# Engineering Tripos Part IIB, 4B23: Optical Fibre Communication, 2018-19

### Module Leader

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### Lecturer

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### Timing and Structure

Lent term. 75% exam / 25% coursework

### Prerequisites

Photonic technology (3B6) and Data transmission (3F4) useful

## Aims

The aims of the course are to:

- Provide an overview of the key technologies that underpin modern optical fibre communication systems including the appropriate theory and practice
- Provide a system level perspective to allow progression from devices and subsystems through to systems and networks
- Expose students to the state of the art both within industry and academia as systems move towards 1 Tbit/s per wavelength

## Objectives

As specific objectives, by the end of the course students should be able to:

- Explain the salient features of a modern optical fibre communication system employing digital coherent transceivers
- Understand the limitations imposed by both noise and nonlinear properties of the optical fibre
- Be able to analyse performance metrics such as signal to noise ratio and bit error rate for an optical fibre communication link
- Understand the principles of coherent detection and the associated photonic subsystems
- Understand the role of digital signal processing and forward error correction in modern communication systems
- Be able to design an optical fibre communication network given appropriate constraints

## Content

Optical fibre communication systems underpin modern communication systems, from the high capacity submarine cables that link continents to the interconnected mobile basestations used in wireless communications. The module will cover the theory and practice of modern optical fibre communication systems which currently achieves a capacity of 400 Gbit/s per wavelength. A systems approach is taken, focusing on the fundamental mathematical modelling of devices, subsystems and systems, to allow students to design and analyse future systems rather than merely reflecting latest technological developments. Nonetheless the students will be exposed to the very latest developments in the field, such as the means of transmitting 10 Pbit/s per fibre.

**Syllabus**

1. **Overview of optical fibre communication:** Why use optical fibres for communication? Basic terminology (power in an optical fibre, power units, wavelength and frequency), attenuation in optical fibres, wavelength dependent refractive index (group velocity, chromatic dispersion, simplified view of waveguides (from rays to modes).

2. **An optical fibre as a dielectric waveguide:** From Maxwell's equations to the Helmhotz equation, solving the Helmhotz equation in cylindrical coordinates, solving the dispersion equation for the LP modes, modal cutoff conditions, single mode fibres (single mode criterion, Gaussian approximation for the field and its application)

3. **Waveguide based devices:** Directional couplers (coupled mode theory and its solution), coherent receivers using directional couplers including the passive quadrature network, electro-optic materials and their use for modulating light (phase modulator, Mach Zehnder modulator, Cartesian modulators, dual polarisation modulator

4. **Propagation of pulses in a single mode optical fibre:** Dispersion due to a frequency dependent refractive index, obtaining the basic linear propagation equation and its application, polarisation mode dispersion in a single mode fibre

5. **The nonlinear Schrödinger equation (NLSE):** Kerr effect and its impact on transmission systems, soliton as a solution of the simplified NLSE, perturbative solution of the NLSE, nonlinear interference power spectral density and its application to system design

6. **Noise in optical fibre communication systems:** shot noise, quantum noise (photon statistics, zero-point energy), thermal noise (for both classical and quantum systems), principles of operation for the EDFA, amplified spontaneous emission (ASE) noise (Heisenberg's uncertainty principle and the minimum noise power from an optical amplifier), noise figure and gain saturation in optical amplifiers, noise from lasers (RIN and phase noise).

7. **Digital coherent transceivers:**Advanced modulation formats including dual polarisation QPSK, digital signal processing (frequency domain implementation of FIR filters, adaptive equalisation), synchronisation algorithms, forward error correction (and channel capacity, ultimate limits including quantum limit for an ideal receiver

8. **Introduction to optical network design:** Network topology (node degree and impact on resilience), wavelength division multiplexing and the ITU grid, all optical networking and wavelength routing, reconfigurable add drop multiplexers, comparison between core and access optical networks, traffic matrices and network throughput. Overview of design exercise.

9. **Industry guest lecture:** Provided to enable students to understand the industrial context for the topics covered within the module.

## Examples papers

Two example papers will be issued with an example class for each example paper.

## Coursework

For the coursework there will be a design exercise worth 25%. Since the coursework will assess optical network design, optical network design will not be assessed in the end of year examination.

| Coursework | Format | Due date<br><br>& marks |
|---|---|---|
| **[Optical Network Design]**<br><br>The coursework exercise is to design an optical network to link the Univeristies of Cambridge, London, Southampton, Bristol, Liverpool and Durham. Students are required to write a report detailing their proposed design and expected performance. Within the report three possible topologies should be compared and any assumptions made within the design should be explicitly stated.<br><br>The report should be no more than 10 sides of A4 with minimum font size of 11, however detailed calculations regarding design choices such as fibre type, amplifier spacing, launch power etc. may be included in a technical appendix that is not subject to page limits.<br><br>Learning objectives:<br><br>• To be able to calculate the throughput of an optical network<br>• To understand impact of topology on network throughput<br>• To understand the design decisions and trade-offs that occur in network design | Individual Report<br><br>anonymously marked | Wed week 9<br><br>[15/60] |

## Examination Guidelines

Please refer to Form & conduct of the examinations [2].

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