2017 Past Paper –Question 1

(a) The mean squared thermal noise current is:

$$I_T^2 = \frac{4kT\Delta f}{R_L} = \frac{4 \times 1.38 \times 10^{-23} \times 300 \times 20 \times 10^6}{220} = 1.5 \times 10^{-15}\ A^2$$

(b) The received photocurrent is 200×0.8 = 160 nA and so:

$$SNR = \frac{(160 \times 10^{-9})^2}{1.5 \times 10^{-15}} = 17.1$$

(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:

$$\overline{I_1} \geq 6I_T = 6 \times \sqrt{1.5 \times 10^{-15}} = 232.4\ \mathrm{nA}$$

So average received power is ≥ 232.4/0.8 = 290.5 nW = -35.4 dBm

(d) The wavelength range is converted to frequencies:

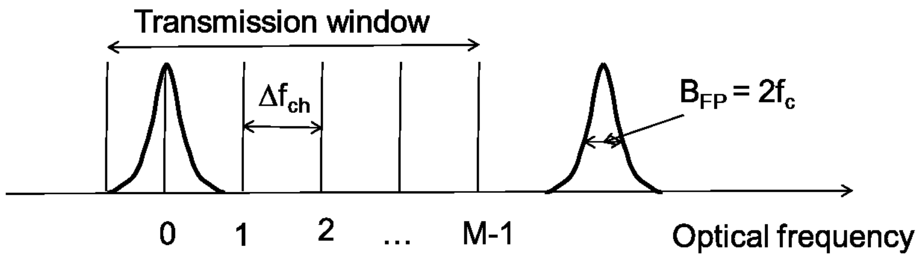
$$f_1 = \frac{2.9979 \times 10^8}{820 \times 10^{-9}} = 3.656 \times 10^{14};\ f_2 = \frac{2.9979 \times 10^8}{820 \times 10^{-9}} = 3.652 \times 10^{14}$$

So the frequency difference is 4×10^{11} Hz. Each OOK channel needs a bandwidth of twice its bit rate, i.e. 2 GHz.

Thus, the absolute maximum number of channels is:

$$N = \frac{4 \times 10^{11}}{2 \times 10^9} = 200$$

(e) The FP filters have a FWHM (B_{FP}) which is twice the cut off frequency of the low pass filter (LPF).



Using the LPF, the worst case cross talk will be:

$$P_X = \bar{P}_1 \sum_{m=1}^{M-1} \frac{1}{1 + (m\Delta f_{ch}/f_c)^2}$$

Since the spacing is more than the 3 dB point and M is large this is

$$P_X \approx \bar{P}_1 \left(\frac{f_c}{\Delta f_{ch}}\right)^2 \sum_{m=1}^{M-1} \frac{1}{m^2} \approx \bar{P}_1 \left(\frac{f_c}{\Delta f_{ch}}\right)^2 \frac{\pi^2}{6}$$

This will produce a photocurrent I_X that offsets the one and zero levels. To maintain performance, we need to increase the power as the new one level is say $\delta_X I_1 + I_X$ and the zero level is I_X and the new decision level is $(\delta_X I_1 + I_X)/2$. To maintain the distance for a zero $(\delta_X I_1 + I_X)/2 - I_X = I_1/2$ so $\delta_X = 1 + I_X/I_1$. For $I_X = I_1$ we will have to double the signal power (3 dB penalty).

For this to be true:

$$\left(\frac{f_c}{\Delta f_{ch}}\right)^2 \frac{\pi^2}{6} = 1 \Rightarrow \Delta f_{ch} = \pi f_c/\sqrt{6}$$

Now, $B_{FP} \approx 0.02 \times 10^{-9} \times 2.9979 \times 10^8/(820 \times 10^{-9})^2 = 8.92\ \text{GHz}$

So, $\Delta f_{ch} = \pi(8.92/2)/\sqrt{6}\ \text{GHz} = 5.72\ \text{GHz}$

Number of channels is

$$N = \frac{4 \times 10^{11}}{5.72 \times 10^9} \approx 70$$

2017 Past Paper –Question 2

(a) The term coherent in optical communications refers to any technique which employs nonlinear mixing between two optical waves. In the case of optical communications, this customarily defines the mixing of a local oscillator with the incoming signal.

