EEE442/6420 Exam solutions 2011

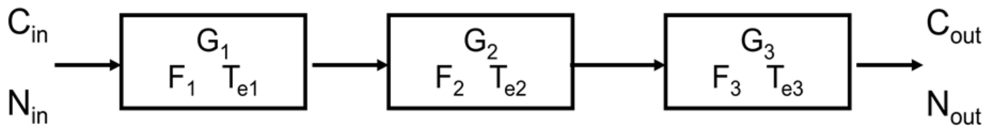
Q1

a. Hostile environment for satellites

Satellite components need to be specially "hardened"
Circuits which work on the ground will fail very rapidly in space
Temperature is also a problem – temperature gradient up to 200ºC across satellite - so satellites use electric heaters to keep circuits and other vital parts warmed up - they also need to control the temperature carefully: antennas need to be heat distortion resistant.
Corrosion
Withstand launch – vibration and G forces
Vacuum

6 marks

b.



Noise generated by each amplifier stage multiplied by gain of next stage and succeeding stages.
3 stage ampifier:
$C_{out} = C_{in}G_1G_2G_3$
$N_{in} = k\,T_0\,B$, $T_0 = 290K$
$N_{out} = k\,T_0\,B\,G_1\,G_2\,G_3 + k\,T_{e1}\,B\,G_1\,G_2\,G_3 + k\,T_{e2}\,B\,G_2\,G_3 + k\,T_{e3}\,B\,G_3$
Now $F_n = 1 + T_{en} / T_0$
Then $N_{out} = N_{in}\,G_1\,G_2\,G_3 + N_{in}\,(F_1 – 1)\,G_1\,G_2\,G_3 + N_{in}\,(F_2 – 1)\,G_2\,G_3 + N_{in}\,(F_3 – 1)\,G_3$
$F = (C_{in}/N_{in})/(C_{out}/N_{out}) =$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots\ldots\ldots \frac{F_n - 1}{G_1 G_2 .. G_{n-1}}$$

6 marks

c.

For receiver alone

$C_o / N_o = C_i/(N_iF)$ $F = (T_o + T_R)/T_o$

$N_i = kT_oB = k290B$ and $N_iF = kT_oB\,(T_o + T_R)/T_o = kB(T_o + T_R)$

$C_o / N_o = C_i / \{k\,B\,(290 + T_R)\} = 6\text{ dB} = 4$ ....**(1)**

For receiver and pre-amplifier

$C_o / N_o = C_i / \{k\,B\,(290 + T_{sys})\} = 18\text{ dB} = 63.1$ ......**(2)**

Pre-amplifier gain = 20 dB = 100

Hence

$T_{sys} = T_{pre\text{-}amp} + T_R / 100$ $(T = T_1 + T_2/G_1)$

Pre-amplifier noise figure = 2 dB = 169.6 K

$T_{sys} = 169.6 + T_R / 100$

Substitute for T_{sys} in equation 2 and solve equations 1 and 2 for T_R

Hence T_R = 8264 K

Receiver noise figure = $10 \log_{10} (1 + 8264 / 290)$ = $\underline{14.7\text{ dB}}$

8 marks

Q2.

a.

i. Coverage footprint; beam pattern laid down on ground from satellite, known as contour it can be shaped for optimum coverage

ii. Orthogonally polarised beams; to obtain frequency reuse signals transmitted on orthogonal polarizations- circular or linear

iii. Antenna noise temperature – noise introduced into receiver by antenna and consists of thermal, cosmic and other noise existing .

b.

LARGE EARTH STATION

Transmit high power signal to satellite
Receive very low power signal from satellite

G/T = 40.7 dB
Noise temp T = 28K

Reflectors efficiency 80%
26m in diameter – 0.2° beamwidth
Track satellite to a fraction of a degree
±0.04° even in a hurricane

Describe main components of earth station particularly antenna and receiver.

Antenna very large reflector, high pointing accuracy, high gain and efficiency. cassegrain systems, shaped, low noise temp etc.

Receiver – state of the art, very low noise preamp cooled in liquid N, down convertor etc
Transmitter – high power, cooled

c.
Given the following information about a satellite communications link, determine the noise temperature of the earth station.

