2019 Past Paper –Question 1

(a) The mean squared thermal noise current is:

$$I_T^2 = \frac{4kT\Delta f}{R_L} = \frac{4 \times 1.38 \times 10^{-23} \times 300 \times 200 \times 10^6}{1000} = 3.31 \times 10^{-15}\ A^2$$

(b) The received photocurrent is $0.8 \times 250 = 200\ \mathrm{nA}$ and so:

$$SNR = \frac{(200 \times 10^{-9})^2}{3.31 \times 10^{-15}} = 12.1$$

(c) With ideal extinction, the Q value is :

$$Q = \frac{I_1}{2I_T} = \frac{\overline{I_1}}{I_T}$$

To achieve 10^{-9}, Q ≥ 6 so:

$$\overline{I_1} \geq 6I_T = 6 \times \sqrt{3.31 \times 10^{-15}} = 345.2\ \mathrm{nA}$$

So average power is ≥ 345.2/0.8 = 431.5 nW = -33.7 dBm

(d) A power budget is the “profit and loss” of a communication system. One begins with the input power and subtracts all the losses to produce an output power. This provides a basic check on any system feasibility.

(e) If half the power is lost, this means a power loss of 3 dB over the 10 km of fibre. Thus, the loss per km is 3/10 = 0.3 dB per km.

(f) To produce the power budget here, the equation below is used

$$P_i = P_o + \alpha_f L + \alpha_{cr} + M_a\ \mathrm{dB}$$

P_i = input power;
P_o = output power;

α_f = fibre loss per km;

L = length of fibre in km;

α_{cr} = connector losses;

M_a = system margin.

For the given system, we need to find the output power that is required; thermal noise dominates

We already know from part (c) that the power required is -33.7 dBm and this is equivalent to -63.7 dB, i.e.:

$$P_o = -63.7 \text{ dB}$$

$$P_i = 1 \text{ mW} = -30 \text{ dB}$$

The fibre loss was calculated to be 0.3 dB per km making the total for a length L:

$$\alpha_f L = 0.3 \times L$$

There are two connectors (one at each end) giving a loss of $2 \times 0.5 = 1$ dB.

Also,

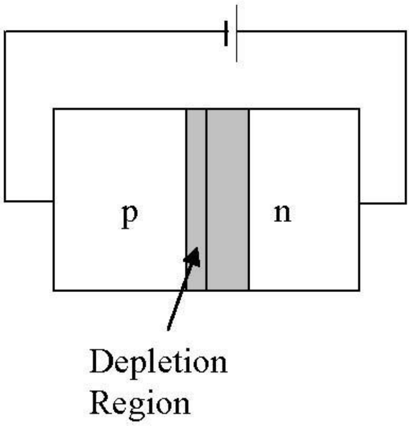
$M_a = 3$ dB

$$-30 = -63.7 + 0.3 \times L + 1 + 3$$

$$0.3 \times L = 29.7; L = 99 \text{ km}$$

2019 Past Paper –Question 2

(a) The fundamental mechanism in photodetection is optical absorption, and the pn diode may be represented in abstract form as below:



The reverse biased p-n junction has depletion region free of carriers where a large electric field opposes n→p flow of electrons and p→n flow of holes.

If the energy of incident photons, *hf*, is greater than the semiconductor bandgap energy then light falling on the junction creates electron hole pairs as the photons are absorbed

The electric field sweeps out the electrons and holes producing a current

Using a lightly doped or undoped intrinsic region between the p and the n layers to make a *pin* diode increases the depletion region width and hence the efficiency of the diode.

