Version TDW/3

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 28 April 2026 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.

You may not remove any stationery from the Examination Room.

1 An equilateral triangular shaped aperture with sides of Δ is illuminated by a coherent laser light source of wavelength λ. A plane of observation is defined some distance R away from the aperture along the z axis.

(a) Explain how the principles of Huygen's wavelets can be used to describe the propagation of light along the z axis between the aperture and the plane of observation. Derive an expression for the light from one elemental wavelet as seen in the plane of observation. State any assumptions made and clearly define any dimensions used in setting up this expression. [30%]

(b) Using the system set up in part (a), explain what is meant by the term Fresnel diffraction and derive an approximate expression for an element of the wave now seen in the Fresnel diffraction plane. State any assumptions made. [25%]

(c) The propagation of the wave can be further simplified using certain assumptions to define the Fraunhofer or far field region. Using these assumptions, derive an expression for an element of the wave in the far field and how these elements can be combined to give the total wavefront in the far field. What is the main feature of the wavefront propagation that defines the far field region? [20%]

(d) Describe how the system defined in part (a) can be modified in order to control the physical size of the wavefront in the far field region and explain how this leads to the concept of a $4f$ system. Why is a $4f$ system an important concept in optical design? [25%]

2 A 256 x 256 pixel binary phase hologram, with square pixels of pitch 10 μm and no deadspace, is to be designed using direct binary search to give a replay field that contains a 10 x 10 array of spots with uniform amplitude, centred on the optical axis. The replay field assumes the same sampling as the hologram and the spots are to be positioned so that there are 3 zero positions between each spot. The illumination is by a laser light source at a wavelength of 880 nm the initial design is using a lens of focal length of f = 100 mm.

(a) Explain how the physical dimensions of the replay field are defined and calculate the spacing of the spots in physical terms, stating any assumptions made. [20%]

(b) Calculate the ratio of the amplitude of the spot closest to the optical axis and the outer most spot in the far right corner of the array. Give two reasons why the value of this ratio can never be one. [30%]

(c) Explain how the direct binary search algorithm works and how it would be set up to calculate the desired replay field. State the main limitation of this algorithm and explain how simulated annealing can greatly improve this limitation. [30%]

(d) Give two ways in which the direct binary search algorithm can be modified to reduce the limitations seen in part (b). [20%]

3 (a) Describe how the properties of a planar aligned nematic liquid crystal can be used to modulate the phase of a light source. Clearly list the parameters that are required to perform the phase modulation and sketch the structure of a suitable reflective cell geometry. How would the liquid crystal have to be changed in order for it to be homeotropically aligned? [30%]

(b) One of the main limitations of the nematic liquid crystal phase modulator is its inherent polarisation dependence. Explain why this limitation occurs and why simple solutions such as the twisted nematic structure do not solve the problem. Why could we not use a ferroelectric liquid crystal in place of the nematic? [30%]

(c) A nematic liquid crystal can be used in a liquid crystal over silicon spatial light modulator. Explain how a quarter waveplate can be used in this sort of device in order to minimise the effects of polarisation dependence. What are the limitations of this technique? [20%]

(d) Give two examples of applications that would benefit from this type of polarisation insensitive phase modulator. Explain your logic for each answer. [20%]

4 In optical image processing applications, the function of optical correlation is a very important mechanism in matching or comparing different two dimensional images.

(a) Explain how the fact that a lens performs a Fourier transform can be used as a means to create an optical correlation function. Show that this process is inherently shift invariant and as a result an optical correlator can recognise multiple objects. [25%]

(b) One way of performing optical correlation practically is with a joint transform correlator. Describe how this architecture works and identify all of the key features that lead to the correlation functionality. [25%]

(c) The function of the joint transform correlator can be simplified using its inherent symmetry. Show that when considering a practical implementation of a joint transform correlator, it can be reduced down to just five components. What are the advantages and disadvantages of this simplification? [30%]

(d) If the architecture in part (c) were set up using a liquid crystal on silicon spatial light modulator, how might the imperfections in both the modulator and the optical system be minimised? [20%]

Numerical solutions Q2a, $6.88\times10^{-5}m$, $2.75\times10^{-4}m$, Q2b, 6.7%

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