There was considerable interest in coherent optical communication in the 1980s because the method substantially increases receiver sensitivity. However, difficulties with maintaining local oscillator phase and frequency stability and rapid developments in WDM and optical amplifiers meant that activity waned. In 2005, digital carrier-phase estimation was demonstrated in coherent receivers prompted renewed developments due to modern DSP. The reinvention of coherent schemes means that a variety of spectrally efficient modulation formats such as M-ary phase-shift keying and quadrature-amplitude modulation (QAM) can be employed since these rely on stable carrier-phase estimation in the digital domain.

(b) Using a local oscillator (LO) at the same frequency as the signal carrier is called Homodyne Detection whereas using one at a different frequency is termed Heterodyne Detection

(c) The coherent receiver signal is formed from the squared sum of the signal and local oscillator contributions.

$$E_R = A_S e^{-j(\omega_S t+\phi_S)} + A_L e^{-j(\omega_L t+\phi_L)}$$
$$P_R = |E_R|^2 = |A_S|^2 + |A_L|^2 + 2\,A_S A_L \cos\{(\omega_S - \omega_L)t + (\phi_S - \phi_L)\}$$

$$P_R = P_S + P_L + 2\sqrt{P_S}\sqrt{P_L}\cos\{\Delta\omega t + \Delta\phi\}$$
$$\Delta\omega = \omega_S - \omega_L; \Delta\phi = \phi_S - \phi_L$$

Homodyne detection means:

$$\omega_S = \omega_L; \Delta\omega = 0$$
$$P_R = P_S + P_L + 2\sqrt{P_S}\sqrt{P_L}\ \cos\{\Delta\phi\}$$

Writing in terms of photocurrent with a zero phase difference:

$$I_{\mathrm{COH}} = RP_S + RP_L + 2R\sqrt{P_S}\sqrt{P_L}$$

Make LO power much greater than signal power so $P_L \gg P_S$ and thus: $P_L + P_S \approx P_L$.

Then since P_L is constant we can low pass filter to leave:

$$I_{\mathrm{COH}} \approx 2R\sqrt{P_S}\sqrt{P_L}$$

(d) In general:

$$SNR = \frac{I_p^2}{\sigma_{\text{SHOT}}^2 + \sigma_{\text{THERMAL}}^2}$$

We have

$$I_{\text{COH}} = 2R\sqrt{P_S}\sqrt{P_L}$$

The filtered version will form the relevant $I_p$and for the shot noise the dc total current $\approx \Re P_L$ is used. Since the local oscillator power dominates the signal, the shot noise from it will be much greater than thermal noise.

$$SNR_{COH} \approx \frac{4R^2 P_S P_L}{2q\Delta f(RP_L)} = \frac{2RP_S}{q\Delta f}$$

(e) Since direct detection schemes are thermal noise dominated, we can say:

$$SNR_{DD} \approx \frac{R^2 P_S^2 R_L}{4kT\Delta f}$$

The ratio of the two for an ideal receiver with $(R = 1)$ is:

$$\frac{SNR_{COH}}{SNR_{DD}} \approx \frac{8kT}{qR_L}\frac{1}{P_S}$$

Now we are given

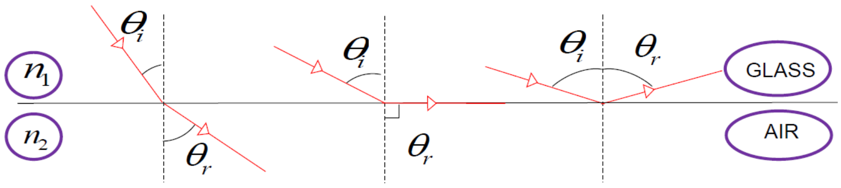
$$P_S = -30 \text{ dBm} = 10^{-6} \text{ W}$$

Also, $R_L = 50\Omega; T = 300\text{K}$

$$\frac{SNR_{COH}}{SNR_{DD}} \approx \frac{8 \times 1.38 \times 10^{-23} \times 300}{1.602 \times 10^{-19} \times 50}\frac{1}{10^{-6}} = 4135 = 36.2 \text{ dB}$$

