EGT3
ENGINEERING TRIPOS PART IIB

Thursday 25 April 2019 14:00 to 15:40

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
Single-sided script 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.

1 (a) Show that the far field diffraction pattern $F(u,v)$ of the aperture shown in Figure 1, having transmission amplitude A, is given by the following expression. State any assumptions made. [20%]

$$F(u,v) = Aa^2\text{sinc}(\pi au)\text{sinc}(\pi av)$$

(b) Using a one dimensional graphical technique, explain the basic structure of the far field diffraction pattern of a binary amplitude ($A \in \{0, 1\}$) grating. State any assumptions made and estimate the efficiency of light diffracted into the first order. [30%]

(c) Using the same technique as in part (b), show how the far field diffraction pattern for a binary amplitude grating can be modified to generate the far field diffraction pattern for a binary phase ($A \in \{-1, +1\}$) grating. Estimate the new efficiency of light diffracted into the first order. [30%]

(d) Describe how the structure of the replay field would change if the aperture in Figure 1 was hexagonal in shape rather than square. [20%]

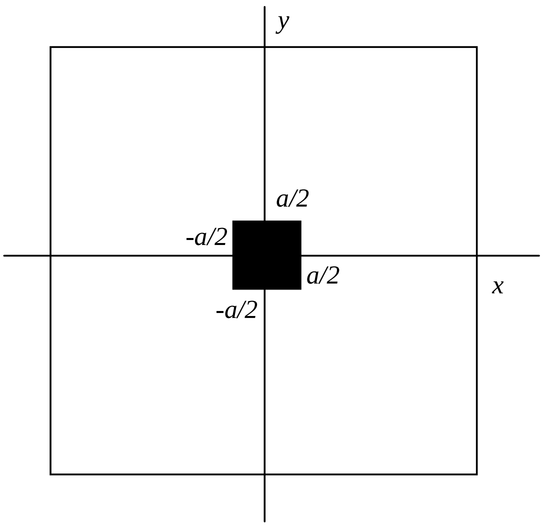

Figure 1. (*The white area represents transmission amplitude zero, black area = A*)

2 (a) Describe how a laser and a lens can be used to generate a replay field from a hologram in a free space optical system. How does the location of the lens with respect to the hologram affect the replay field? Explain how the wavelength of the laser and the focal length of the lens relate to the properties of the replay field. What are the limitations of using a lens in this way? [35%]

(b) Derive an expression to calculate the physical size of the first order when a 150 mm focal length lens is used to form the replay field in a holographic projector based on a 1280x1280 pixel binary phase only spatial light modulator (SLM) with 13 μm pitch pixels using the three primary wavelengths of 412 nm, 532 nm and 635 nm. Why is this potentially a problem in the holographic projector? [25%]

(c) Give two ways in which the problem indicated in part b) could be remedied. Explain what the advantages and disadvantages of each solution might be in a real holographic projector. [25%]

(d) How would the calculation in part (a) have to be modified to calculate the optical field a distance $\frac{3f}{4}$ away from the lens? [15%]

3 (a) Describe, using the concept of Jones algebra and matrices, how polarised light propagates. Include definitions of *linear*, *circular* and *elliptically* polarised light in your explanation. [30%]

(b) Use the properties of Jones matrices to define a vertical linear polarisor and show that the generalised Jones matrix P of a linear polarisor at an angle ψ to the vertical axis, is given by [30%]

$$P = \begin{pmatrix} \sin^2\psi & -\frac{1}{2}\sin 2\psi \\ -\frac{1}{2}\sin 2\psi & \cos^2\psi \end{pmatrix}.$$

State all assumptions made.

(c) Sketch the way in which a ferroelectric liquid crystal pixel can be used to form a binary amplitude modulator. Use Jones matrices to derive the optimal cell gap thickness d for binary amplitude modulation using a ferroelectric liquid crystal with switching angle θ and birefringence Δn, at a wavelength λ. The generalised form of an optical retarder with retardance Γ at an angle ψ is as follows [40%]

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

4 (a) In an adaptive optical system, one of the key principles governing system performance and functionality is phase conjugation. Use a simple sketch of a closed loop adaptive optical system, identifying the key elements, to show how phase conjugation can greatly improve the optical quality of the system. [30%]

(b) In an adaptive optical system, Zernike polynomials are often used to express an aberration function. What are the key properties of Zernike polynomials that make them useful? Use a simple sketch to show their basic structural properties. [30%]

(c) A matched filter has been designed using two transmissive ferroelectric liquid crystal spatial light modulators. Sketch the overall structure of the optical system and identify points in the optical system where aberrations might affect performance. [25%]

(d) How might the properties of one of the spatial light modulators in the matched filter system be used minimise the effects of these aberrations? [15%]

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Numerical solutions

Q1 b) 20% c) 41%

Q2 b) 9.5 mm, 12.3 mm, 14.7 mm

Q3 c) $\Gamma = \pi$, $\theta = 45^{o}$, $d = \lambda/2\Delta n$