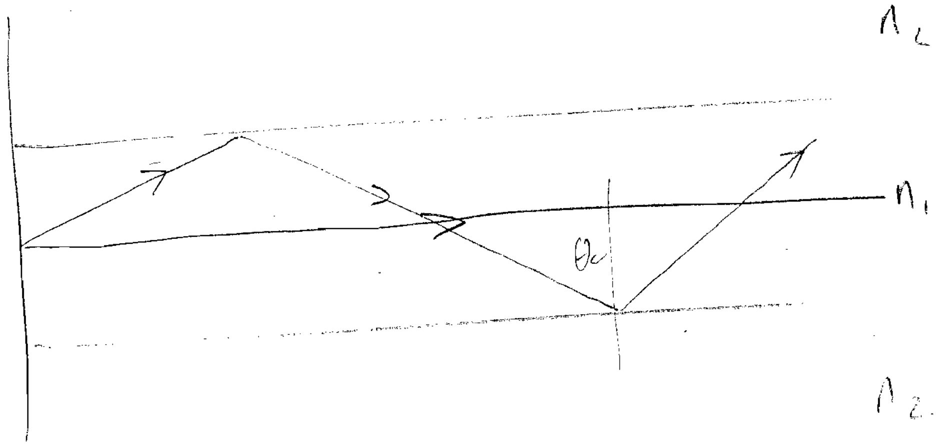
1 (a)

Multimode → chromatic dispersion effects small compared to intra modal dispersion.



Meridional Ray

$$t_A = \frac{L}{v_1} = \frac{Ln_1}{c}$$

Critical Ray $\quad t_c = \frac{Ln_1}{c \cdot \sin\theta_c} = \frac{Ln_1}{c} \cdot \frac{n_1}{n_2}$

Differential time delay

$$\delta t = t_c - t_A$$

$$= \frac{Ln_1}{c} \cdot \frac{n_1}{n_2} - \frac{Ln_1}{c}$$

$$= \frac{Ln_1}{c}\left(\frac{n_1}{n_2} - 1\right).$$

$$\approx \frac{Ln_1}{c}\left(\frac{n_1 - n_2}{n_1}\right) \qquad \text{as } n_1 \sim n_2$$

(6)

$$\approx Ln_1 \, \Delta n$$

1 (b)

Dispersion Limits.

$$BLD \leq \frac{1}{4}$$

$D = 100\ ns/km$.

$$BL \leq \frac{1}{4 \times 100 \times 10^{-12}} \quad s/M.$$

$$BL \leq 2.5 \times 10^{9} \quad s/m.$$

B in $MBit\ s^{-1}$
L in km.

$$BL \leq 2.5 \quad Mbits\ s^{-1}$$

$B = 0.1 \quad L = 25$ km

$B = 1 \quad L = 2.5$ km

$B = 10 \quad L = 0.25$ km

Loss Limits

60 dB Power Budget

200 dB / km loss.

Loss not function of Bit Rate

for ALL Max transmission is

$$\frac{60}{200}\ km = 300\ m.$$

$L = 0.3$ km

$L = 0.3$ km

$L = 0.3$ km

Limiting factor

$B = 0.1$ — loss

$B = 1$ — loss

$B = 10$ — Dispersion

(10)

1(c).

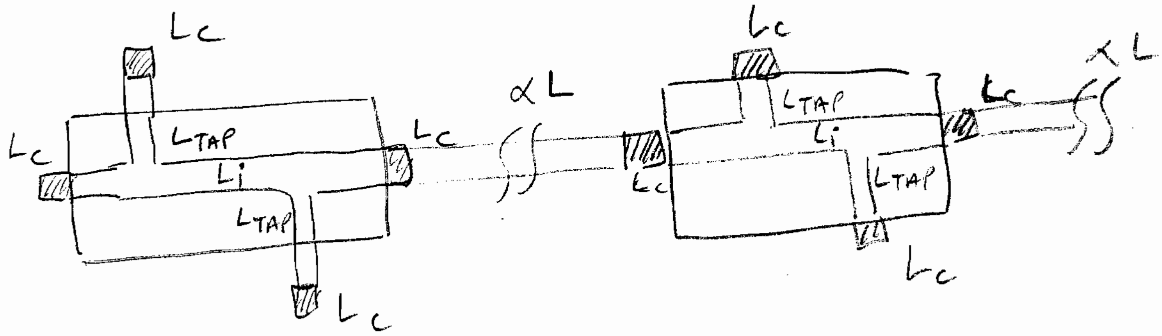
If loss limited - need lower α fibre, or higher P_{launch}, or lower P_{rec}.

