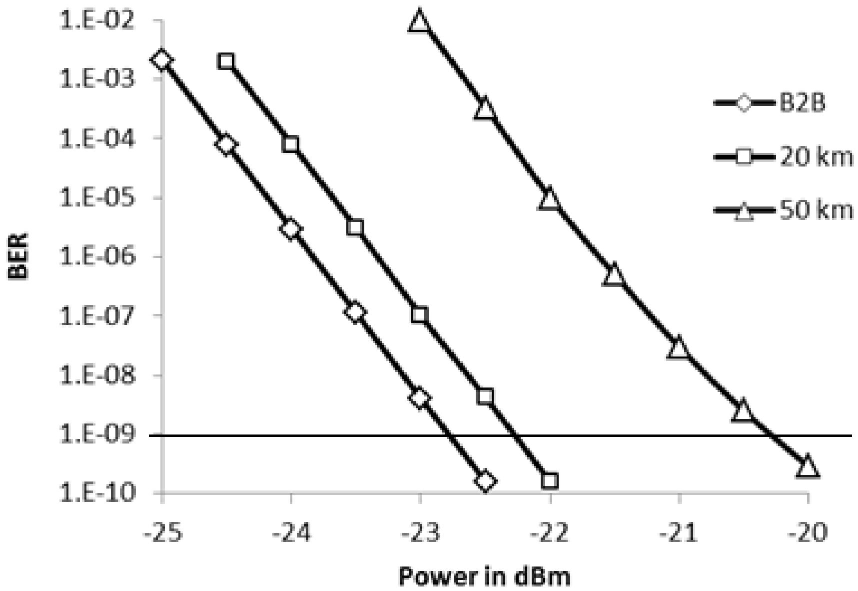
2018 Past Paper –Question 1

(a) A logarithmic plot as below is needed:



Reading off the values: B2B: -22.8 dBm; 20 km: -22.3 dBm; 50 km: -20.3 dBm

(b) There are two sources of fibre loss, namely the attenuation and the dispersion. There are also losses arising from connectors. When transmitting back to back, the only loss will be from connectors. Once we have a fibre in place the others kick in. Over the 20 km link the BER characteristic remains the same shape as for back to back, suggesting there is no significant dispersion, resulting in a modest power penalty. Over 50 km, however, the characteristic's shape shows signs of an error floor and a much bigger penalty from the dispersion becoming significant in addition to the extra attenuation from the longer fibre.

(c) For back-to-back transmission, there is only the connector loss.

The laser given produces:

$$P_{\mathrm{dBm}} = 10\log_{10}\left(\frac{8\times10^{-6}}{10^{-3}}\right) = -21\ \mathrm{dBm}$$

Since the B2B sensitivity is -22.8 dBm, there is a loss of 1.8 dB that must come from the connectors.

(d) Using 20 km, we get a negligible appreciable loss from dispersion so the penalty at the receiver is from 20 km of fibre loss.

The sensitivity from the graph for 20 km is –22.3 dBm compared to -22.8 dBm B2B.

Thus, there is a 0.5 dB penalty over 20 km of fibre and the loss is

$$\alpha_F = \frac{0.5}{20} = 0.025 \text{ dB km}^{-1}$$

(e) Over the 20 km length, there is both a dispersion penalty and attenuation losses as stated earlier (shape of the curve).

We now know the attenuation per km to be 0.025 dB from the last part.

Therefore, the attenuation loss is:

$$50 \times 0.025 = 1.25 \text{ dB}$$

we get a negligible appreciable loss from dispersion so the penalty at the receiver is from 20 km of fibre loss.

The sensitivity from the graph for 50 km is –20.3 dBm compared to -22.8 dBm B2B.

So, the total loss is 2.5 dB of which 1.25 dB comes from attenuation.

This leaves a further 1.25 dB as the dispersion penalty.

