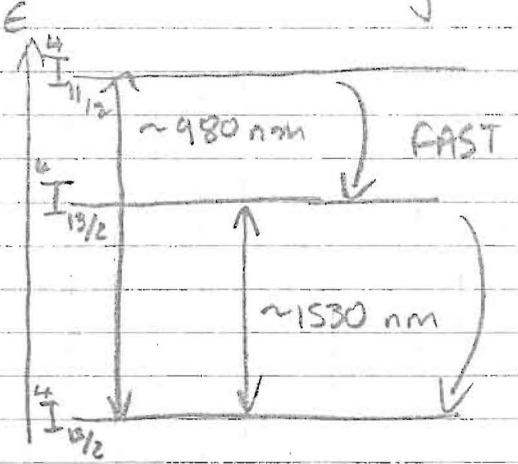
ii) External Efficiency Decreases. Two main causes
a) Reduced internal efficiency due to hot carriers escaping from lasing λ
b) Increased internal loss due to inter-valence-band absorption. [2]

Effect ⟹ Increases BER [1]

b for p-n photodiode increased temperature increases thermal noise in receiver. To maintain constant BER $P_{rec} \propto T^{\frac{1}{2}}$ so you need to increase launch power or amplify the signal optically. [4]

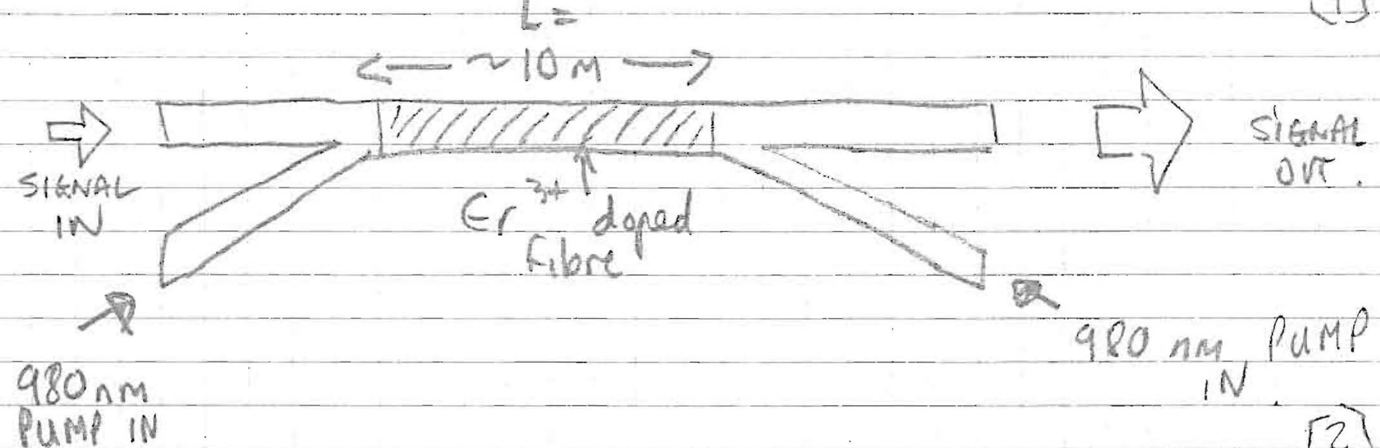
2c

EDFA → Single-mode fibre impregnated with Er^{3+} ions



By exciting this system (pumping) with 980 nm light population inversion and optical gain may be obtained.

[4]



[2]

Advantages over SOA.

Polarization independant

High coupling efficiency

Lower ASE / Noise figure.

