ENGINEERING TRIPOS PART IIB

ELECTRICAL AND INFORMATION SCIENCES TRIPOS PART II

Thursday 24 April 2003 2.30 to 4.00

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.*

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

(TURN OVER

1 (a) Describe how Huygens wavelets can be used to solve any arbitrary optical propagation problem. Sketch a diagram showing how plane waves of light propagate through free space. [30%]

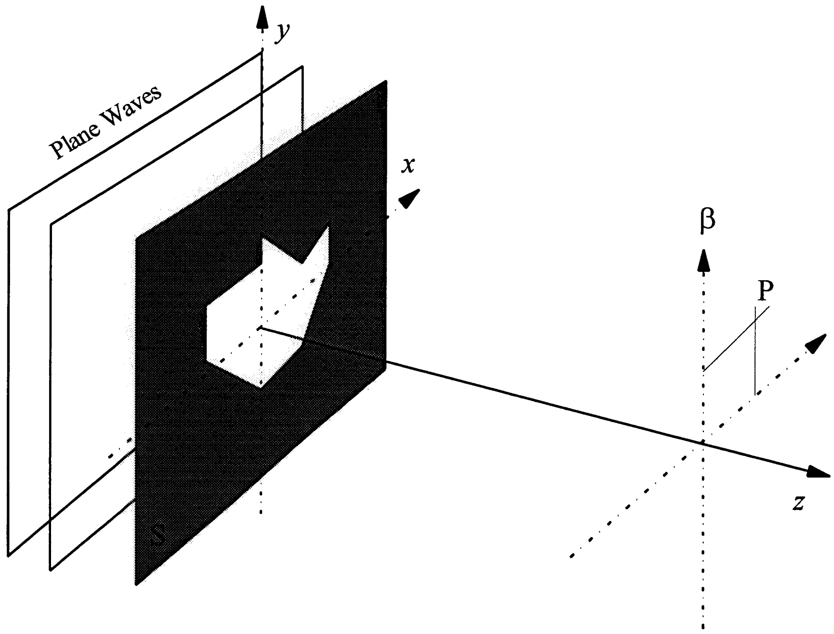

Fig. 1

(b) Given the aperture *A(x,y)* and axis system shown in Figure 1, use Huygens wavelets, stating any assumptions made, to prove that the energy at the point *P* is given by:

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

Describe how this can be simplified to get the far field diffraction pattern of the aperture *A(x,y)*. [30%]

(c) Given that a lens will perform a Fourier transform in its focal plane, explain how diffraction can be used to create an optically transparent fibre to fibre switch in a telecommunications system, capable of switching either spatial or wavelength channels. [40%]

2 (a) Sketch a simple diagram to show the operation of a joint transform correlator (JTC). Describe the role of each of the components in the system and suggest a way in which they could be implemented optically. [30%]

(b) Given a square law non-linearity based JTC with a reference object $r(x,y)$ located at a position $[0, y_1]$ and an unknown object $s(x,y)$ located at $[x_2, -y_2]$. Show that the correlation plane contains a pair of peaks located at $[x_2, -(y_1 + y_2)]$ and $[-x_2, (y_1 + y_2)]$. State any assumptions made. [30%]

(c) A second unknown object $p(x,y)$ is placed at a position $[x_3, -y_3]$ in the input along with $s(x,y)$ in part (b). Find the new location of the correlation peaks.

Explain why the detection of the correlation peaks is no longer trivial and suggest a possible solution to the problem. [40%]

3 (a) What are the main potential advantages of using optical interconnections over short distances? What are the principle problems in implementing such interconnections within VLSI circuitry? [20%]

(b) How might the following changes favour the potential use of optical or electrical interconnections within a CMOS VLSI circuit? Briefly state the reason for your conclusion.

(i) Increasing fan-out in the circuitry;
(ii) Replacing optical transmitters (such as lasers) with optical modulators;
(iii) Decreasing feature size in CMOS circuitry;
(iv) Replacing free space interconnections with guided wave channels. [30%]

(c) Consider an optical channel between two points on a CMOS chip consisting of a vertical cavity laser source transmitting to a simple CMOS photo-detector via a routing hologram.

(i) Estimate the optical power incident on the photodetector if the modulated power of the laser is 1 milliwatt and the laser dissipates 0.5 milliwatt of power before it lases. The efficiency of the hologram is 75% and the efficiency of the laser is 40%. [10%]

(ii) What is the photodetector current for this incident power? (Assume that the laser wavelength is around 1 micron, so that the photon energy is approximately 1eV. The quantum efficiency of the photodetector is 30%.) [15%]

(iii) The capacitance of the photo-detector and the CMOS gate it drives is 25 femtofarads. The supply voltage is 5 volts. Estimate the maximum data rate of this optical channel. [15%]

(iv) How might this maximum data rate be increased? [10%]

4 (a) Define the splay, twist and bend elastic constants in a nematic liquid crystal and illustrate each of these deformations.

What is a Freedericksz transition and how may it be used to experimentally measure the elastic constants? [40%]

(b) Outline the principles of a twisted nematic colour display using passive matrix addressing. [30%]

(c) A planar aligned nematic liquid crystal is observed to have a threshold voltage of 1 volt. If it's dielectric anisotropy, $\Delta\epsilon$ is 8, what is the elastic constant and which deformation does it correspond to? [30%]

(The permittivity of free space ϵ_0=8.854 10^{-12} F m^{-1})

END OF PAPER