2018 Past Paper –Question 2

(a) The intensity of the light is the square modulus of the amplitude of the light, so is the power. Intensity modulation is the variation of this quantity to transmit information in an optical system. This could generally be analogue or digital and one may either vary the intensity of the source (direct) or have a constant wave (CW) source with a modulator device in front of it (external). Using an external modulator sometimes enables greater operating speed but if particularly relevant to lasers since their frequency varies (chirps) when they are directly modulated. Such chirping often causes adverse effects such as increased pulse dispersion and so high speed systems commonly employ external modulation.

(b) The extinction ratio is defined by:

$$r = \frac{I_1}{I_0} \Rightarrow I_1 = rI_0 \qquad (1)$$

The mean receiver current, $\bar{I}$, is:

$$\bar{I} = \frac{1}{2}(I_0 + I_1) \Rightarrow I_0 + I_1 = 2\bar{I} \qquad (2)$$

Substitute for I_1 from (1):

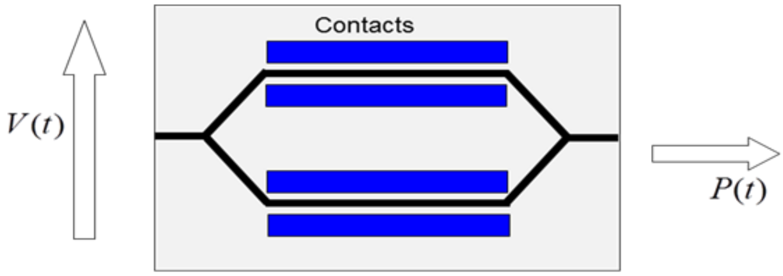
$$I_0 + rI_0 = 2\bar{I} \Rightarrow I_0 = \frac{2\bar{I}}{1+r} \qquad (3)$$

Then use (3) in (2)

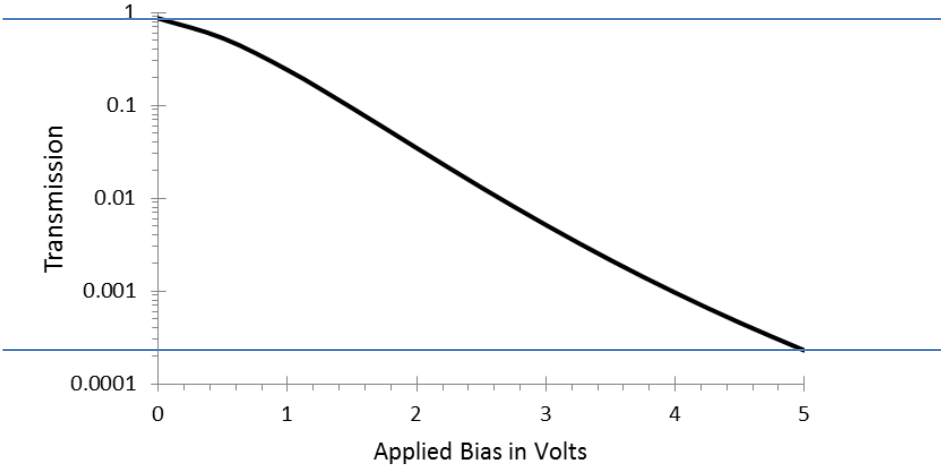
$$\frac{2\bar{I}}{1+r} + I_1 = 2\bar{I}$$

$$I_1 = 2\bar{I}\left(1 - \frac{1}{r+1}\right) = \frac{2r\bar{I}}{1+r}$$

(c) Lithium Niobate modulators make use of a Mach-Zehnder Interferometer (MZI) arrangement on a slab of $LiNbO_3$ shown in the figure below. An electric field applied across the arms as shown varies their refractive index via the electro-optic effect. There is thus a difference in propagation speed between the arms and an amplitude modulator can be made using constructive or destructive interference.



(d) The characteristic turns downwards monotonically with no sign of a minimum produced by interference nor of a rapid sinusoidal decline and concave shape. This is typical of electroabsorption and thus the diagram is that of an electroabsorption device.