2017 Past Paper –Question 3

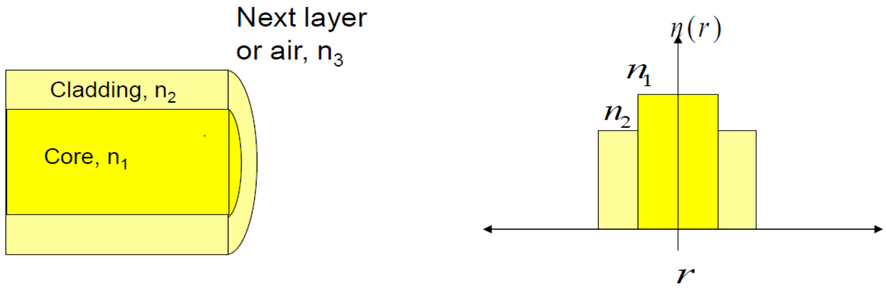
(a) Optical fibres use the principle of total internal reflection to guide light and near infrared wavelengths. The diagram below shows the relationships, based on Snell's Law, which appertain:



(a) Snell's Law	(b) Critical Angle	(c) T. I. R.
$n_1 \sin\theta_i = n_2 \sin\theta_r$	$n_1 \sin\theta_i = n_2$	$\theta_i = \theta_r$

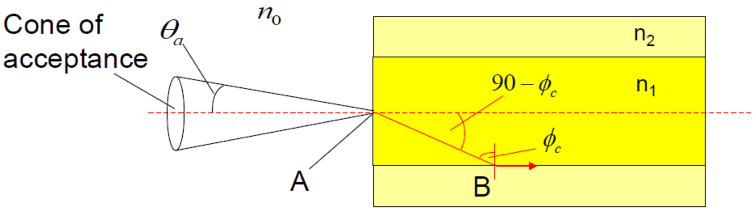
The general step index fibre structure is shown below:

Step Index



(a) Cross section (b) Refractive index profile

(b) The numerical aperture is determined from the geometry of the ends of the fibre interfacing with the external medium to allow the required Total Internal Reflection (TIR):



The incident θ must be < θ_a to ensure that the rays undergo T.I.R.
The incident ray is refracted so that

$$\sin\phi_c = n_2/n_1$$

If the conditions for TIR are met, then the following applies:

$$n_0 \sin\theta_a = n_1 \sin(90-\phi_c) = n_1 \cos\phi_c = n_1\sqrt{1-\sin^2\phi_c}$$

Substitute for ϕ_c:

$$NA = n_0 \sin\theta_a = n_1\sqrt{1-\frac{n_2^2}{n_1^2}} = \sqrt{n_1^2 - n_2^2}$$

(c) Using the formula above and substituting the values given:

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{1.5^2 - 1.492^2} = 0.155$$

(d) The maximum radius is found by recalling that V ≤ 2.405 for single mode operation

$$a \le \frac{V\lambda}{2\pi(NA)} = \frac{2.405 \times 1300 \times 10^{-9}}{2\pi \times 0.155} = 3.21\ \mu\text{m}$$

(e) The Gaussian approximation is: $P(r) = P_0 \exp(-2r^2/\omega_0^2)$ and

$$\frac{P_{\text{cladding}}}{P_{\text{total}}} = \frac{\int_a^\infty r\,P(r)dr}{\int_0^\infty rP(r)dr} = \frac{P_0\left[-\frac{\omega_0^2}{4}e^{-\frac{2r^2}{\omega_0^2}}\right]_a^\infty}{P_0\left[-\frac{\omega_0^2}{4}e^{-\frac{2r^2}{\omega_0^2}}\right]_0^\infty} = e^{-\frac{2a^2}{\omega_0^2}}$$

So

$$\frac{P_{\text{core}}}{P_{\text{total}}} = 1 - \frac{P_{\text{cladding}}}{P_{\text{total}}} = 1 - e^{-\frac{2a^2}{\omega_0^2}}$$

