EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 29 April 2025 2 to 3:40

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed.
Engineering Data Book.

10 minutes reading time is allowed for this paper at the start of the exam.

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

You may not remove any stationery from the Examination Room.

1. (a) An aperture, as depicted in Fig. 1, is illuminated with a collimated light source. Using the principles of wave propagation and diffraction, describe what will happen to the light a short distance along the z axis just before and just after the aperture plane [*x*, *y*]. Clearly state any assumptions made. [25%]

(b) Using the axes as defined in Fig.1, show how the principles of wave propagation and diffraction can be used, with suitable approximations, to prove that the far field diffraction pattern of the aperture function *A(x,y)* is the Fourier transform of the aperture function. [40%]

(c) If the aperture were square shaped, then an array of such apertures can be arranged to form a hologram. Explain how the original aperture dimensions dictate the structure of the far field diffraction pattern of such a hologram. [25%]

(d) How would the structure of the far field diffraction pattern differ if the shape of the apertures were hexagonal? [10%]

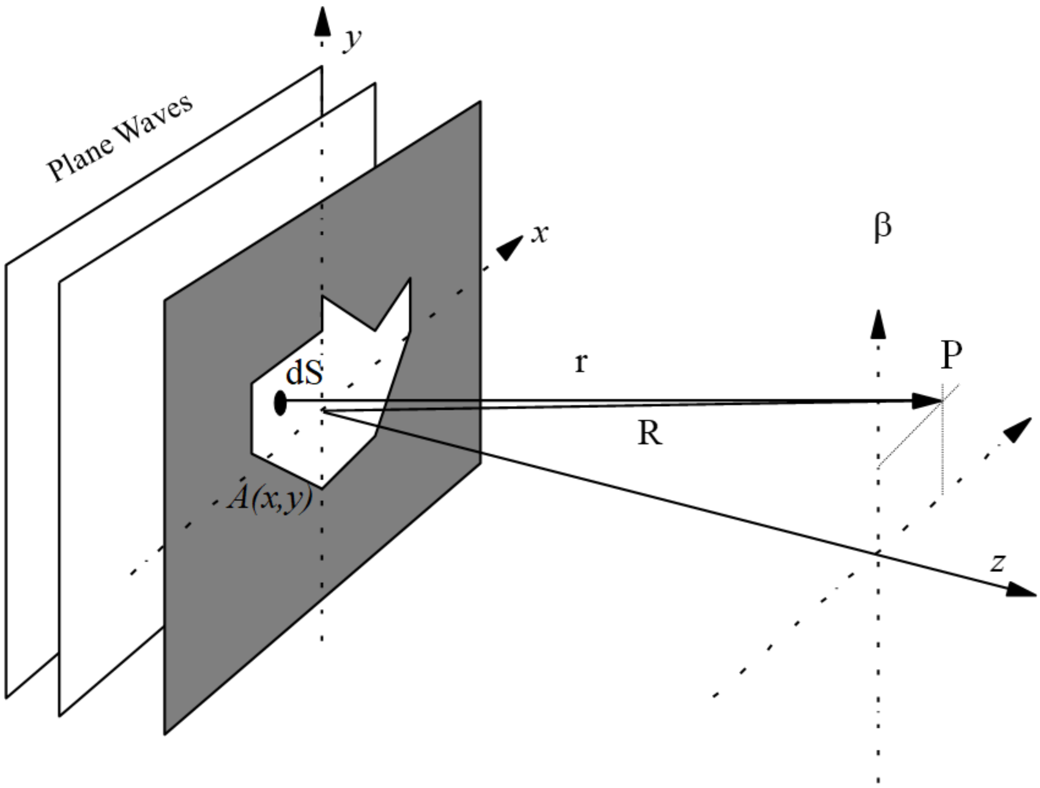

Fig. 1

2 (a) The polarisation state of a forward propagating light beam of wavelength λ, can be expressed using Jones matrices. Explain why you only need three parameters to express this light beam using Jones matrices and give examples of linear, circular and elliptical polarisation. [30%]

(b) An optical system is comprised of a horizontally polarised laser of wavelength λ, followed by a quarter waveplate, optimised for the wavelength λ with its extraordinary axis aligned to the y axis and then followed by a vertical polariser. Using Jones matrices, derive an expression for the resulting polarisation state of the light after the polariser. [30%]

(c) Using Jones matrices, explain what will happen to the polarisation state if the quarter waveplate is rotated clockwise by 45 degrees and by 90 degrees about the optical axis. [20%]

(d) How could the results in parts (b) and (c) lead to a binary intensity modulation effect using a ferroelectric liquid crystal. What switching angle, cell thickness and birefringence would be required for this modulation scheme to work optimally? What are the advantages and disadvantages of this scheme? [20%]

The Jones matrix for a waveplate with retardance Γ, oriented with its extraordinary axis angle Ψ to the y axis is as follows.

$$W = \begin{pmatrix} e^{-j\Gamma/2}\cos^2\psi + e^{j\Gamma/2}\sin^2\psi & -j\sin\frac{\Gamma}{2}\sin(2\psi) \\ -j\sin\frac{\Gamma}{2}\sin(2\psi) & e^{j\Gamma/2}\cos^2\psi + e^{-j\Gamma/2}\sin^2\psi \end{pmatrix}$$

3 (a) Sketch a functional diagram to show the operation of a joint transform correlator (JTC). Describe the role of each component 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 a matching object *s(x,y)* located at $[x_2, -y_2]$, calculate the location of all the correlation peaks in the output plane of the correlator. State any assumptions made. [20%]

(c) What is the limitation of this JTC architecture when using a square law non-linearity? Give two ways in which this limitation could be avoided by redesigning the components of the JTC. Explain how this design will change the layout of the JTC and identify what the drawbacks would be in these changes to the JTC architecture. [30%]

(d) Another limitation of the JTC is rotation invariance. Give three different techniques that could be applied to the reference image *r(x,y)* in order to make it invariant to rotation of the object in the input scene and briefly identify any limitations in their use. [20%]

4 (a) Optical shutter based switches are a promising candidate for use in optical single-mode fibre telecommunications networks. In a shutter based optical switch, one of the key functions is optical fan-out. Use a diagram to explain what is meant by the term fan-out and what its role is in creating a shutter based switch. How might fan-out be implemented using a computer generated hologram? [35%]

(b) The second stage of an optical shutter based switch is the optical shutter itself. Explain how the fan-out process places limitations on the performance of the optical switch when considering the operation of the shutter in this switch architecture. If the shutter were to be liquid crystal based what type of liquid crystal would be best choice and why? [25%]

(c) The performance of any optical system will be limited by the aberrations in the optics and devices. Explain why the aberrations contained in the fan-out and shutter processes of parts (a) and (b) could be a limit on the overall number of single-mode fibres possible in the optical switch. Describe two ways in which these aberrations might be eliminated. [25%]

(d) How might this shutter based switch be modified to allow it to switch a single input fibre to multiple output fibres? [15%]

END OF PAPER

Numerical solutions: Q2b 0, Q2c $-jV_x/\sqrt{2}$, 0, Q3b $(x_2,-(y_1+y_2))$, $(-x_2,(y_1+y_2))$.

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