If dispersion limited - need fibre with lower dispersion coefficient - e.g. GRIN fibre.

Single-mode silica fibre would improve both at once...

(4)

2 (a)



Loss between couplers / stations 1 & N ....

2 CONNECTORS PER STATION

@ '1' & 'N' – ONE TAP

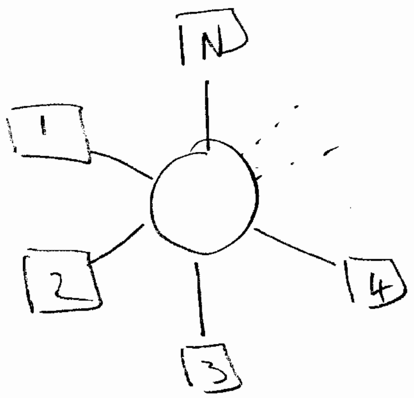
@ 2 ... 1–N – TWO TAPS

αL FIBRE LOSS BETWEEN ALL COUPLERS / STATIONS

TOTAL LOSS (dB) = $(N-1)\,\alpha L + 2NL_c + 2L_{TAP}$

$+ 2(N-2)\,L_{TAP} + NL_i$ (5)

STAR COUPLER → DIVIDE POWER EQUALLY N-WAYS



in dB $L_{SPLIT} = 10 \log N$

FROM $P_{OUT} = \dfrac{P_{IN}}{N}$

& Loss (dB) = $10 \log \dfrac{P_{in}}{P_{OUT}}$

In SIMILAR WAY

TOTAL LOSS = $2\alpha L + 2L_c + 10 \log N$

$+ L_{excess}$ (4)

2(a) cont

ADVANTAGE OF STAR NETWORK – loss $\propto \log N$

not $\propto N$ (1)

Book

DISADVANTAGES OF BUS OVERCOME WITH AMPLIFIERS &/OR REPEATERS

MOST COMMON APPLICATION IS CABLE TV (2)

NEEDS BACKGROUND READING

1(b)

(i) 850 nm VCSEL.

AlGaAs / GaAs materials.

1300 & 1550 EDGE EMITTERS

InP substrate, AlInGaAs / GaInAsP Alloys (2)

REQUIRES

(ii) Linewidths governed by optical feed back mechanism

VCSEL → VERTICAL DBR GRATING. SIMILAR TO SHORT CAVITY FABRY-PEROT

EDGE EMITTER → CAVITY MODE FINESSE GIVES LINEWIDTH

FP LASER → ETALON-LIKE CAVITY. LASING FROM SEVERAL MODES OF CAVITY

DFB → BRAGG GRATING → SELECTS ONE WAVELENGTH VIA BRAGG DIFFRACTION

(3)

iii) 850 VCSEL. → TYPICALLY LANS.

~ 10 GBIT over 300 m

1300 FP → LANS / WANS
~ 10 GBIT ~ / ~ 10 km

1550 DFB → MANS / SUB-MARINE

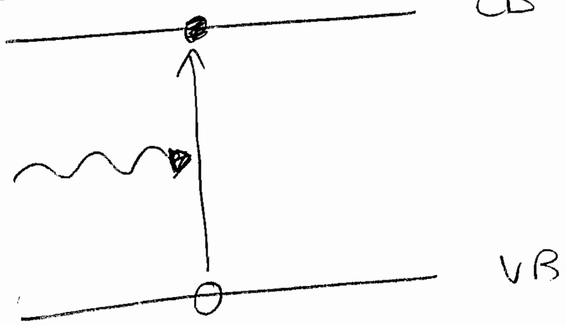
~ 10-40 GBIT ~ 40 km

BOOKWORK
B/GROUND READING.

(3).

