Solutions to EEE442/6420 for 2011-12 RF and Optical systems

R J Langley

Q1

a. ORBITS

LEO – 500-1500km, uses – mobile satellite phones, path losses small

MEO – 5000-15000 km, - weather/sensing applications

GEO 36000 km, tv broadcast, fixed comms links, losses high 6 marks

b.

Main Advantages

- Extend capability of existing terrestrial cellular system
- Coverage in remote locations
- Large coverage area
- Seamless service to subscriber in any part of the world

Challenges

- Propagation delay
- Attenuation – path loss 200 dB
- Low Spectral efficiency
- Costs – $100M+
- Power limited
- Reliability – 10 years + lifetime

6 marks

c.

Noise power is expressed in Watts or Watts/Hz but it is more convenient in system design to relate it to a fictitious noise temperature T through the formula

P = kTB Watts

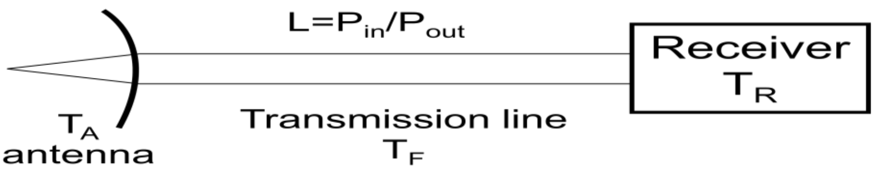
Noise factor F is defined by

$$F = \frac{C_{in} / N_{in}}{C_{out} / N_{out}} = \frac{\text{output noise power}}{\text{input noise power}}$$

where C = carrier power, N = noise power

Noise figure = 10 log(F)

d.



Now noise temperature **<u>at receiver</u>** is $T'_S = \frac{T_A}{L} + (1 - \frac{1}{L})T_P + T_R$

since noise factor for lossy line = loss L and noise temperature referred to output is

$$T_{eout} = (1 - 1/L)T_F$$

Now L = 2 dB = 1.585,

For the receiver $F = 1 + \frac{T_e}{T_0}$ = 1.585, T_R = 170 K

So T'_S = 100/1.585 + 0.585.290/1.585 + 170 = 63.1 + 107 + 170 = 340.1 K

Q2

a.

SATELLITE TV RECEIVER

The receiving system is made up of 4 items:

- Antenna
- Low noise block (down converter)
- Set top box
- TV receiver

Antenna

Normally a parabolic dish either circular or elliptical in shape and 40-80 cm in diameter. Dish provides signal collecting area and focuses signal onto a small horn antenna at the front of the low noise block.

Low noise block - LNB

This amplifies the incoming signal (either horizontally or` vertically polarised), depending on the satellite channel being received) and down converts it from around 11 GHz to ~1 GHz.
Signal fed to set top box via coaxial cable.
Power and control signals are fed up the same coaxial cable.

The satellite signal polarisation is selected by changing the supply voltage – 13V (vertical) or 18V (horizontal).

LNB receives signals in 2 sub bands, 10.7-11.7 GHz and 11.7-12.75 GHz, by switching local oscillator to 9.75 GHz or 10.6 GHz.

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6 marks

b. Capacity optimised by tailoring coverage footprint to not waste power in unwanted areas such as the sea, frequency reuse using spacial or polarisation techniques.

4 marks

c.

$$\left(\frac{C}{N}\right)_D = E_s - L_D - M + \frac{G_e}{T_e} + 228.6 - 10\log B_{RF}$$

Minimum C/N = 11 dB
EIRP of satellite transponder Es = 51 dBW = 100w + 31db

B = 26 MHz, k = 1.38 x 10^{-23} dBW/K
10 log(kB) = -154.45 dBW/K

Path loss = 20log(4πd/λ) = L_D
freq = 10.8175 GHz
d = 39237.73 km, λ = 2.773 cm
Path loss = 205 dB

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10.8175\times10^9} = 2.773\times10^{-2}\,m$$

Now - Assume M = 4 dB – rain and elevation losses

Hence G_e/T_e = **14.55 dB/K** = 28.5 (linear units)

Under clear sky conditions, T_e = 55 K =
Receiver noise temperature = 75 K
Overall T=130K
Hence receiving antenna gain G_e = 130 x 28.5 = 3706
Design an antenna to fulfill the requirements for a domestic satellite tv system
Design offset parabola antenna. Low noise max efficiency,

aperture = $A_e = \dfrac{\lambda^2}{4\pi} G$ $=2268\ \text{cm}^2 = \text{pi}\ r^2$

Hence Diameter = 54 cm. assuming 100% efficiency.

If assume 60% efficient then area increased to 2268/0.6 = 3780
Hence dish diameter 70cm.