Earth station: Pt = 200 W; Ge = 55 dB; Te = ?K
Satellite : Gs = 25 dB; Ps = 10 W; Ts = 1500K
Overall: Path losses – uplink = 201 dB, down link = 199 dB
Bandwidth = 8 MHz
Operating margin = 4 dB
Overall C/N = 21 dB
$k = 1.38 \times 10^{-23}$ J/K (8)

Answer
Ts = 1500K = 31.76 dBK
Ps = 10dBW
Pt = 23 dBW

Down link: $$\left(\frac{C}{T}\right)_D = E_s - L_D - M + \frac{G_e}{T_e}$$

$C/T_D = 10 + 25 - 199 - 4 + 55 - T_e = -113 - T_e$

Uplink: $$\left(\frac{C}{T}\right)_U = E_e - L_U - M + \frac{G_s}{T_s}$$

C/T_U = 23 + 55 – 201 – 4 + 25 – 31.76 = -133.76 dBW/K = 4.2 -14

Overall C/N = 21 dB, hence C/T_T = -138.6 dBW/K = 1.38 -14

$$\left(\frac{C}{T}\right)_T = \frac{1}{\frac{1}{(C/T)_U} + \frac{1}{(C/T)_D}}$$

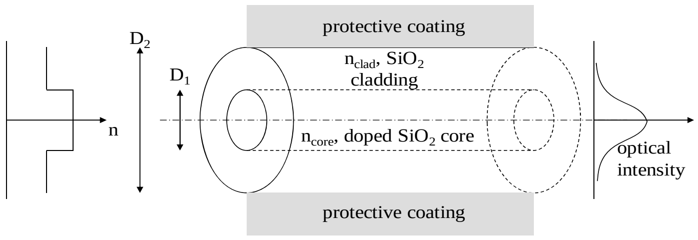
Hence C/T_D = -136.87 dBW/K **=** $-113 - T_e$

Te = 23.87 dBK = 243K

Q3

Fibre Optic Cable

Total internal reflection



SiO2- high purity: low loss, n_{ref} ~ 1.45

Dopants: Boron, Fluorine: decrease n_{ref} ,

Phos, Ge, Ti: increase n_{ref}

a.

Snells Law :

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

Reflection *Condition*

$\theta_1 = \theta_3$

When $n_1 > n_2$ *and as* θ_1 *increases eventually* θ_2 *goes to* 90 *degrees and*

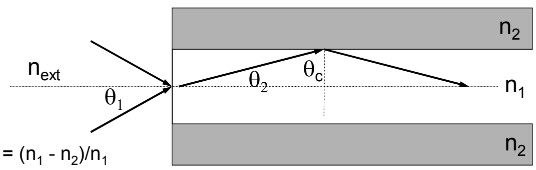
$n_1 \sin\theta_c = n_2$ *or* $\sin\theta_c = \frac{n_2}{n_1}$

θ_c *is called the Critical angle*

For $\theta_1 > \theta_c$ *there is no propagating refracted ray*

For all angles θ_1 larger than this get total internal reflection

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 $\mathrm{Sin}^2\phi + \mathrm{Cos}^2\phi = 1$

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

(6 marks)

b.

Single Mode Fibre – Manufacture

Students need to describe one method on manufacture with drawings.

- Step 1 – Preform

A large scale version of the fibre is manufactured by some form of chemical vapour deposition of glasses of different composition (hence refractive index)– e.g. on the inside of a glass tube which is then collapsed onto itself. Diagram needed here.

- Step 2 – Drawing

  Simply (!) stretch out to obtain correct dimensions

Need to ensure dimensions constant and minimise impurities

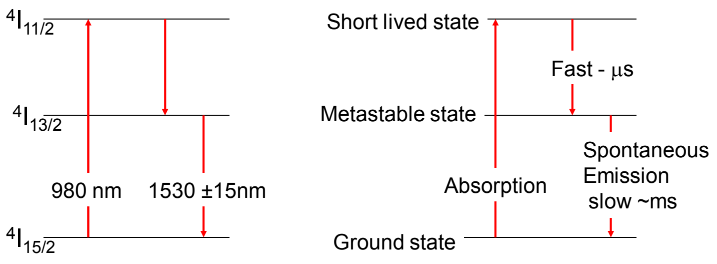
(4 marks)

c.