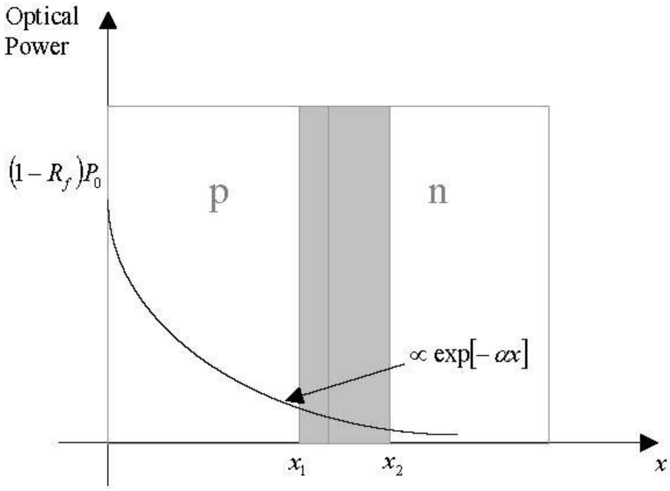
(b) The quantum efficiency, η, represents how many electrons are produced per photon

$$\eta = \frac{\text{electron generation rate}}{\text{photon incidence rate}}$$

Since the number of electrons per second is the current divided by the electronic charge and the number of photons per second is the power divided by the energy per photon, we can say:

$$\eta = \frac{I_p/q}{P_o/hf} \quad \text{rearranging} \quad I_p = \frac{\eta q}{hf}P_o$$

(b) Pictorially, the absorption appears as below:



Power that is absorbed and creates a photocurrent is the difference between the power entering the depletion region and that leaving

$$P_\mathrm{a} = P_0(1 - R_\mathrm{f}).\{\exp(-\alpha x_1) - \exp(-\alpha x_2)\}$$

The *quantum efficiency* can thus be defined as

$$\eta = \frac{P_\mathrm{a}}{P_0} = (1 - R_\mathrm{f}).\exp(-\alpha x_1).\{1 - \exp(-\alpha[x_2 - x_1])\}$$

To optimise this $x_1 \to 0$ (small p-layer) and $x_2 \to \infty$ (maximum depletion width).

(d) The difference $x_2 - x_1$ is the *i*-layer thickness and for 633 nm, using the equation given, $\alpha = 6.9 \times 10^7 \times \exp\left(-\frac{633}{130}\right) = 5.3 \times 10^5\ \mathrm{m}^{-1}$; similarly for 850 nm $\alpha = 6.9 \times 10^7 \times \exp\left(-\frac{850}{130}\right) = 10^5\ \mathrm{m}^{-1}$

$$\eta_{633} = 0.7 \exp(-5.3 \times 10^5 \times 0.5 \times 10^{-6})\{1 - \exp(-5.3 \times 10^5 \times 10 \times 10^{-6})\} = 0.534$$

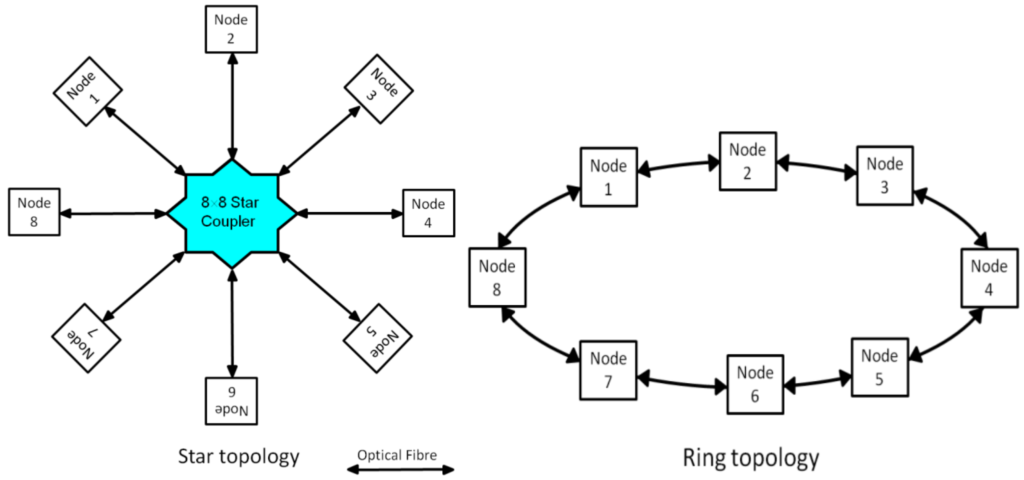
$I_{633} =$
$(0.534 \times 1.602 \times 10^{-19} \times 10^{-6} \times 633 \times 10^{-9})/(6.626 \times 10^{-34} \times 2.9979 \times 10^8) =$
$272.6\ \mathrm{nA}$

