ES4C41

THE UNIVERSITY OF WARWICK

Fourth Year Examinations: Summer 2016

OPTICAL COMMUNICATION SYSTEMS (MSc)

Candidates should answer all FOUR questions.

Time Allowed: 3 hours.

Only calculators that conform to the list of models approved by the School of Engineering may be used in this examination. The Engineering Databook and standard graph paper will be provided.

Read carefully the instructions on the answer book and make sure that the particulars required are entered on each answer book used.

You may assume the following,

Planck's constant $= 6.63 \times 10^{-34}$ Joule seconds
Velocity of light $= 3 \times 10^{8}$ metres per second
Electronic charge $= 1.6 \times 10^{-19}$ Coulomb
1 eV $\equiv 1.6 \times 10^{-19}$ Joule

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1. A Fabry-Perot filter with identical ideal mirrors, length L, contains a medium of refractive index n. The round trip phase shift is given by $2\theta = 2kL$, where k is the unguided propagation constant of the light impinging on the cavity in the medium between the mirrors.

(a) Show that the Free Spectral Range (FSR) of the filter is $c/2nL$. (4 marks)

(b) Show further that the intensity transmission function of the filter is given by

$$T_F(\theta) = \frac{(1-R)^2}{1 + R^2 - 2R\cos(2\theta)}$$

where R is the reflectivity of the mirrors. (10 marks)

(c) Hence, by making a suitable approximation when the full width at half maximum (FWHM) is very small, obtain the expression

$$\text{FWHM} = \frac{(1-R)}{2\sqrt{R}}$$

for the FWHM of the filter. (8 marks)

(d) Estimate the maximum number of 50 GHz channels that a Fabry-Perot filter with an air gap of 50 μm between its mirrors can select. (3 marks)

2. (a) Explain what is meant by the terms core network and access network. (2 marks)

   (b) Briefly describe, with the aid of diagrams, two access network architecture options. (6 marks)

   (c) Outline what is meant by the term store and forward in packet switching, and why this is difficult in optical networks. (2 marks)

   (d) A star network is to be designed to connect 8 nodes.

      (i) Draw a block diagram of the star topology to connect the 8 nodes and describe with the aid of suitable diagrams, how each node of the optical star network can be implemented.

      (ii) Illustrate how the required 8×8 star coupler may be made using 2×2 optical couplers and determine the splitting power loss.

      (iii) Identical optical transmitters each with an output power of 1 mW and an optical connector loss of 3dB are used at the input ports of the 8×8 star coupler. Determine the optical power at the coupler's output ports.

   (10 marks)

   (e) Explain the difference between short haul and long haul point-to-point architectures and why fibres are beneficial. Furthermore for long haul point-to-point links explain the difference between regenerators and optical amplifiers and why and when they are used. (5 marks)

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3. (a) Briefly describe, with the aid of a diagram, the operation of a *pn* photodiode, indicating the advantage of using a *pin* structure instead. (7 marks)

(b) Define the quantum efficiency η of a photodiode. Show that the photocurrent, I_P, from a photodiode illuminated with light of power P_O is given by:

$$I_P = P_O \frac{\eta q}{hf}$$

where q is the electronic charge, h is Planck's constant, and f is the frequency of the light. (4 marks)

(c) A *pn* photodiode is illuminated from its *p* side, and has a front face reflectivity of R_f and an absorption coefficient α (assumed to be independent of material doping). Show that, when x_1 represents the start of the depletion region and x_2 its end, the diode's quantum efficiency η is given by the formula below.

$$\eta = (1 - R_f)e^{-\alpha x_1} \cdot \left[1 - e^{-\alpha(x_2 - x_1)}\right]$$

Further, comment on the implications for photodiode design. (8 marks)

(d) Assuming that the *p* and *n* depletion regions are negligibly small, estimate the photocurrent produced by 1μW of optical power at 633 nm and 850 nm illuminating a silicon *pin* photodiode with the following characteristics: top *p*-layer thickness 1 μm; intrinsic layer thickness 25 μm; top face reflectivity of 30%. The optical absorption coefficient of silicon, α, in units of m^{-1}, over this wavelength range may be approximated by the equation:

$$\alpha = 6.9 \times 10^7 e^{(-\lambda/130)}$$

where λ is in nanometres, and the change in reflectivity between the two wavelengths above may be assumed to be negligible. (6 marks)

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4. (a) Explain what is meant by the terms phase velocity and group velocity. (2 marks)

(b) Define, using appropriate mathematical expressions, the group index, N_{ge}, and the normalised propagation constant for an optical fibre. (4 marks)

(c) Show that the propagation constant in a fibre, β, is given in terms of the free space propagation constant k, the cladding index n_2, the relative refractive index difference Δ and the normalised propagation constant b, for small Δ, by:

$$\beta \approx kn_2(1 + b\Delta)$$

(6 marks)

(d) The group delay of a single mode step index optical fibre is given by:

$$\tau_g = \frac{1}{c}\frac{d\beta}{dk}$$

Show that, assuming $b\Delta$ is negligible compared to 1, this may be expressed approximately in terms of the normalised propagation constant and the fibre V parameter as:

$$\tau_g \approx \frac{1}{c}\left\{n_2 + k\frac{dn_2}{dk} + n_2\Delta\frac{d(Vb)}{dV}\right\}$$

(9 marks)

(e) A step index optical fibre has a core refractive index of 1.5, a cladding refractive index of 1.495 and is designed to be just single-moded at 1300 nm. Estimate the group delay of the fibre at 1300 nm. You may assume the following empirical relationship based on the V parameter:

$$\frac{d(bV)}{dV} \approx 1.3 - \frac{1}{V^2}$$

and that $kdn_2/dk = 0.01$ at 1300 nm. (9 marks)