3 (a)

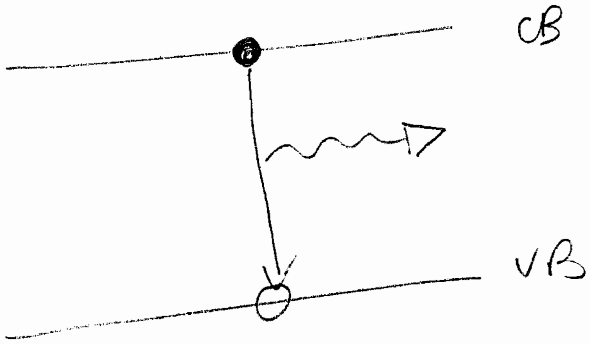
ABSORPTION



PHOTON GIVES UP ENERGY TO AN ELECTRON – PROMOTES IT TO CB

Probability = A_{12} × photon density × density e in VB × density holes in CB.

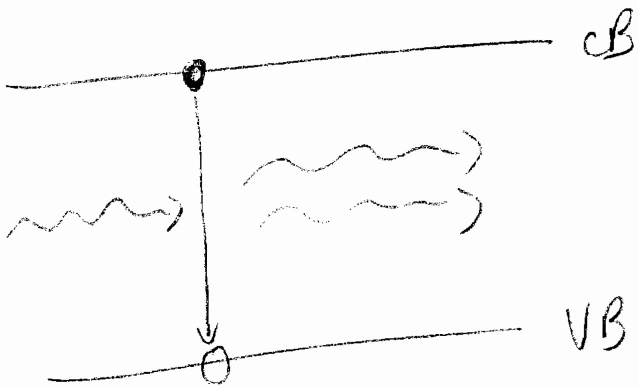
Spontaneous Emission



ELECTRON GIVES UP ENERGY TO FALL TO VB ; EMITTING A PHOTON OF RANDOM DRN, PHASE.

Probability = B_{21} × density e in CB × density holes in VB.

Stimulated Emission



PHOTON STIMULATES RECOMBINATI – ELECTRON FALLS TO VB. ENERGY GIVEN UP IN CREATION OF PHOTON WITH SAME ENERG PHASE & DIRECTION AS STIMU ATING PHOTON.

Probability = A_{21} × density e in CB × density holes in VB × photon density

(6)

3(c)

For QW LDs limited by relaxation oscillation for mod rate.

$$\omega_R^2 = \frac{v \frac{dg}{dn} N_{photon}}{t_{photon}}.$$

only t_{photon} changes in these diodes. $\frac{dg}{dn} = \text{const.}$ etc.

so $\omega_R^2 \propto \frac{1}{t_{photon}} \propto g_{th}$

300 μm has highest g_{th} (shortest τ_{ph}) so is fastest. (2).

3(b)

L (μm)	I_{th} (mA)
300	8
400	9.75

$R = 0.32$

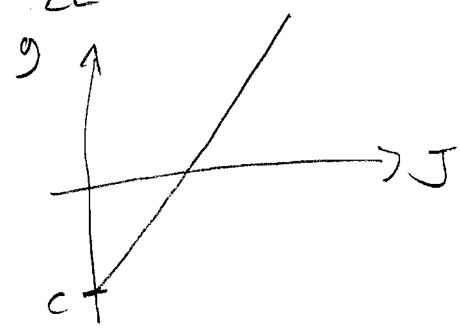
$W = 2\,\mu m$

$\alpha_i = 5\ cm^{-1}$

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

$g_{th} = 5 + \frac{1}{2L} \ln R_1 R_2$

gain linear



$J = A\ cm^{-2}$
$A = A\ cm^{-1}$

$$g = \frac{J}{A} - c$$

Need: J_{th} & g_{th} (in cm).

300 μm: $A = 2 \times 10^{-4} \times 300 \times 10^{-4}\ cm^2$

$\rightarrow J = 1.34\ kA\ cm^{-2}$

$g_{th} = 5 + \frac{1}{2 \times 300 \times 10^{-4}} \ln(0.32 \times 0.32)$

$= 43\ cm^{-1}$

400 μm: $A = 2 \times 10^{-4} \times 400 \times 10^{-4}\ cm^2$

$\rightarrow J = 1.218\ kA\ cm^{-2}$

$g_{th} = 33.5\ cm^{-1}$

Now use g_{th}, J_{th} values.

300 μm $$43 = \frac{1.34 \times 10^3}{A} - C \qquad (1)$$

400 μm $$33.5 = \frac{1.218 \times 10^3}{A} - C. \qquad (2)$$

Can now solve for A & C.