Disadvantages over SOA

Tied to 1530 ± 20 nm [2]

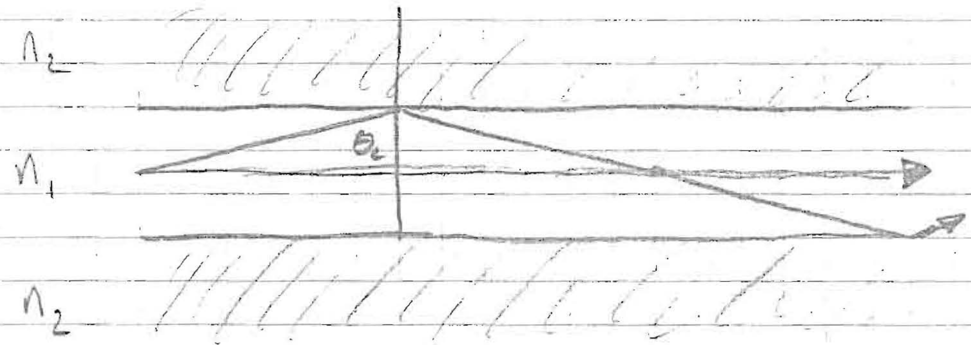
(2)
c EDFA - excess noise in link

This is mainly due to amplified spontaneos emission. ASE arrises as excited Er^{3+} ions may emit light which is guided by the fibre. This light is amplified in the same manner as signal light, producing (excess) noise.

[2]

3a Dispersion acts to temporally broaden an amplitude modulated optical pulse. In extreme cases this results in inter-symbol interference and the (significant) increase in bit-error-rate. [2]

b. In multi-mode fibre, dispersion occurs due to the different path lengths of the allowed modes.



CONSIDER MERIDIONAL & CRITICAL RAY AS TWO EXTREME CASES FOR PATH LENGTH DIFFERENCE

MERIDIONAL RAY:

$$t_M = \frac{L}{v_1} = \frac{L n_1}{c}$$

CRITICAL RAY.

$$t_c = \frac{L n_1}{c \sin\theta_c} = \frac{L n_1}{c}\left(\frac{n_1}{n_2}\right)$$ from Snell's Law

Differential time Delay $\delta t = t_c - t_M = \frac{L n_1}{c}\left[\frac{n_1}{n_2} - 1\right]$

This could be further simplified but this isn't needed

3b cont

$$\frac{\delta t}{L} = \frac{n_1}{c}\left[\frac{n_1}{n_2} - 1\right] = \frac{1.5}{3\times10^8}\left[\frac{1.5}{1.48} - 1\right]$$

$$= \frac{1.5}{3\times10^8} \quad 1.35\times10^{-2}$$

$$= 6.75 \times 10^{-11} \ \mathrm{s\,m^{-1}}$$

Assume δt may be bit slot/4 (could be up to $\frac{1}{2}$ too!)