(f) Using $\omega_0/\mathrm{a} \approx \left(\sqrt{\ln \mathrm{V}}\right)^{-1}$

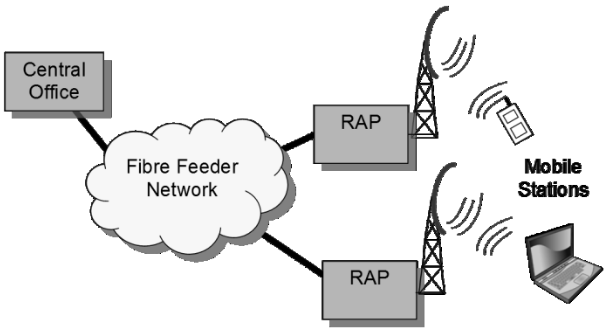
$$\frac{P_{\text{core}}}{P_{\text{total}}} \approx 1 - \frac{1}{e^{2\ln V}} = 1 - \frac{1}{V^2} = 1 - \frac{1}{2.405^2} = 0.827$$

2017 Past Paper –Question 4

(a) The increasing bandwidth demands of modern society have led to a search for more capacity in local RF access systems. The use of higher frequency carriers and proliferation of indoor applications lead to smaller mobile cell sizes –Microcells and Picocells. These small cells cover small areas so there need to be a lot of them.

To have a full base station (BS) for each small cell would not be cost effective and we therefore use simplified radio access points (RAPs)

For the downlink, we modulate RF onto an optical signal and transmit over fibre. At the RAP we recover the RF and transmit via the radio antenna. The process is reversed for the uplink.



(b) The abbreviations are:

L = laser diode
PD = photodiode
PA = power amplifier (microwave)
LNA = low noise amplifier (microwave)

(c) We employ the equation for the overall noise factor

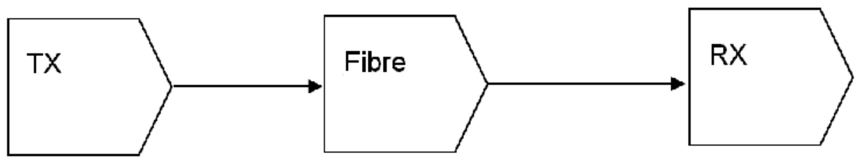
$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

The fibre length is 10 km with a loss of 0.2 dB per km, so the fibre loss is 2 dB.

The situation is shown in the diagram below and we note that

$F_2 = 1$ so

$$F = F_1 + \frac{F_3 - 1}{G_1 G_2}$$



$F_1 = 10^2 = 100$, $G_1 = 10^{-2} = 0.01$ $F_2 = 10^0 = 1$, $G_2 = 10^{-0.2} = 0.63$ $F_3 = 10^1 = 10$, $G_3 = 10^1 = 10$

Total loss is 20 dB + 2 dB –10 dB = 12 dB

$$F = 100 + \frac{10 - 1}{0.01 \times 0.63} = 1528.6 = 31.8 \text{ dB}$$

These are to be employed below for SNR calculations

(d) For the up- and downlinks, we can use the equation for the overall noise factor

$$F = F_1 + \frac{F_2 - 1}{G_1}$$

For the uplink, device 1 is the LNA and device 2 is the fibre

So $F_1 = 10^{0.3} = 2$; $F_2 = 1528.6$;$G_1 = 10^{2.5} = 316.2$

$$F_U = 2 + \frac{1528.6 - 1}{316.2} = 6.83 = 8.3 \text{ dB}$$

In dB:

$$SNR_{\text{OUT}} = SNR_{\text{IN}} - NF = 20 - 8.3 = 11.7 \text{ dB}$$

For the downlink, device 1 is the fibre link and device 2 is the PA

So $F_1 = 1528.6$; $F_2 = 10^{0.7} = 5$;$G_1 = 10^{-1.2} = 0.063$

$$F_D = 1528.6 + \frac{5 - 1}{0.063} = 1592 = 32 \text{ dB}$$

In dB:

$$SNR_{\text{OUT}} = SNR_{\text{IN}} - NF = 40 - 32 = 8 \text{ dB}$$