Module Name: Photonic Sub-Systems

Module Acronym: PSS
Undergraduate Code: ELECGT25; Masters Code: ELECMT25

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Course Summary:
This module teaches to the state of the art in design, fabrication and performance of photonic circuits. Applications are discussed in communications and high precision measurement. It covers digital coding, advanced modulation formats, digital and analogue optical modulation, modulator and optical amplifier photonic device design, laser transmitter design, laser direct detection and coherent detection receiver design including electronic and optical feedback, signal to noise ratio and bit error rate, planar photonic circuit technology, wireless over fibre systems, systems for measurement of distance, time and material composition and optical systems for generation and detection of terahertz and microwave radiation.

Intended Learning Outcomes
On completion of this course, students should be able to:

- Know and understand the scientific principles and methodology necessary to underpin their education in photonic subsystems, to enable appreciation of its scientific and engineering context, and to support their understanding of historical, current, and future developments and technologies.
- Comprehensively understand the scientific principles of photonic subsystems and related disciplines such as knowing how to generate terahertz and microwave radiation using lasers.
- Know and understand the mathematical principles necessary to underpin their education in photonic subsystems to enable them to apply mathematical methods, tools and notations proficiently in the analysis and solution of engineering problems.
- Be aware of developing technologies related to photonic subsystems such as generation of terahertz and microwave radiation using lasers.
- Ability to apply and integrate knowledge and understanding of other engineering disciplines such as telecommunications and metrology to support study of photonic subsystems.
- An ability to use fundamental knowledge to investigate new and emerging technologies such as how to fabricate planar photonic circuits and how to design photonic sub-systems for high precision measurement (metrology) of time and distance.
- Extract data pertinent to an unfamiliar problem, and apply in its solution computer based engineering tools when appropriate.
- Apply a systems approach to engineering problems.
- Have a wide knowledge and comprehensive understanding of design processes and methodologies for photonic devices and interconnects and the ability to apply and adapt them in unfamiliar situations, knowing their limitations such as to design a wide range of photonic transmitters and photonic receivers using basic and advanced modulation formats to meet specific signal to noise ratio and bit error rate requirements.
- Make general evaluations of commercial risks through some understanding of the basis of
such risks by considering the creation of photonic circuit sub-system designs to solve practical problems of industrial relevance.

- Thoroughly understand current practice and its limitations, and have some appreciation of likely new developments such as how to design photonic sub-systems for high precision measurement (metrology) of time and distance
- Apply engineering techniques taking account of a range of commercial and industrial constraints by creating photonic circuit sub-system designs to solve practical problems of industrial relevance.

**Course Content:**

**Modulation Coding Formats and Multiplexing**
- Coding Formats; Multiplexing; Bandwidth Efficiency; Noise; Bit Error Rate, BER; Receiver Design: Detection Threshold Level; Intersymbol Interference; Wave Shaping; Hamming Distance; Forward Error Correction, FEC; Constellation Symbol Diagrams; Transmitter Design, RZ, NRZ, CSRZ

**Photonic Modulator Devices**
- Quantum Confined Stark Effect, QCSE; Electro-Absorption Modulator, EAM; Asymmetric Fabry Perot Modulator, AFPM; Mach-Zehnder Modulator, MZ; Semiconductor Optical Amplifier, SOA; Travelling Wave Amplifier, TWA; Electro-Optic Polymer Fibre Modulator; Phase Modulators; Amplitude-Phase Coupling, Henry Factor; Polarisation Modulation

**Optical Fibre Amplifier Devices**
- Erbium Doped Fibre Amplifiers, EDFA; Optical Pumping; Saturation; Raman Amplifier; Cascaded Optical Fibre Amplifiers; Signal to Noise Ratio; Amplified Spontaneous Emission, ASE; Power Self-Regulation; Unrepeatered submarine optical fibre links

**Photonic Transmitter Design**
- Laser Drive Circuit with two feedback loops; Bias-T Laser Driver; AC or DC coupling; Parasitic Impedances; Case Study of Real Laser Driver Designs

**Direct Detection Receiver Design**
- Clock Recovery; Front End Circuit Designs; Bandwidth, Noise, Receiver Dynamic Range Planar

**Photonic Circuits**
- Silicon Optical Microbench; Silicon V-Grooves; Transmitter Optical Sub-Assembly, TOSA; Receiver Optical Sub-Assembly, ROSA; Compact Transceiver Sub-Assemblies, XFP, SFP, SFP+; Microelectromechanical Systems, MEMS; Silicon Waveguides; Plasmonic Integrated Circuits; Silica Waveguides on Silicon Wafers; Polymer Waveguides on Printed Circuit Boards; 80 Gb/s Pluggable Optical Connector Design

**Industrial Design Case Study: Optical Link Design**

**Photodetector Noise in Optical Communications Systems**
- Types of Noise; Calculation of Total Noise by combining the noise contributions; Signal to noise ratio effect on the photocurrent

**Wireless over Fibre Transmission Systems**
- Link Analysis; Signal to Noise Ratio; Link Linearisation; Optical Feed-Forward Transmitter Circuit; Performance; Eye Diagrams; Single Mode and Multimode Wireless over Fibre Links; Intermediate Frequency, IF over Optical Multimode Fibre, MMF; Digital Signals over MMF; Radio Frequency over MMF; Frequency Response and Eye Diagrams; Commercial Case Studies

**Future Coherent Optical Systems**
- Fundamental Coherent Detection Principles; Coherent Detection Theory; Homodyne,
Heterodyne and Intradyne detection; Coherent Gain; Balanced Detection; Noise; BER

**Advanced Modulation Formats and their Detection and Demodulation**

- QPSK; 90 degree optical hybrids; Quadrature Amplitude Modulation, QAM; Orthogonal Frequency Division Multiplexing, OFDM; IQ Receivers; Polarisation Modulation

**Optical Phase Locking**

- Optical phase locked loops, OPLL; Loop Filter Response; The effect of Laser Phase Noise on Locking stability; Laser injection Locking; Digital Optical Coherent Receivers; Digital Signal Processing, DSP

**High Precision Measurement (Metrology) and Precise Frequency Generation**

- Laser Range Finding Systems; Light Detection and Ranging, LIDAR; Generation of multiple narrow laser spectral lines equally spaced in frequency, Frequency Comb; Mode-Locked Lasers; Time domain spectroscopy; Calibration of Time relative to an Atomic Clock; Terahertz and Microwave Radiation Generation and Detection

**Assessment:**

A 2.5 hour unseen written examination is held under UCL examination regulations at UCL.

**Tutorials/Workshops:**

An afternoon tutorial is held at UCL after the module delivery as specified by the timetable.