Optical Comms Solutions

Tutorial Sheet Solutions

Q1 Phase and Group velocities equal when the phase velocity is frequency independent i.e. in a non-dispersive media.

Dispersion occurs – "chromatic dispersion" – due to difference in phase velocity at different frequencies – a pulse for example becomes distorted.

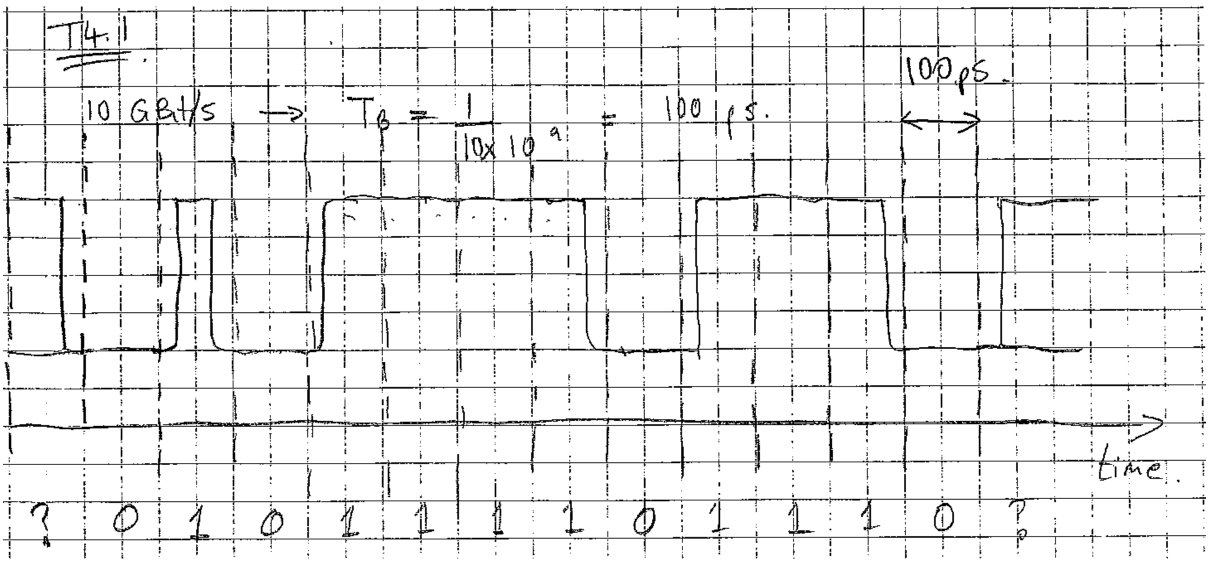
Q2
No of words per hour lecture = 60x200 = 12000
No of letters = 12000x5 = 60000
No of bits (8bits/letter) = 8x60000 = 480000 bits.

Data transmitted at 1GBit/s = 10^9
Time = bits/rate = 480000/1000000000 = 480 μs

Q3 (a) loss = 10 Log_{10} P_i/P_o = 16 dB
(a) attenuation per kilometre = 16/8 = 2dB/km
(b) –9.2 dBm
(c) –25.2 dBm

Q4 10 GBit/s pulse stream gives time slot T_B = $1/10\text{x}10^9$ = 100ps

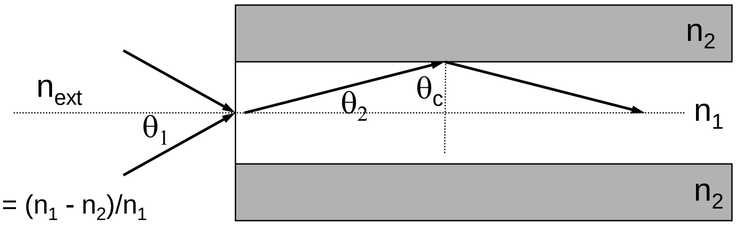
Assume zero rise time and therefore shortest pulse occupies 50ps and longest pulse stream occupies 350ps.



Now average launch power = half peak power for a NRZ pulse stream - since probability of a 1 or 0 is equal and o and 1 are uncorrelated.
Hence peak power = 4mW

Q5

Acceptance Angle and Numerical Aperture



$\Delta = (n_1 - n_2)/n_1$

Acceptance angle – largest θ_1 such that all light is guided

$n_{ext}\mathrm{Sin}\theta_1 = n_1\mathrm{Sin}\theta_2 = n_1\mathrm{Cos}\theta_c$