Q3.
a. Dispersion

Dispersion Summary

Intermodal dispersion (ie between modes) → **MODAL DISPERSION**

Multi-mode fibres only; minimised for graded-index fibres

Chromatic or Intramodal dispersion (ie within a single mode) → **MATERIAL DISPERSION**, **WAVEGUIDE DISPERSION**

Single or multi-mode fibres but only significant for single mode fibres.

Chromatic dispersions are wavelength dependent

Chromatic much less than modal dispersion.

Transmitter should have a narrow linewidth – laser. 6 marks

b. 4 marks

V - normalised frequency

In an optical fibre, the **normalized frequency**, V (also called the **V number**), is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{{n_1}^2 - {n_2}^2} \quad = \frac{2\pi a}{\lambda}\mathrm{NA},$$

where a is the core radius, λ is the wavelength, n_1 is the maximum refractive index of the core, n_2 is the refractive index of the homogeneous cladding, and NA the numerical aperture.

In multimode operation of an optical fiber, the approximate number of bound modes is given by

$$\frac{V^2}{2}\left(\frac{g}{g+2}\right) \quad ,$$

where g is the profile parameter, and V is the normalized frequency, which must be greater than 5 for the approximation to be valid.

For a step index fibre, the mode volume is given by $V^2/2$. For single-mode operation is required that $V < 2.405$, which is the first root of the Bessel function J_0.

c. $E = h\nu = hc/\lambda$

At 1550 nm Energy of 1 photon = $6.6 \times 10^{-34} \times 3\times10^{8}/1550\times10^{-9} = 1.28 \times 10^{-19}$ J

Need 1000 photons to detect 1 bit at 1Gb/s

Need a peak received power of $1.28 \times 10^{-19} \times 1000 \times 1000 \times 10^{6} = 1.28 \times 10^{-7}$ W

Average power = peak power/2 = 6.4×10^{-8} = -42 dBm

Launch power = 10 dBm

Assuming no margin have 52 dB available in power budget as a loss in fibre

Loss = 2dB/km, **hence fibre length = 52/2 = 26 km.**

d. To transmit a much higher data rate over the same distance –

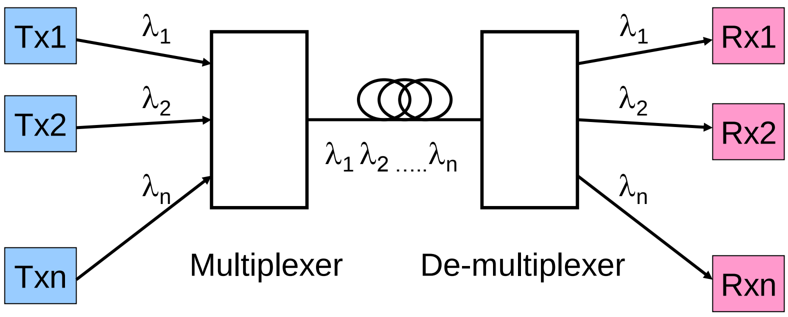
- use narrower line widrth source
- use course wdm
- change wavelength to 13 microns where D=0

Q4

a. WDM

Wavelength Division Multiplexing

WDM –photons of different wavelength can occupy the same space and be transmitted over one fibre



Uses multiplexers to combine the channels at different wavelengths and de-multiplexers to separate (filter) the channels at the receiver. One channel delivered to each receiver.

WDM Components

Narrow emission linewidth transmitters

Tuneable wavelength transmitters?

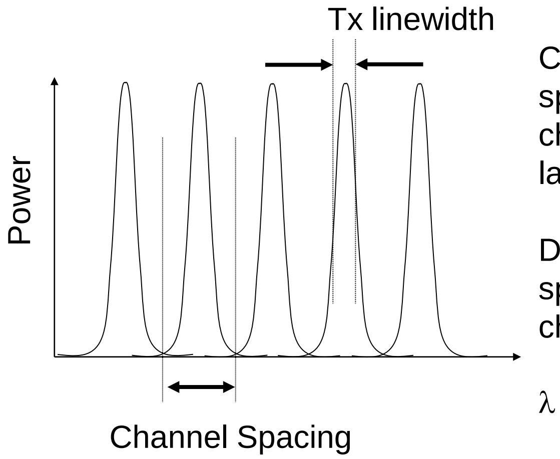
Multiplexers – light combiners – easy e.g. coupler

De-multiplexers – (high finesse wavelength filters)

The last two are sometimes the same device in reverse

Wavelength Division Multiplexing

Many channels can be deployed massively increasing available bandwidth of one fibre



Coarse – CWDM – large spacing between channels compared to laser linewidth (~10nm)

Dense – DWDM – small spacing between channels (~<1nm)

