Version TDW/3

EGT3
ENGINEERING TRIPOS PART IIB

27 April 2022 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) State the relationship between a computer generated hologram (CGH) and its associated replay field. Mathematically calculate the replay field of the aperture shown in Fig. 1, with amplitude *A*. State any assumptions made. Why is this result so fundamental to the field of computer generated holography? [20%]

(b) Explain how the aperture in Fig. 1 can be adapted to create a binary amplitude ($A \in [0,1]$) grating with periodicity $2a$. Using a simple graphical technique, derive the replay field structure of this grating and explain the significance of the result with respect to the calculation of part (a). [30%]

(c) Using the same graphical technique, show how the replay field for a binary amplitude grating can be used to derive the replay field for a binary phase ($A \in [-1, +1]$) grating. Comment on the diffraction efficiency into the first order of each type of grating. [30%]

(d) Explain what features of the binary phase grating in part (c) make it a suitable candidate for a routing hologram in an optical switch. What features make it less than ideal for use in the same application? [20%]

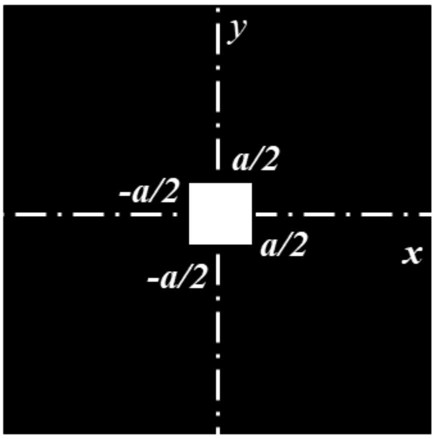

Figure 1. The white square represents amplitude *A*

2 (a) A nematic liquid crystal material is contained in a transmissive cell with uniform parallel alignment. Sketch the optical indicatrix for the liquid crystal in this cell at an angle θ to the bottom substrate. If the angle θ is a function of the applied electric field across the cell, show how this can be seen as an equivalent variation of phase retardation of the light passing through the cell. State any assumptions made. [35%]

(b) The Jones matrix *W*, for a general retarder of retardance Γ and oriented with respect to the *y* axis by an angle ψ is given below. Using this matrix, calculate the Jones matrix of a quarter waveplate with its extraordinary axis parallel to the *x* axis. [20%]

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

(c) Horizontally polarised light illuminates two quarter wave plates in series, both with their extraordinary axis parallel to the *x* axis. Use Jones matrix analysis to derive the resulting output polarisation state. Repeat the calculation, but this time with vertically polarised light at the input. Comment on the result of the two states and how they would effect the polarisation at the output as the pair of quarter waveplate were rotated about the *z* axis. How might this principle be useful in the context of a nematic liquid crystal material when used as a phase modulator? [30%]

(d) Why is it better to design a nematic liquid crystal phase modulator with a total phase modulation greater then 2π ? [15%]

3 (a) Sketch the physical construction and outline the basic operation of the binary phase *1/f* joint transform correlator (JTC). Explain the role of each component in the optical system and the overall operating principle of the system, highlighting any issues that might occur with the limitations of the modulation scheme and how they might be overcome. [30%]

(b) Show, with the aid of diagrams how a binary phase *1/f* JTC could be used as the basis for a head tracking system in the cockpit of an aircraft such as the Eurofighter. You may assume the pilot has a camera mounted in their helmet which takes a continuous view of the cockpit and its instrumentation. [30%]

(c) An accurate head tracking JTC must have at least 20% overlap between consecutive video frames in order to correlate reliably. Given a correlator operating at 50 correlations per second, a video camera with a 20º field of view and a distance of 1.3 m between the pilot and the cockpit console, estimate the maximum allowable angular speed of rotation of the pilot's head. State any assumptions made. [25%]

(d) What will happen when the pilot looks out of the canopy of the aircraft? Suggest a possible modification to the system to prevent this problem. [15%]

4 (a) Sketch the functional architecture of a matched filter and describe mathematically the process of how it operates. What are the main advantages and disadvantages of a matched filter over other forms of optical correlator? [25%]

(b) How is the filter generated for the matched filter architecture and what are the limitations of this process in terms of correlation functionality? Give two ways in which the performance of the filter can be improved and discuss any potential drawbacks from these techniques. [30%]

(c) A very desirable feature which could be included in a matched filter is scale invariance. Explain how a synthetic discriminant function (SDF) based filter can be designed to enhance the function of a matched filter to include scale invariance. What are the limitations of this type of filter and why might the processes discussed in part (b) also limit the effectiveness of the SDF? [30%]

(d) The matched filter architecture can be built using several lenses and two spatial light modulators (SLMs). It is desirable to make the matched filter as compact as possible, but in doing so it is likely that optical aberrations will be introduced. How might these aberrations be detected and corrected in such an optical system? [15%]

END OF PAPER

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