$$\eta_{850} = 0.7 \exp(-10^5 \times 0.5 \times 10^{-6})\{1 - \exp(-10^5 \times 10 \times 10^{-6})\} = 0.421$$

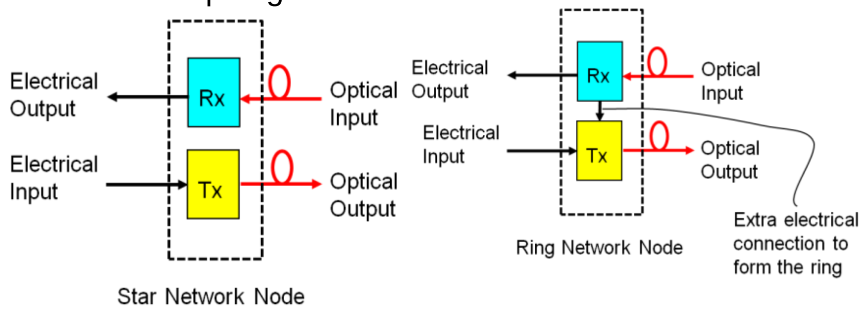
$I_{850} =$
$(0.408 \times 1.602 \times 10^{-19} \times 10^{-6} \times 850 \times 10^{-9})/(6.626 \times 10^{-34} \times 2.9979 \times 10^8) =$
$288.6\ \mathrm{nA}$

2019 Past Paper –Question 3

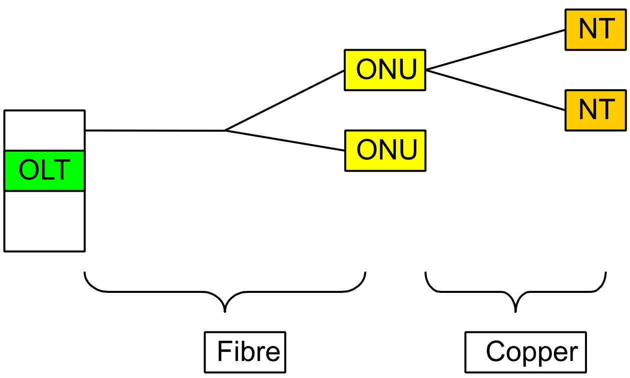
(a) Block diagrams of star and ring optical fibre network topologies.



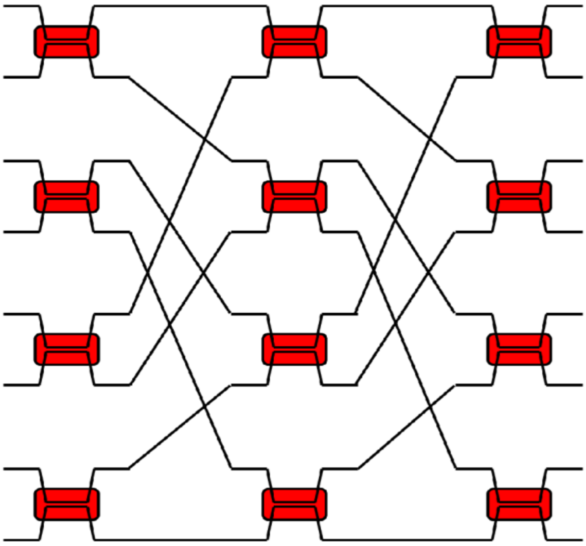
Although the nodes in both cases contain the same elements of optical transmitter (Tx) and optical receiver (Rx), they are connected differently to reflect the difference in the topologies thus:



(b) A passive optical network or PON is a type of access network in which provision for multiple customers is by means of passive splitters. This removes the need for power and maintenance except at the head end, which is known as the optical line termination (OLT) and controls the transmissions to customers. Fibres are terminated by optical network units (ONUs) near to the customer premises. These may connect into customer premises (fibre to the home – FTTH) or link to copper cables in a fibre to the kerb arrangement. The final interface to the customer is known as the network termination (NT). A part of a PON is shown below.



(c) The 8×8 coupler is made from 2×2 couplers as shown below:



Each passage through a 2×2 coupler divides the power in half so the loss is 2^n for n stages. Here, n=3 so

$$P_{\text{out}} = P_{\text{in}}(\text{dBm}) - 10\log_{10}(2^3) = -20(\text{dBm}) - 9.03 = -29.03\ \text{dBm}$$

(d) As we know:

$$\lambda = \frac{c}{f}$$

So, we have:

$$\Delta\lambda = -\frac{c}{f^2}\Delta f$$

and thus:

$$|\Delta\lambda| = \left|-\frac{c}{f^2}\Delta f\right| = \frac{\lambda^2}{c}\Delta f = 0.4\ \text{nm}$$

(e) The two 50GHz WDM signals have to be staggered to implement a channel spacing of 25 GHz, so that they can be combined using a WDM interleaver.

2019 Past Paper –Question 4

(a)

(i) The dispersion compensating fibre is employed to compensate the dispersion in the single mode fibre.

$$D_{\mathrm{DCL}} \times L_{\mathrm{DCF}} = D_{\mathrm{SMF}} \times L_{\mathrm{SMF}}$$

So, we have:

$$\frac{L_{\mathrm{DCF}}}{L_{\mathrm{SMF}}} = \frac{D_{\mathrm{SMF}}}{D_{\mathrm{DCL}}} = \frac{16}{85}$$

$$L_{\mathrm{SMF}} + L_{\mathrm{DCF}} = 1200\ \mathrm{km}$$

$$L_{\mathrm{SMF}} = 1009.9\ \mathrm{km}$$

$$L_{\mathrm{DCF}} = 190.1\ \mathrm{km}$$

(ii) If the span length is 80 km, the 1200 km transmission link will have 15 sections of fibre. Each section contains **67.3 km of SMF** and **12.7 km of DCF**.

(iii) In this case, the transmission link will have 3 sections.

The first section is a **504.95 km of SMF**, followed by a **190.1 km of DCF**, then another **504.95 km of SMF**.

(b)

(i) As the fibre dispersion coefficient D is positive then the dispersion parameter β_2 is negative, therefore the product between dispersion parameter β_2 and chirp is negative and the pulse will be compressed before it broadens.

As the fibre dispersion coefficient D is negative then the dispersion parameter β_2 is positive, therefore the product between dispersion parameter β_2 and chirp is positive and the pulse will always be broadened.

(c) The V-parameter (or the normalised frequency) can be calculated according to the following equation:

$$V = \frac{2\pi a n_1 \sqrt{2\Delta}}{\lambda}$$

To guarantee a single-mode operation, we will have:

$$V = \frac{2\pi a n_1 \sqrt{2\Delta}}{\lambda} \leq 2.405$$

So that

$$\lambda = \frac{2\pi a n_1 \sqrt{2\Delta}}{V} \geq \frac{2\pi a n_1 \sqrt{2\Delta}}{2.405}$$

The question gives the diameter as $3.6\ \mu m$ so the radius is $1.8\ \mu m$

$$= \frac{2 \times 3.14 \times 1.8 \times 10^{-6} \times 1.48 \times \sqrt{2 \times 0.005}}{2.405}$$

$$\lambda \geq 695.63 \text{ nm}$$