Erbium

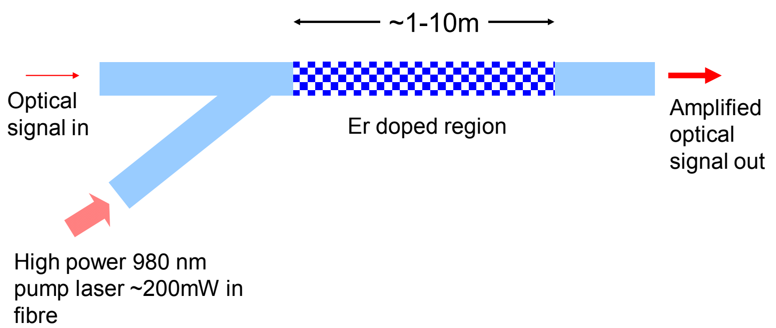
Erbium has an optical transition at ~1.55 um – pump at 980nm or 1480nm

Er 4f-shell



States not infinitely narrow
– broadened by inhomogeneous surroundings

Erbium Doped Fibre Amplifier (EDFA)



Pump laser can travel in same or opposite direction as pulse to be amplified

EDFA cont.

- A length of optical fibre doped with erbium (Er)
- - Y coupler (3dB) allows Er region to be pumped with a semiconductor laser (usually 980nm)
- Absorption of 980nm photon by Er^{3+} ion results in the excitation of electrons within the electronic levels of the ion.
- The electron occupies a short-lived state before relaxing to a long-lived energy level.
- The relaxation from this level to the ground state results in the emission of a photon at 1550nm
- Due to inhomogenaities a broad band (=/-20nm) emission is possible.
- If excitation is sufficiently strong a population inversion is possible – in such a case a signal photon is highly likely to trigger the stimulated emission of a photon amplifying the signal.

EDFA – Conclusions from Rate Equations

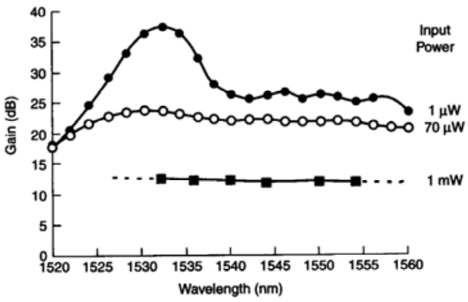
No signal and strong pump – obtain population inversion

Introduce signal – get gain

As we increase signal strength, deplete level N_2 and gain saturates as system cannot keep up – **Gain Saturation**

For maximum gain
– need large concentration of Er atoms, high pump power

Max gain ~ 30dB/EDFA



7 marks

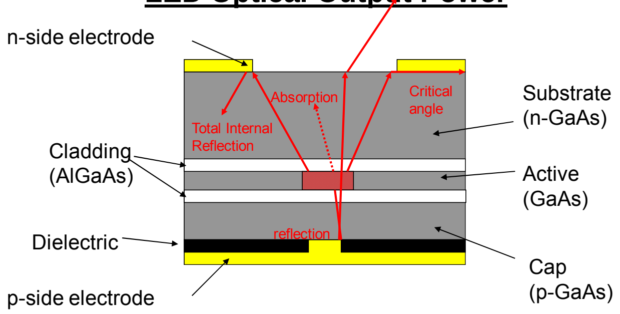
d. Erbium amplifier is simpler and more robust. Not tied to specific data type.
Does not cope with dispersion , adds noise (amplified spontaneous emission), cross talk may be a problem. **3 marks**

Q4

a.

LED – spontaneous emission – low current densities

LED Optical Output Power

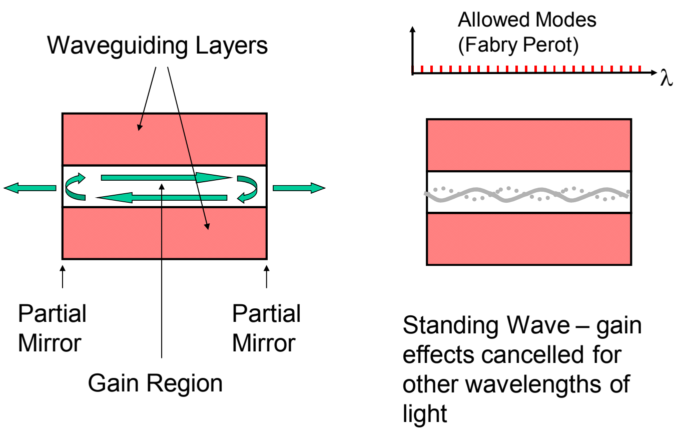


Typical external efficiencies of only ~1-3%

Surface and edge emitting types

Laser – high current densities – stimulated emission – optical feedback

Gain and Optical Feedback – LASER



Fabry Perot cavity length = nλ/2 for transmission

(6)

b.

