ENGINEERING TRIPOS PART IIB

Thursday 23 April 2009 2.30 - 4

Module 4B11

PHOTONIC SYSTEMS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

1. (a) The principles of diffraction all stem from Huygens wavelets. By analysing a simple illuminated aperture function $A(x,y)$ with Huygens wavelets it is possible to show that the diffracted light through the aperture will be given by the expression

$$dE = \frac{A(x,y)e^{j\omega t}e^{-jkR\sqrt{1-\frac{2\alpha x+2\beta y}{R^2}+\frac{x^2+y^2}{R^2}}}}{R\sqrt{1-\frac{2\alpha x+2\beta y}{R^2}+\frac{x^2+y^2}{R^2}}}dxdy,$$

where dE is the diffracted light from an element of area, $dxdy$ in the $[x, y]$ plane, R is the distance from the centre of the aperture to the point of observation P in the $[\alpha, \beta]$ plane a distance z along the direction of propagation and $k = 2\pi/\lambda$ is the wave number and λ is the wavelength of the light.

(i) Sketch a simple diagram of this system and state any assumption made in producing the above expression (do not derive it). [20%]

(ii) Show, that with further approximations, the distribution $E(\alpha,\beta)$ seen in the far field of the aperture is proportional to the Fourier transform of the aperture function $A(x,y)$ [30%]

(iii) Use this analysis to define and sketch the near field, Fresnel and Fraunhofer regions of the diffraction plane. [10%]

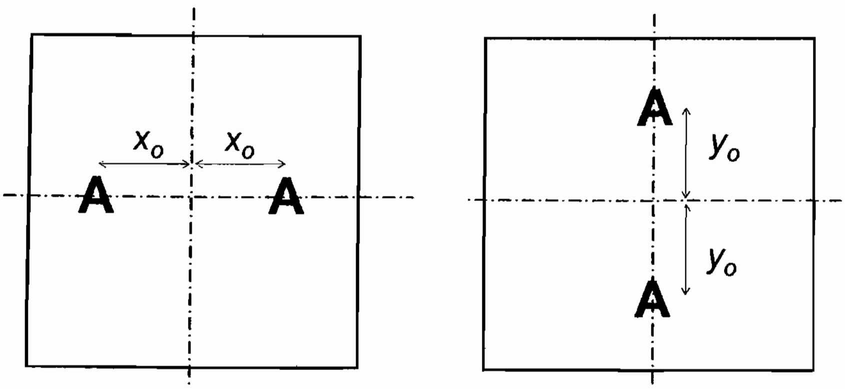
(b) Given the relationship derived in part (a), explain how a basic theory for the structural properties of the replay field of a binary hologram can be expressed. In particular define the terms *pixel*, *envelope*, *order* and comment on the role of repetition in the hologram function. [40%]

2 (a) Describe the main differences between a joint transform correlator and a matched filter when trying to recognise alphabetic letters in a page of typed text. Discuss the relative merits of each architecture for this application. [25%]

(b) Sketch the optical layout of a binary phase only matched filter (BPOMF) and explain the technology that could be used to implement each component. Calculate the focal length of the main transform lens based on the devices in your architecture. [30%]

(c) If the image in Fig 1(a) were used as the reference function for the BPOMF and the image in Fig 1(b) were used as the input, derive and sketch the position of the correlation peaks in the output plane. [30%]

(d) If the input spatial light modulator was a high definition (1900x1080) resolution nematic liquid crystal device, what sort of problems might occur if used in the BPOMF? [15%]



(a) (b)

Fig 1

3 (a) Explain the basic principles of how liquid crystals can be used to modulate light in an optical system. Show that two basic geometries are best suited to phase modulation. What is the difference between pure phase modulation and polarisation modulation? Give an example of each type. [25%]

(b) A nematic liquid crystal material has refractive indices n_e and n_o and is planar aligned parallel to the surface of the glass substrates of a cell. An electric field is then applied and the molecules all then rotate uniformly to an equilibrium position at an angle θ with respect to the substrates.

(i) Sketch the geometry of this cell and show the optical indicatrix and the direction of light propagation in order to create a phase modulator. [15%]

(ii) Show that the refractive index of the cell as a function of θ is given by

$$n(\theta) = \frac{n_o n_e}{\left(n_e{}^2 \sin^2\theta + n_o{}^2 \cos^2\theta\right)^{1/2}}.$$

[20%]

(iii) Use this result to estimate the retardance of the cell as a function of the electric field. Sketch the function, define all of the variables in this system and state any assumptions made. [20%]

(iv) Use this example to explain what is meant by polarisation dependent phase modulation. How can this problem be remedied? [20%]

4 Consider an optical fibre, core diameter $2a$, and with refractive indices of its core and cladding layers equal to n_1 and n_2 respectively. A ray of light travelling within the surrounding air is incident upon the fibre's end facet at some angle to the normal, in an attempt to couple light into it.

(a) (i) Sketch the geometry and write down an expression for the numerical aperture (NA) of this optical fibre, as a function of the maximum acceptance angle, α. [10%]

(ii) By considering critical angle ray propagation within the fibre, derive the following expression for the numerical aperture:

$$NA = n_1\sqrt{2\Delta}$$

where Δ is the index difference, $\Delta = \dfrac{n_1^2 - n_2^2}{2n_1^2} \approx \dfrac{n_1 - n_2}{n_1}$ [25%]

(b) (i) A multimode optical fibre has $n_1 = 1.52$ and $n_2 = 1.50$. What is the maximum acceptance angle for this fibre? [10%]

(ii) What is the limiting bandwidth of this fibre for propagation over a certain length (the Bandwidth-Length Product), in units of Gbit/s . m ? [15%]

(c) Consider a second identical optical fibre, its end facet aligned exactly opposite the first fibre, but separated a distance S away from it. Light emerges from the first fibre and acts as a diverging source of illumination for the second fibre. (*Assume that radiation emerges from the first fibre with a uniform angular distribution, and ignore reflection losses*). Show that the fraction of light that is coupled into the second fibre from the first fibre, η, can be expressed by: [30%]

$$\eta = \frac{a^2}{(S\tan\alpha + a)^2}$$

For the refractive indices stated above, core radius of $a = 6$ μm, and fibre separation of $S = 100$ μm, calculate the percentage of light coupled between the two fibres. [10%]

END OF PAPER