$$\delta t = L \,.\, 6.76\times10^{-11} \qquad T_B = \frac{1}{\text{Bit Rate}}$$

$$\delta t \leq \frac{1}{4B}$$

$$\therefore \frac{1}{4B} \geqslant L \,.\, 6.76\times10^{-11}$$

$$\frac{1}{4 \,.\, 6.76\times10^{-11}} \geqslant BL$$

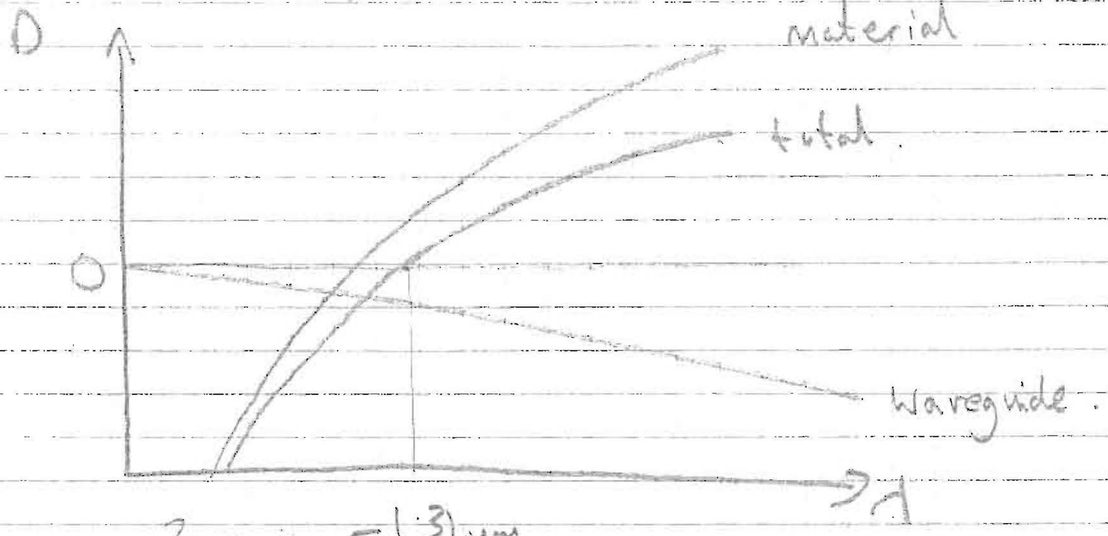
$$3.7\times10^9 \geqslant BL$$

Bits/Sec m

which gives ... $3700 \geqslant B(\text{kBits/sec})\ L(\text{km})$ [8]

3c

Chromatic dispersion → due to group index of Silica fibre being a function of λ. [1]



Zero in dispersion = 1.31 μm. [4]

Dispersion is made up of material dispersion and a correction factor - waveguide dispersion to account for particular fibre designs [1]

⇒ CHOICE OF TRANSMITTER.

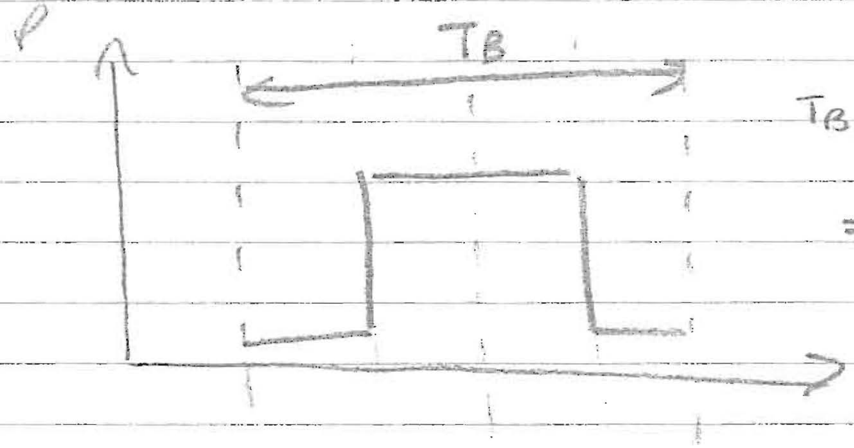
TO MINIMISE DISPERSION EFFECTS A TRANSMITTER A 1.31 μm IS IDEAL HOWEVER THE MINIMUM IN ABSORPTION IS AT ~1.55 μm FOR SMF. AS A RESULT THE CHOICE BECOMES TWO-FOLD FOR A SIMPLE LINK

~ NARROW LINEWIDTH TRANSMITTER @ 1550 nm (OR MANAGE DISPERSION SOME OTHER WAY.

~ MODEST LINEWIDTH TRANSMITTER @ 1310 nm [4]

4 a Visualizing Info...

Tx		Rx
$\lambda = 1.27\,\mu m$ $\Delta\lambda = ?$ $P_{LAUNCH} = 10\,dBm$	$D = (2\,ps/km).\Delta\lambda$ $\alpha = 0.5\,dB/km$	$P_{rec} = -25\,dBm$ $Margin = 20\,dB$



$$T_B = \frac{1}{10 \times 10^9}\ s = 100\ ps.$$

Maximum σT due to dispersion $= 0.4 \times 100\,ps$
$= 40\,ps$

(1) LOSS LIMIT

Power budget gives $P_{Launch} - P_{rec} - Margin = 15\,dB$ of loss which can be used for attenuation in fibre

$$L^{LOSS}_{MAX} = \frac{\text{Available Loss}}{\text{Attenuation Coeff}} = \frac{15\ (dB)}{0.5\ (dB/km)} = 30\ km$$

