Version TDW/3

EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 25 April 2018 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

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

1 (a) Using the basic principles of wave propagation and optical diffraction, briefly explain why the far field diffraction pattern of an aperture *A(x,y)* is given by its Fourier transformation. State any assumptions made. [30%]

(b) The aperture *A(x,y)* is illuminated by a uniformly collimated laser of wavelength λ and a positive lens with focal length f is placed a distance d from the aperture. The resulting distribution of optical energy $E(\alpha,\beta)$ after the lens in the [α, β] plane is given by the equation

$$E(\alpha,\beta) = e^{\frac{jk}{2f}\left(1-\frac{d}{f}\right)\left(\alpha^2+\beta^2\right)} \iint_A A(x,y) e^{\frac{jk}{f}(\alpha x+\beta y)} dxdy .$$

Sketch a diagram showing the propagation of optical wavefronts through this system and show where the various planes in the system are located. Explain what optical principle allows the lens to perform this operation and what properties the lens must have in order for it to work. How does this system lead to the concept of a 4f system and what are the main benefits of this approach? [30%]

(c) The aperture *A(x,y)* in the 4f system above is now replaced by a binary phase grating with a pitch of Δ and the laser is replaced by a fibre amplifier with a uniform amplitude spontaneous emission spectrum from 1500 to 1600 nm. Describe, with the aid of a diagram, what the energy distribution would look like in the [α, β] plane. [20%]

(d) A single mode fibre is placed at a fixed position in the [α, β] plane of the system in part c). Explain, using a simple sketch, what the spectrum of the light would look like coming out of the fibre stating any assumptions made. [20%]

2 (a) A nematic liquid crystal is contained in a transmissive cell with uniform parallel alignment. Explain what is meant by the optical indicatrix for the liquid crystal in this cell and how it can be used to calculate optical phase modulation. Sketch the expected modulation curve for this cell and highlight any key features. State any assumptions made. [30%]

(b) The cell in (a) has one major limitation when being considered for use as a wavelength selective filter in an optical network. How does this limitation relate to the optical indicatrix? Give two techniques that might be used to overcome this limitation. [30%]

(c) The Jones matrix W, for a general waveplate of retardance Γ and oriented with respect to the y axis by an angle ψ, is given below. Use Jones matrix analysis on the cell of part (a) to derive the optimal thickness of the cell for 2π phase modulation with a nematic liquid crystal with $\Delta n = 0.18$ and at a wavelength of 1550 nm. [25%]

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

(d) Why is it better to design a phase modulator with a total phase modulation greater than 2π? What is the penalty for doing this? [15%]

3 (a) Define the terms *fan-in loss* and *crosstalk* in the context of a single mode fibre to fibre holographic beam steering optical switch. [20%]

(b) Show that for a 1 by n port holographic beam steering optical switch, with a NxN pixel binary phase hologram, that a bounding value for the crosstalk can be derived as [30%]

$$C = \frac{\eta}{1-2\eta} N^2 .$$

Define all of the variables in the equation and state all assumptions made.

(c) Explain with the aid of a sketch how a 1 by n holographic switch can be expanded into a n by n holographic switch. How does this expansion affect the crosstalk of the switch and what is the new bound on the crosstalk? [25%]

(d) Comment on the validity of the bounding crosstalk value derived in part (c) and explain why this form of n by n optical switch is not really practical. How could the design of the switch be changed to improve the crosstalk? What is the penalty for this change and how would it alter the bounding crosstalk value? [25%]

4 (a) Sketch the basic layout for a joint transform correlator (JTC) based on a square law non-linearity. Clearly identify all of the parts in the system and describe how they could be implemented using real optical components. [40%]

(b) Fig. 1 shows the input plane for a square law based non-linearity JTC. Calculate the positions of the correlation peaks in the output plane. Draw a sketch of the lower half of this output plane and comment on its structure in terms of how well the correlator would perform the task set by the input plane of Fig. 1 [40%]

(c) Explain why the non-linearity is a key element in the performance of the JTC. Describe how the performance of the JTC can be improved by changing the non-linearity and list two possible technologies which could be used to implement it. [20%]

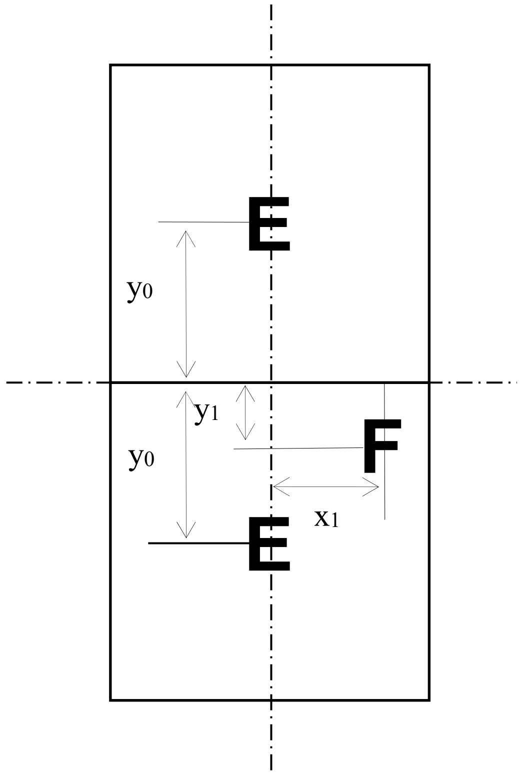

Fig. 1

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