Optical Communication

Minor – II solutions

Q.1. Given that,

The p-i-n photo diode generates 1 electron-hole pair / 3 photons

wave length incident light $\lambda = 0.8\ \mu m$

Received optical power $P_{in} = 10^{-7}$ W.

(a) Quantum efficiency of the photo diode

$$\eta = \frac{\text{no. of } e^- \text{ collected}}{\text{no. of photons incident}} = \frac{r_e}{r_p}$$

$$\boxed{\eta = \frac{1}{3} = 0.333}$$

$\therefore$ At $0.8\ \mu m$, the quantum efficiency is 33.3%

(b) The maximum possible band gap energy $E_g = \frac{hc}{\lambda}$

$$E_g = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{0.8 \times 10^{-6}}\ J$$

$$\boxed{E_g = 24.8475 \times 10^{-20}\ J}$$

(c) The mean output photo current $I_p = R\, P_{in}$

where $R \rightarrow$ responsivity

$$R = \frac{\eta q}{E_g} = \frac{0.33 \times 1.602 \times 10^{-19}}{24.8475 \times 10^{-20}}$$

$$= 0.2127$$

$$\therefore I_p = 0.2127 \times 10^{-7} \text{ A} = \boxed{21.27 \text{ nA}}$$

Q2

Given that,

For p-i-n photo diode, area of photon capture $A = 1.5 \text{ mm}^2$

load resistance $R_L = 100 \,\Omega$

electron drift velocity $v_d = 10^7$ m/s

The permitivity of Si $\epsilon = 1.04 \times 10^{-10}$ F/m

The junction (intrinsic layer) capacitance

$$C_j = \frac{\epsilon A}{w}$$; where w = thickness of the i-layer

For fast response time, $R_L C_j = \frac{w}{v_d}$

$$R_L \frac{\epsilon A}{w} = \frac{w}{v_d}$$

$$w = \sqrt{v_d R_L \epsilon A} = 3.95 \times 10^{-4} \text{ m}$$

$$\boxed{\therefore w = 395 \,\mu\text{m}}$$

Q 3. Given that,

Incoming signal power $P_{in} = 1.28\ nW$

$SNR = 9\ dB$

Quantum efficiency of the photodetector $\eta = 75\%$

Transmission bandwidth $B = 400\ MHz$.

$$SNR = \frac{I_p^2}{\sigma_s^2}$$ (Assume shot noise is dominated component)

where

shot noise $\sigma_s^2 = 2q I_p B$

$$10^{0.9} = \frac{I_p}{2qB} \Rightarrow I_p = 15.886\, q B \longrightarrow (1)$$

We know that $\eta = \dfrac{I_p/q}{P_{in}/E_{ph}} \Rightarrow$

$$E_{ph} = \frac{hc}{\lambda} = \frac{\eta P_{in}}{I_p/q} \Rightarrow \lambda = \frac{hc\,(I_p/q)}{\eta P_{in}}$$

$$\therefore \lambda = \frac{6.626\times10^{-34} \times 3\times10^{8} \times 15.886 \times 400\times10^{6}}{0.75 \times 1.28 \times 10^{-9}}\ m$$

$$\boxed{\lambda = 1.3157\ \mu m}$$

Q.4 Given that

For a digital single mode optical fiber system,

the operating wavelength $\lambda = 1.5\ \mu m$

Transmission rate $= 560$ Mbps

length of the fiber link $L = 50$ km

Mean optical power launched into fiber $P_{in} = -13$ dBm

fiber loss $\alpha_{fiber} = 0.25$ dB/km

splice loss $\alpha_{splice} = 0.1$ dB (at 1 km interval i.e., 49 splices)

$\alpha_{connector} = 0.5$ dB (only one at the receiver)

system margin $\alpha_{system} = 1$ dB

Receiver sensitivity $P_s = -39$ dBm

The total power loss $= L\,\alpha_{fiber} + 49\,\alpha_{splices} + \alpha_{connector} + \alpha_{system}$

$= 50 \times 0.25 + 49 \times 0.1 + 0.5 + 1$

$= 18.9$ dB

The maximum allowable loss $= P_{in} - P_s = 26$ dB.

$\therefore$ The maximum safety margin for this system is

$\alpha_{safety\ margin} = 26 - 18.9 = \boxed{7.1\ dB.}$

Q 5

Given that, the number of homes subscribed for FTTH service is 280

The power budget $= 23\,dB$; fiber loss $(\alpha) = 0.2\,dB/km$

$$P_{budget}(dB) > \alpha L + P_{L,split} + M_s(dB)$$

where L = length of the fiber

$P_{L,split}$ = Power loss due to splitter

M_s = system margin (can be neglected) because $M_s \approx 1$, $10\log_{10}(M_s) = 0\,dB$.

$$P_{budget}(dB) = 23\,dB > \alpha L + P_{L,split}$$

The FTTH system uses a PON architecture and star topology.

⇒ For proper network development, the total loss due to the power splitter and fiber loss must be less than 23dB.