Dispersion

$BL\Delta\lambda D(\lambda) \leq 2/5 \quad \leftarrow$ from $0.4 \times T_B$

$B = 10\times10^{9}\ s^{-1}$
$\Delta\lambda\ (nm)$
$D(\lambda) = 2ps/km = 2\times10^{-15}\ s/m$

$$L_{MAX} = \frac{2}{5\times10\times10^{9}\ \Delta\lambda(nm)\ 2\times10^{-15}}$$ (L unit is m)

$$L_{MAX} = \frac{1}{5\times10^{-5}\ \Delta\lambda(nm)}$$

$$L_{MAX} = \frac{1\times10^{2}}{5\times\Delta\lambda(nm)}$$ in km

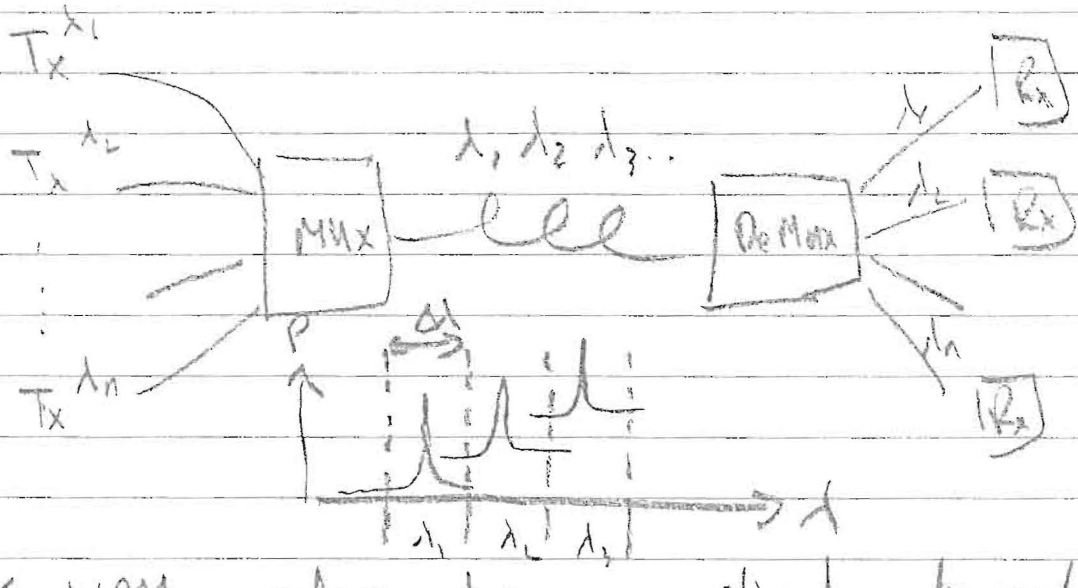
$$L_{MAX} = \frac{25}{\Delta\lambda(nm)}$$ (in km) [5]

b. For 10 km $\Delta\lambda = 2.5$ nm
30 km $\Delta\lambda = 0.83$ nm

$\Delta\lambda = 2.5$nm may be achieved using a Fabry-Perot laser - USUALLY A FEW MODES 1-3 PARTICIPATE IN LASING WITH MODE SEP. OF ~ 1nm.
$\Delta\lambda \approx 0.8$nm may be impossible/challenging for a Fabry-Perot laser. A DBR/DFB laser structure may be required [4]

4c

CWDM. A wavelength division multiplexed system uses a multiplexer to combine transmitters of different λ into one physical channel. This link is subsequently filtered to recover each optical channel onto one physical channel.



CWDM refers to an optical channel spacing of 20 nm (ITU standard) centered at 1271, 1291...

In order to implement such a system at this Bit rate it is highly likely that a DFB laser will be required as dispersion effects will be severe at λ > 1300 nm or so. λ to be centred on channel centre [8]

what about transmitter?