(e) From the diagram:

$$T_{\text{MAX}} \approx 0.85$$
$$T_{\text{MIN}} \approx 0.00022$$

Since current depends linearly on intensity, we have:

$$r_{\text{ex}} = 10\log_{10}\left(\frac{0.85}{0.00022}\right) = 35.7\text{ dB}$$

(f) Now, the transmission is given for length L by:

$$T = \exp(-\alpha L)$$

So, for half the length this will be:

$$T_{1/2} = \exp(-\alpha L/2) = \sqrt{T}$$

This will halve the extinction ratio in dB as it produces a factor of a half, so the modulator has an extinction ratio of 17.85 dB

2018 Past Paper –Question 3

(a) The V parameter determines the number of modes supported by a fibre. To design a single-mode optical fibre, we should have the value of $V \leq 2.405$. The V parameter plays an important role in determine the cut-off condition and is defined as $V = k_0 a(n_1^2 - n_2^2)^{1/2} \approx (2\pi/\lambda) a n_1 \sqrt{2\Delta}$ where n_1 is the refractive index of the fibre core, n_2 is the refractive index of the fibre cladding, Δ is the refractive index change at the core-cladding interface.

(b)

(i). The group velocity dispersion (GVD) parameter β_2 is related to dispersion coefficient D by:

$$\beta_2 = -D \cdot \frac{\lambda^2}{2\pi c} = -17 \times 10^{-12}/(10^3 \times 10^{-9}) \times \frac{(1550 \times 10^{-9})^2}{2\pi \times 2.9979 \times 10^8}$$
$$= -2.1683 \times 10^{-26}\ \mathrm{s^2 m^{-1}}$$

The dispersion length is $L_D = T_0^2/|\beta_2|$

$$L_D = T_0^2/|\beta_2| = (10 \times 10^{-12})^2/|-2.1683 \times 10^{-26}| = 4611.9\ \mathrm{m}$$

(ii) The pulse width at distance z is $T_z = T_0 \cdot \left[1 + \left(\frac{z}{L_D}\right)^2\right]^{1/2}$

The pulse width at $z = L_D$ will be $T_{L_D} = T_0 \cdot \left[1 + \left(\frac{L_D}{L_D}\right)^2\right]^{1/2} = 1.4142 \times T_0 = 14.142\ \mathrm{ps}$

$T_z = T_0 \cdot \left[1 + \left(\frac{z}{L_D}\right)^2\right]^{1/2}$ when $T_z = 2T_0$, $(z/L_D)^2 = 3$ so we have $z = L_D \cdot \sqrt{3} = 7988.1\ \mathrm{m}$

(c)

(i) The pulse peak power is $P_o = 1$ W, so the peak intensity is

$$I_o = P_o/A_e = 1\ \mathrm{W}/50\ \mu\mathrm{m}^2 = 0.02\ \mathrm{W}\ \mu\mathrm{m}^{-2}$$

So, the index change:

$$n_{\mathrm{NL}} = 0.02\ \mathrm{W}\ \mu\mathrm{m}^{-2} \times 3 \times 10^{-8}\ \mu\mathrm{m}^2\ \mathrm{W}^{-1} = 6 \times 10^{-10}$$

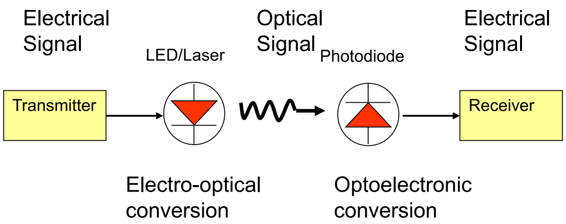
(ii) The nonlinear length can be calculated as

$$L_{NL} = \frac{\lambda A_e}{2\pi n_{NL} P_0} = \frac{1550 \times 10^{-9} \times 50}{2 \times \pi \times 2.9979 \times 10^{-8} \times 1} = 411.4383\ \mathrm{m}$$