Use; Snell's Law $\mathrm{Sin}\theta_c = n_2/n_1$ and Trig Identity $\mathrm{Sin}^2\phi + \mathrm{Cos}^2\phi = 1$

$$n_{ext}\mathrm{Sin}\theta_1 = \sqrt{(n_1^2 - n_2^2)} = \mathrm{NA}$$

$\Delta = (n_1 - n_2)/n_1$, hence $n_2 = 1.47$

$n_{ext}\mathrm{Sin}\theta_1 = n_1\mathrm{Sin}\theta_2 = n_1\mathrm{Cos}\theta_c$

$\theta_2 = 11.5°$, $\theta_1 = 17.4°$,

Time to travel distance L down fibre for

- Axial ray: $t_A = L/v_1 = Ln_1/c$
- Critical ray: $t_C = Ln_1/(c\times\sin\theta_C) = (Ln_1/c)(n_1/n_2)$.
- Differential time delay: $\delta t = t_C - t_A = (Ln_1/c)\{(n_1/n_2) - 1\}$
  $= (Ln_1/c)(n_1 - n_2)/n_2 \approx (Ln_1/c)(n_1 - n_2)/n_1 = Ln_1\Delta/c$.
- The pulse spreads in time by $\delta t = Ln_1\Delta/c$ in a distance L.

$\delta t/L = n_1\Delta/c = \underline{10^{-10}\ \mathrm{s/m} = 10\text{-}^{7}\ \mathrm{s/km}}$
So for L = 10km: $\delta t = 1\mu s$

$\Rightarrow B_{max} \approx 1/\delta t = 1\mathrm{MB/s}$

NA = $\sqrt{(n_1^2 - n_2^2)} = 0.3$

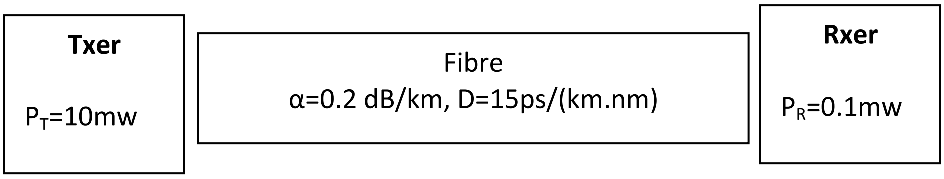
Q6. $\sqrt{(n_1^2 - n_2^2)}$ =NA = 14°

Q7.

Q8.

a. loss = 10 $\mathrm{Log}_{10}\ P_i/P_o$ = 16dB
b. attenuation per kilometre = 16/8 = 2dB/km
c. Source power = 120 μW = –9.2 dBm
d. Output power = 3μW = –25.23 dBm

Q9.



No Margin:
Maximum attenuation for line L km long = $\alpha L = 10\log_{10}(P_T/P_R)$
$P_T/P_R = 10/0.1 = 100$ hence αL = 20dB
L = 20/0.2 = 100km

Dispersion limited distance:
Bit slot length = 1/data rate = 1000ps (10^{-9} s)
Assume pulse broadening allowed to be ¼ Bit slot width = 250ps
$\Delta\lambda$ = 1nm so broadening due to dispersion = D x $\Delta\lambda$ = 15ps/km
Hence dispersion limit is 250/15 km = 16.7 km

<u>Maximum length is determined by dispersion not attenuation = 16.7km</u>.

For an 18dB margin:
Loss limit $\alpha L + 18 = 10\log_{10}(P_T/P_R)$
Hence αL = 2 dB and L = 10 km.
Dispersion limit as before and so fibre length determined by attenuation not dispersion in this case.

Q10.
$\Delta\lambda$ = 1.6 – 1.3 µm = 300 nm
Channel width = 0.4 nm
No of channels = 300/0.4 = 750

Total capacity = no of channels x bit rate = 750 x 40Gb/s = 30Tb/s

Q11.
$\Delta\lambda$ = 1.61 – 1.53 µm = 80 nm
Channel width = 0.8 nm
No of channels = 80/0.8 = 100

Total capacity = no of channels x bit rate = 100 x 10Gb/s = 1Tb/s

Bit rate-distance product = 1Tb/s x 2000km = 2000 Tb/s.km

Q12.
800nm light $E = h\nu = hc/\lambda$
Energy of 1 photon = $6.6 \times 10^{-34} \times 3\times10^{8}/800\times10^{-9} = 2.5 \times 10^{-19}$ J

Need 1000 photons to detect 1 bit at 100Mb/s
Need a peak received power of $2.5 \times 10^{-19} \times 1000 \times 100 \times 10^{6} = 2.5 \times 10^{-8}$ W

Average power = peak power/2 = 1.25×10^{-8} = 1.25×10^{-5} mW = -49 dBm

Launch power = -10 dBm
Assuming no margin have 39 dB available in power budget as a loss in fibre
Loss = 2dB/km, **hence fibre length = 39/2 = 19.5 km.**