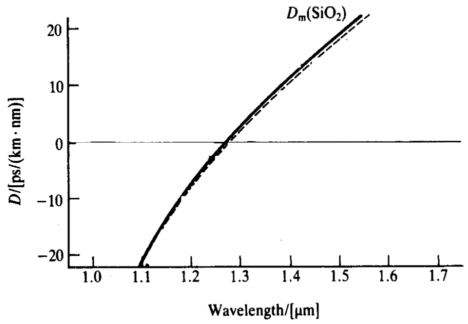
Chromatic dispersion – SM fibre

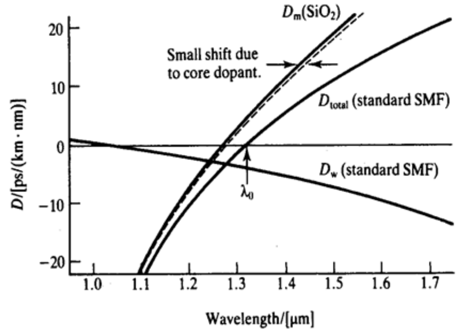
Chromatic Dispersion of single mode fibre made up of two components – material ($n_{group}(\lambda)$) and waveguide dispersion (average n_{group} the mode sees is a function of λ as mode size is fn of λ)

For silica – group index is a function of wavelength
Turning point at 1.25 μm
To first order – signals with reasonable emission linewidths will propagate with no dispersion
Away from this point - different wavelength components of emission will travel with different velocities
Speed of wavepacket = c/n_g
Longer than 1.25 μm -red faster than blue
Shorter than 1.25 μm- blue faster than red

Leads to pulse broadening

Material Dispersion – Silica Glass





Waveguide dispersion - Longer wavelength light spreads out laterally - more than shorter wavelength light
Each pulse will be broadened due to the difference in core and cladding refractive index – waveguide dispersion
Two pulses broadened differently due to different effective refractive index

For silica – refractive index is a function of wavelength – so have Material Dispersion (6)

c.
Loss limitation for system

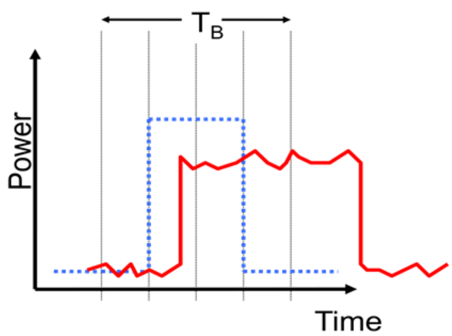
Txer	Fibre	Rxer
P_T=2 dBm	α=0.2 dB/km, D=15ps/(km.nm)	P_R=-40 dBm

Tx power - total loss+ amplification = margin + Rx sensitivity

$P_T - \alpha L = M + P_R$

Hence L = fibre length = $(M + P_R - P_T)/\alpha$ = 20 -40 – 2 / 0.2
L = 110 km

Dispersion limited distance:



Commonly used criterion is that broadening $\Delta t \leq T_B/4$

$\Delta t = L\Delta\lambda\, D(\lambda)$

$L\Delta\lambda\, D(\lambda) \leq T_B/4$

$BL\Delta\lambda\, D(\lambda) \leq 1/4$

$BL=1/[4\ \Delta\lambda\ D(\lambda)]$

Note: $\Delta\lambda\, D(\lambda)$ often quoted as dispersion in ns/km

Bit slot length = 1/data rate = 2000ps (10^{-9} s)
Assume pulse broadening allowed to be ¼ Bit slot width = 500ps
$\Delta\lambda$ = 1nm so broadening due to dispersion = D x $\Delta\lambda$ = 15ps/km
Hence dispersion limit is 500/15 km = 33.3 km

Hence optical fibre length = 33.3 km determined by dispersion. (7)

Reduce the dispersion constant which may be difficult or the line width. (1)