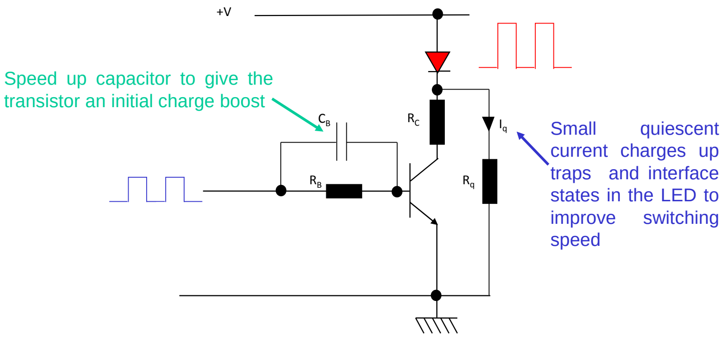
(iii) The pulse width will be shorter, since the nonlinear effect will cause a positive chirp in the pulse, while the fibre GVD coefficient β_2 value is negative. Therefore, the pulse will experience some compression due to this chirp.

2018 Past Paper –Question 4

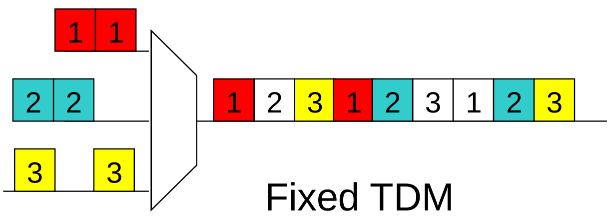
(a) An optical wireless system consists of optical transmitter and optical receiver part. Optical transmitter consists of driver and LED/Laser device, and optical receiver is implemented by a detector circuit including PIN diode or Avalanche diode.



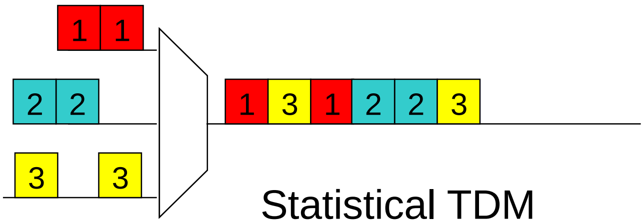
The circuit of a simple optical wireless transmitter consists of an LED as the emitting device, and a bipolar transistor acting as an on/off switch, to ensure a certain current in the LED as determined by the voltage drop across the transistor and the current limiting resistor R_C. To ensure a faster turn on, the device is usually kept on slightly, so that interface states and traps in the semiconductor remain filled - both of which slow switch-on if not.



(b) The sharing of a communication channel between users via timeslots is known as time division multiplexing (TDM). Conventional TDM assigns timeslots to channels in rotation 1...N, which can be illustrated as the following figure.



However, when the traffic comes in bursts there will be many empty slots (in white above). This is inefficient so in statistical time division multiplexing (STDM), the next available slot is used for traffic from a stream that needs it regardless of its position. For a fair comparison, we can take the next channel that has traffic in rotation as shown below. All the slots are used and the efficiency is thus much higher. We can further and have an output which does not have the capacity to fit in all the channels - above that would mean running at 2/3 the speed shown. This is effective in saving resources but does lead to a blocking probability.



Statistical TDM

(c)

(i) For the transmission at the OLT, it is the downlink communication.

The total power budget for downlink is

P_{budget} = 10 km × 0.2 dB/km + 5 dB + 10×$\log_{10}$64 (split) dB + 10 km × 0.2 dB/km
= 27.06 dB

Therefore, the minimum transmission power that the OLT needs to transmit is:

P_{min} = -35 dBm + 27.06 dB = - 7.94 dBm.

(ii) For the transmission at the farthest ONT, it is the uplink communication.

The power budget of the uplink for the farthest ONT is

P_{budget} = 10 km × 0.5 dB/km + 5 dB + 10×$\log_{10}$64 (split) dB + 10 km × 0.5 dB/km
= 33.06 dB

Therefore, the minimum transmission power that the ONT needs to transmit is:

P_{min} = -38 dBm + 33.06 dB = -4.94 dBm