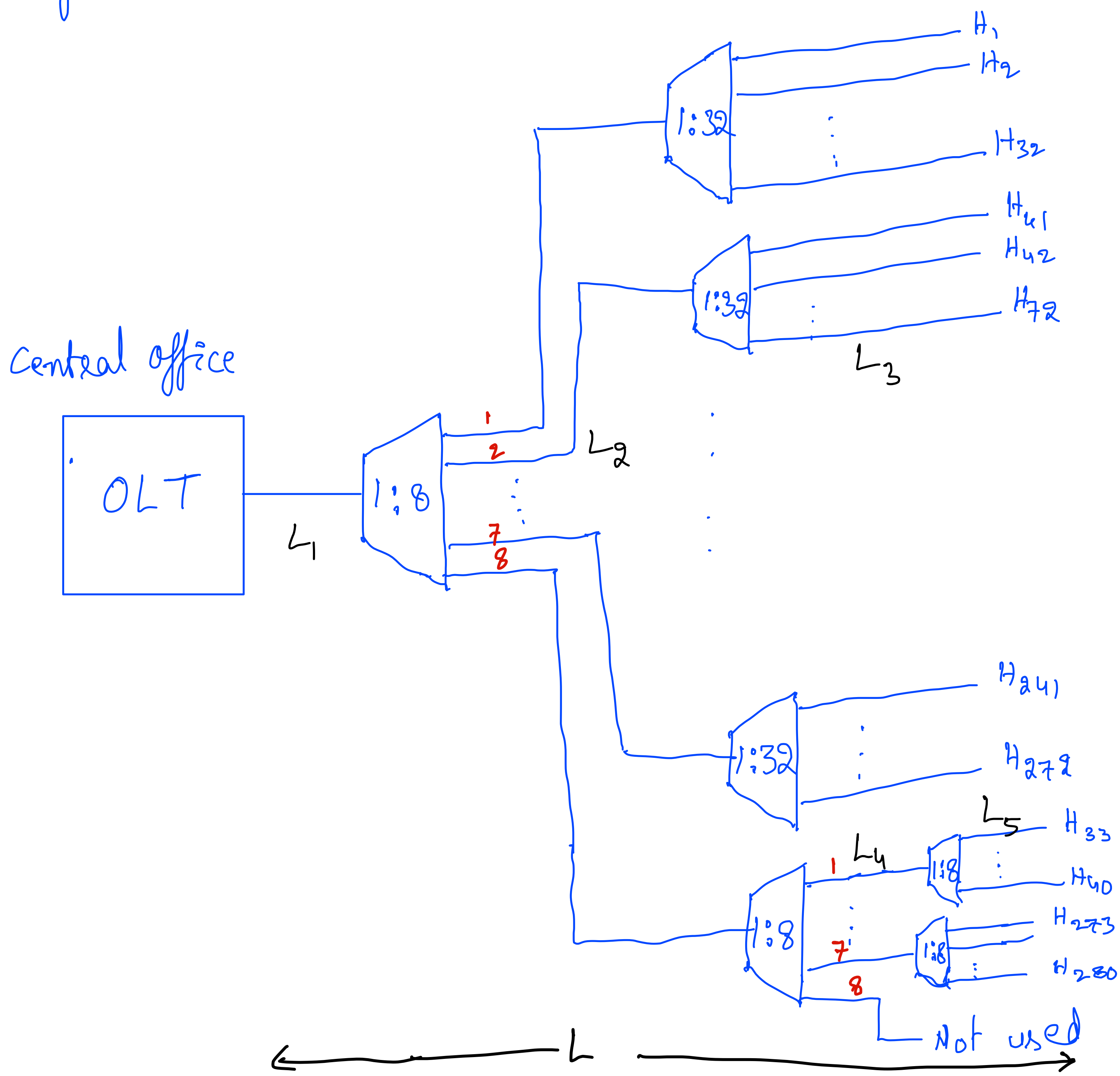
⇒ According to the architecture of FTTH, there might be multiple splitter stages between OLT and homes

⇒ In general, the FTTH uses 1:32 power splitter or less splitter ratio

$$\therefore P_{L,split}(32) = 10\log_{10}(32) \approx 15\,dB$$

Similarly $P_{L,split}(16) \approx 12$; $P_{L,split}(8) = 9\,dB$

To provide service to everyone in the network, we need to use optical power amplifier. Let consider the following FTTH network shown in fig. In the given area there are 7 streets, that means we can use 1:8 splitter to provide the connection to all. After that, based on the no. of homes we can use 1:32 or 1:16 splitters.



Now the power budget for this network is defined as

$$P_{budget} \geq \alpha L + P_{L,split}$$

The maximum loss due to splitters in the network is

$$P_{L,split,max} = 3\, P_{L,split}(8) \quad (or) \quad P_{L,split}(8) + P_{L,split}(32)$$

$$= 27\ dB \qquad\qquad = 23\ dB$$

Here, the total fiber link loss from central office to end is more than the maximum allowable fiber link loss.

$\therefore$ It is required to use optical amplifier any-where between OLT to ONU.

Now $\quad P_{budget} \geq \alpha L + P_{L,split} - A$

where A = gain of the amplifier

Here based on the distance between OLT and ONU, power splitter ratio, we can adjust the amplifier gain.