6 marks

DWDM systems

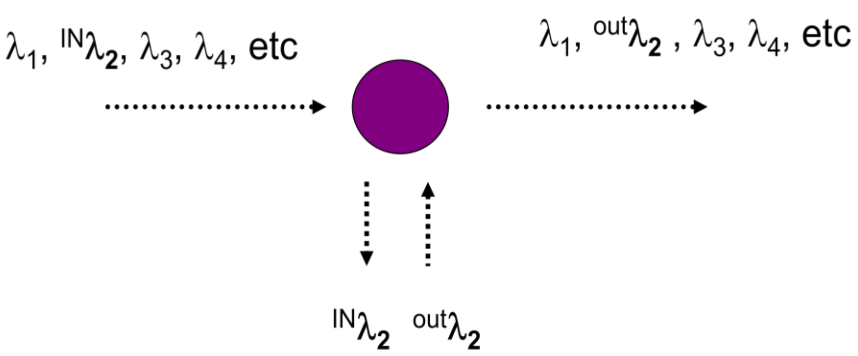
Tightly spaced channels

Number of channels limited by

(1) Wavelength stability of laser (DFB)
(2) Signal degradation – non-linear effects
(3) Interchannel crosstalk at DEMUX
(4) Need for accurate demultiplexing filters 4 marks

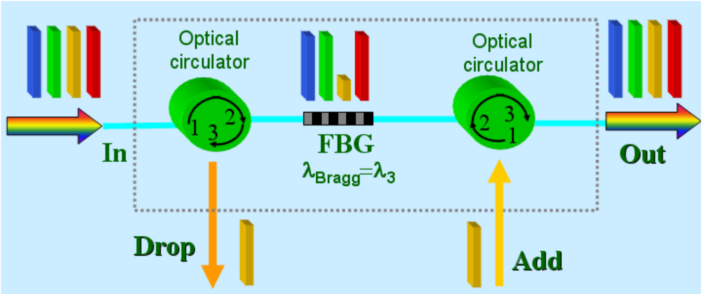
Gives Tb/s performance

b. Add/drop demultiplexer

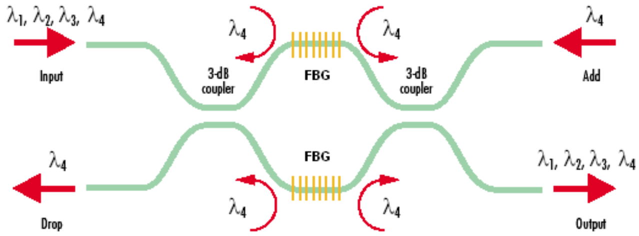


Add or drop a channel at each node

❑ Circulators with FBG / TFF

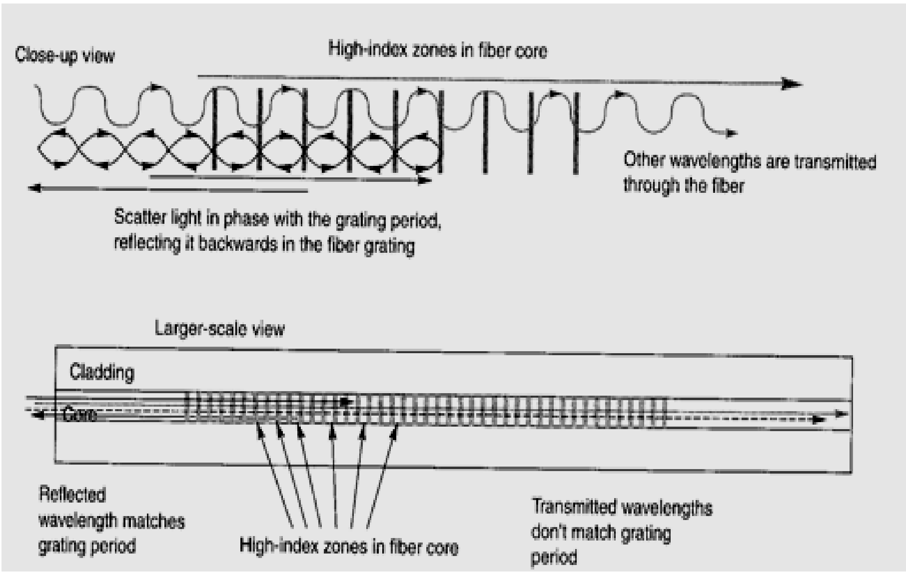


❑ MZI with FBG



MZI or coupler and Bragg grating filter

Reflection at FBG



e.g. (De) Multiplexer

Unbalanced Mach-Zehnder Interferometer

Change in phase along longer arm $\Delta\theta_i = \beta\Delta L$

$P_1(\lambda_1)/P_{in} = \cos^2[\Delta\theta_1/2]$ $\qquad$ $P_2(\lambda_2)/P_{in} = \cos^2[\Delta\theta_2/2]$

Make $\Delta\theta_1 = 2\pi n$ direct all power at λ_1 into output 1
Make $\Delta\theta_2 = 2\pi m$ direct all power at λ_2 into output 2