Cancelling C.

$$\frac{1.34 \times 10^3}{A} - 43 = \frac{1.218 \times 10^3}{A} - 33.5.$$

$$\frac{122}{A} = 9.5$$

$$A = \frac{122}{9.5} = 12.84 \text{ A cm}^{-1}$$

Now subst into (1) or (2).

$C = 64.8 \text{ cm}^{-1}$ → J_0 when $g = 0$.

$$64.8 = \frac{J_0}{12.84} \qquad J_0 = 832 \text{ A cm}^{-2}$$

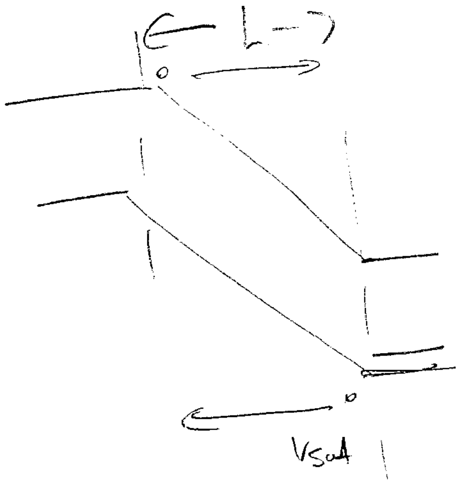
4 (a)

3 Key considerations.

1). Responsivity $\eta = 1 - e^{-\alpha L}$ α = abs coeff. L = length

Ideally $L > \frac{1}{\alpha}$ (L large).

2) Bandwidth (1) — Carrier Collection.



Carrier Collection time needs to be minimized.

$t_c = \frac{L}{V_{sat}}$.

$\therefore$ L needs to be small

3). Bandwidth (2). — RC

C needs to be small. $C = \frac{\varepsilon \varepsilon_0 A}{L}$.

$\therefore$ L needs to be large.

(6)

4. (b).

(1) $\sigma^2_{shot} = 2q\left(I + I_{DARK}\right)\Delta f$

(2) $\sigma^2_{therm} = \left(\frac{4\,k_B\,T}{R_L}\right) F_N \Delta f$

(3) Need to determine $I = \frac{\eta q \lambda}{hc} \cdot P_{in}$ (hidden - need to recall this).

(4) $I = \frac{0.7 \cdot 1.6\times10^{-19} \cdot 1.55\times10^{-6}}{6.63\times10^{-34} \times 3\times10^{8}} \cdot 2\times10^{-3}$ (3).

$I = 1.75$ mA.

From (1)

(5) $\sigma^2_{shot} = 2\times1.6\times10^{-19}\left(1.75\times10^{-3} + 1\times10^{-6}\right) 5\times10^{9}$

$\sigma_{shot} = 1.67\ \mu A$

Now need to determine $R_L = \frac{1}{2\pi f C}$ (RC bandwidth limited).

$= \frac{1}{6.284 \times 5\times10^{9} \times 0.6\times10^{-12}}$

$R_L = 53\ \Omega$

4. (b) cont.

At Room temp $T = 290$ K.

$$\sigma_{Therm} = \left(\frac{4 \times 1.38 \times 10^{-23} \times 290 \times 2 \times 5 \times 10^{9}}{53} \right)^{\frac{1}{2}}$$

(3)

$$= 1.74 \ \mu A.$$

$$SNR = \frac{I^2}{\sigma^2} = \frac{I^2}{(\sigma^2_{Shot} + \sigma^2_{Therm})}$$

$$= \frac{(1.75 \times 10^{-3})^2}{(1.67 \times 10^{-6})^2 + (1.74 \times 10^{-6})^2}$$

$$= \frac{3.06 \times 10^{-6}}{2.79 \times 10^{-12} + 3.03 \times 10^{-12}}$$

$$= \frac{3.06}{5.82} \times 10^{6}$$

$$= 5.25 \times 10^{5}$$

$$= 57.2 \text{ dB}$$

(3)

4. (c):

Strategies to improve SNR.

By inspection if $I \uparrow$ SNR IMPROVES (!).
So larger optical power is advantagoous.

Reducing I_{DARK} is advantageous, although small effect here, as optical power is large.

Reducing R_x temperature will make a bigger impact on σ_{therm}.

Another possibility is to achieve some RC time constant with smaller C so larger R_L → acting to reduce σ_{therm}.

Ensuring Δf does not exceed system needs is also sensible.

(5).